Aircraft noise, overheating and poor air quality in London primary schools' classrooms

Azadeh Montazami

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This research and its finding might be of interest to people who participated including pupils, teachers and head teachers. The findings would also be useful to architects, designer and policy-makers who are involved in building and renovation of schools for future.

Abstract:

Providing a comfortable environment is the fundamental aim in Architecture. Comfortable environment mainly refers to a surrounding atmosphere which is thermally, acoustically, visually, aesthetically, etc. comfortable. Generally, environmental comfort is assessed by environmental factors such as thermal, acoustic and lighting comfort as well as air quality.

There is a significant relationship between various environmental factors and students' academic achievements as well as health. Providing all of the environmental factors together is critical as they are interrelated and could conflict if they are considered separately, if the conditions over the life of the building change or relaxed benchmarks are used for design at the first stage.

One of the conflicts reviewed in this study, is the conflict between acoustic comfort with thermal comfort and air quality. The hypothesis of this research is that the naturally ventilated schools located in noisy areas (e.g. Heathrow airport) suffer from overheating and poor air quality as well as a high level of background noise during summer periods, due to the lack of ventilation.

The main means of ventilation in majority of the UK schools is window. In noisy areas, the classrooms' occupants (i.e. pupils, teachers) often tend to shut windows especially during silent (such as exams and readings) and lecturing activities to reduce the aircraft noise, which varies from 57dB-75dB according to their distances to Heathrow airport. On an average, as a result of closing windows, the aircraft noise drops by 15dB (depending on the type of windows) which makes the inside noise to be around 42dB-60dB. This is still higher than the 35dB which is the acceptable limit for background noise for primary school classrooms as recommended by Building Bulletin 93.

The results of the study show that closing of windows does not reduce the high level of background noise to the recommended level, but it also has two negative impacts on classrooms' environments. Firstly it increases the potential for classrooms to experience overheating and secondly it causes poor air quality due to the lack of sufficient ventilation in the building.

Through objective and subjective surveys, classrooms' indoor temperatures, air quality and background noise levels were evaluated and it was learnt that those schools located in the vicinity of Heathrow Airport are more likely to experience overheating and poor air quality. This has a negative impact on students' achievements.

In addition, one of the reasons for the lack of environmental comfort is the use of relaxed benchmarks. It is shown in this study that overheating and air quality benchmarks which are proposed by 'Department for Education and Skills' in Building Bulletin 101 and used to design and refurbish the UK schools, are relaxed benchmarks in comparison with the others which are proposed by different organisations and researchers.

The overall findings of this thesis have been developed to draw the attention of school designers' to the current and future potential conflicts between the comfort factors in schools' classrooms. To

prevent failure, extra care should be taken to select a suitable ventilation strategy for providing both air quality and thermal comfort during summer for the schools located under the flights paths. For such schools, it would be beneficial that the solar gain and internal gain are controlled and heavy thermal mass materials are used for their construction. Such strategies would counterweigh the lack of ventilation in protecting the classrooms from overheating.

It is also suggested that a further section is incorporated to the comfort section of the school design assessment tools to evaluate the current and future potential conflict between comfort issues in the schools' buildings. In addition, air quality and summer thermal comfort guidelines incorporated to BB101 are recommended to be revised (similar to the acoustic section of this guideline which was revised to stringent benchmarks for background noise level and reverberation time and included in BB93).

Chapter 1: Introduction

1.1. Research motivation

This section presents the author personal motivation to continue further studies in to the PhD level and to carry out this research. My experience of childhood education made me think about the problems that I experienced in the day to day school life, and how a school can be a pleasant and favourable place for children. Creating such a place for children became my predominant aim when I stepped in to the world of architecture which encouraged me to pursue this aim through the Master's degree and the PhD studies.

Schools need to be well designed and satisfactory for their users. However, there are schools that have failed to meet these requirements. Based on my own experience from primary and secondary schools (from 7 to 18 years old), I always asked myself the following questions:

Why did I feel so sleepy as soon as I walked into my classroom and did not like to listen to my teacher in some years? Why did my teacher write only to one side of the whiteboard (right or left) leaving the rest of the boards empty making it difficult for some students to see what was being written? Why were there always discussions among students about whether to close and/or open windows? Why did not I like my classroom and wished to move to other classrooms in some years? Why was the adjoining class so noisy that my teacher had to ask them to be quiet? Why was my classroom so gloomy that we had to turn on the lights as soon as we walked in? Why did the Physical Exercise (PE) lessons of other classes make us close the windows and pull the curtain down, etc. On the whole, why did I feel so comfortable in some classrooms and uncomfortable in the others?

The university gave me the chance to review my questions and try to answer them in a more logical manner. My passion was always to design a space which could give me a comfortable feeling.

My Masters studies in Energy and Sustainability in Architecture provided me with the opportunity to become deeply familiar with comfort factors such as thermal, lighting and acoustic comfort and air quality.

There has always been a concern regarding the indoor environment of schools due the following two reasons (Heath et al, 2000):

1. Among other public buildings, schools have a higher possibility to have poor environmental conditions due to the shortage of funding allocated for operation and maintenance of the schools' facilities.

2. Poor environments have a greater impact on children than on adults. For example, if a classroom has poor air quality, children are affected more than adults since they have a higher breathing rate as they are actively growing. In addition, the length of time that children spend at

school is higher than the time they spend at home. Consequently the schools' environments have significant effect, either immediate or lifelong on the students' health and performance.

It has been argued that the school environment can affect a student's and a teacher's health, work, leisure, emotion and sense of place and belonging (Sanoff et al., 2001). The fact that an occupant's performance can be improved by providing good environmental conditions, and that environmental factors can have a higher impact on students of age 5 to 11 (Dudek 2000) brought me to the opinion that the way I design a school can improve the students' performances. When consulted my supervisors, I came to the conclusion to focus my PhD topic on the conflict between comfort factors in primary school classrooms, which have negative impacts on classrooms' environments and consequently on academic achievements of students aged 5 to 11.

1.2. Background

The constant goal of any building designer is to design in a way as to achieve high quality and energy efficient internal environment. Failure to achieve these goals may cause poor quality internal environment which has significant impact on reducing productivity of the occupants-and underperforming buildings.

High quality environment mainly refers to an environment which provides thermal, visual, acoustic comfort and have an adequate level of fresh air (air quality).

According to the extensive research available, it can be seen that there is a significant relation between academic performance of students and the level of noise (Shield & Dockrell, 2003b), temperature (Limb, 1997), air quality (Coley et al, 2007) & light (BB90, 1999).

In particular, concern has been shown for students in the age range of 5 to 11 years old (Dudek, 2000). This can be attributed to the ease with which students in this age group can be easily distracted by overheating, poor lighting and different kinds of noise. Generally, academic performance could be increased if classrooms had good acoustics without any external noise, as well as comfortable temperatures. good air quality and good lighting design, especially for natural light.

It is important that good environmental conditions are provided, especially to children, as they spend most of their time inside classrooms. Environmental comfort is a wide context. A comfortable space is provided by maintaining various comfort factors such as thermal comfort, lighting comfort, acoustic comfort and air quality, at an optimum level. It should be noted that providing all of these factors at an optimum level is a challenge, as these factors are interrelated and excessive care should be applied to eliminate the conflict between them.

There have been some other researchers who have looked at other types of conflicts between comfort factors in classrooms which are as follows:

- **Eduardo and Zanin (2004)** studied the acoustic, thermal and luminous situations in classrooms in Centre of the Technological Education in Brazil. In this research, the luminous and thermal situations of various classrooms are examined. Also, one type of conflict between thermal and lighting comfort is reviewed.

This research discovers that the classrooms which have the potential to receive a high amount of daylight (up to 300 lux) at the end of class (up to 3pm), even in winter with no need for artificial light, have a high risk of overheating as a result of direct solar gain during summer. This shows conflict between thermal comfort and lighting comfort and means that natural lights needs to be controlled and artificial light needs to be used. According to this research, light shelf is proposed to reduce the risk of overheating and also maintain lighting comfort.

- **Mumvic et al (2009)** studies the winter indoor air quality, thermal comfort and acoustic performance of a newly built secondary school in England followed by BSF investment. Based on this research, complex interactions between thermal comfort, ventilation and acoustic comfort are studied. Two types of conflict are shown in the research:

-Conflict between acoustic comfort and air quality:

Schools in this research are equipped with mechanical ventilation to maintain indoor air quality. The noise level measured inside the classrooms when occupants were occupied with a quiet test, exceeded 50dB (A), which is far above the requirement proposed by BB93. This is due to the result of noise produced by the mechanical ventilation. This shows one kind of conflict between air quality and acoustic comfort.

- Conflict between air quality and thermal comfort:

The mechanical ventilation installed to provide good air quality, in this situation, should provide 8l/s per person fresh air but produces cold droughts that have a negative impact on thermal comfort.

Hence it can be seen that although the school has recently been built based on the BSF programme, it does not provide a comfortable environment as the comfort factors conflict and interact with each other.

1.3.Objective

The schools located in close proximity of airports, usually suffer from high noise pollution. There are a number of busy airports operating within or close to London, and therefore the neighbouring schools are not exempt from this problem. This research looks at one of the likely conflicts between comfort factors in primary school classrooms which are located under the Heathrow flight paths. The author posits this research to be the first of its kind in this field.

The main hypothesis of this research is that the noise pollution problem is not an isolated problem for the primary school classrooms but it usually leads to classrooms having further problems such as overheating and poor air quality. This may relate to the fact that the occupants in the schools located near noisy areas, close windows in order to prevent inside from a high level of noise and consequently diminish ventilation. By reduced natural ventilation, a classroom loses its opportunity to have fresh air to provide good air quality and cool down during a hot summer, and hence classroom may become overheated and stuffy. Thus, overheating and lack of fresh air may be two major problems in schools which are located near noisy areas such as airports.

Due to the short duration of schools' summer term and high cost of air conditioning systems, most of the UK schools are not equipped with cooling systems. These schools mainly rely on opening windows in order to have fresh air and to cool down the classroom temperature during summer term.

Apart from the lack of ventilation that may cause overheating problems, overheating can also be related to the lack of designers, concern regarding other factors such as the building's thermal mass, solar gain, internal gain and internal layout, all of which are examined in this research.

Maintaining good environmental conditions and providing good comfort conditions are the fundamental factors that have always been considered in schools constructed from the Victorian era up to date. However, the requirements for comfort conditions have consistently been improved. In all school design tools and methods a section is allocated to the requirement of comfort factors (explained in chapter 2 in detail).

Despite comfort being the major consideration in school design guidelines, some classrooms may still fail to satisfy the occupants. This may be related to the unsuitability of guidelines and benchmarks, which are used to design and refurbish the school classrooms to provide satisfactory comfort conditions such as thermal comfort and air quality.

A wide range of guidelines regarding thermal comfort and air quality have been in place for a number of years. Building Bulletin 87 and 101 which were published in 2003 & 2006 respectively (by the Department for Education and Skill) are used for design and refurbishment of schools. In addition, CIBSE guide 'A' & 'B' make different recommendations regarding thermal comfort and air quality respectively. This study carries out a comparison between the guidelines proposed by CIBSE and Building Bulletin in order to evaluate which recommends more relaxed (or stringent) benchmarks in terms of thermal comfort and air quality. The thermal benchmarks which are proposed by CIBSE and Building Bulletin are based on fixed thermal models. In a fixed thermal model, thermal comfort is related to fixed thresholds (i.e. 25°C when occupants will start to feel warm and 28°C when occupants will start to feel hot).

There is another type of thermal model called adaptive model. In adaptive thermal model, thermal comfort is not related to fixed thresholds but to the outdoor temperature. In this study, a comparison is carried out between classrooms' indoor temperatures based on fixed and adaptive models with teachers' perceptions regarding thermal comfort, in order to assess the reliability of adaptive and fixed thermal models. Therefore, other than answering the main hypotheses (see 1 to 7 below), additional critical thinking issues (8 to 11) are also addressed in this study.

The main questions which are answered in this thesis are as follows:

- How occupants use the building to prevent the high level of aircraft noise from entering the classroom?
- Do the occupants prevent external noise from entering their classroom at all the time?
- Is there any relationship between occupants' activities and method of preventing external noise? Under which conditions (type of activities), the occupants are more likely to try to prevent external noise from entering classroom?
- What is the relationship between occupant's method of preventing external noise and use of natural ventilation?
- Do the classrooms located under flight paths have a higher / lower risk of experiencing overheating and poor air quality?

Critical thinking issues which are answered in this thesis are as follows:

- Are the thermal and air quality benchmarks proposed by Department for Education and Skill (BB101) suitable benchmark?
- Which overheating models (fixed/adaptive) better represent the occupants feeling?
- Do the current thermal and air quality benchmarks (Building Bulletin 101) used to design and refurbish school need to be revised in order to provide better environmental conditions for school classrooms?
- If the answer to the above question is yes, which overheating guideline should be considered in order to revise the overheating benchmarks?

1.4. Outline of methodology:

First (main) hypothesis methodology:

This research is a broad topic and looks at different problems at primary school classrooms. The first stage of this analysis is to choose correct samples. As the main hypothesis of the research is that the high level of background noise in areas which are exposed to aircraft noise causes problems for having natural ventilation through windows, schools are chosen from two different areas i.e. exposed to aircraft noise (Hounslow borough) and silent areas. The schools are selected from a list, received upon request from Hounslow Council, naming those exposed to aircraft noise

(Appendix 1.A). Following authors' personal communication with Prof. B. Sheild, the schools located in silent areas are selected from a survey that was carried out her. In her survey, the background noise level for the schools located in Haringey and Islington boroughs were reordered and categorised to quiet and noisy (Appendix 1.B). Noisy schools are defined as those lying in the Heathrow noise map of above 57dBA and Quiet schools are defined as those lying outside the noise map. 57 dBA is regarded as the limit to the noise impact of the airport because the percentage of people who found aircraft noise to be unacceptable, increases from 15% at 57 dBA to around 57% at 69 dBA based on Aircraft Noise Index study (ANIS) in 1984 (Peters et al. 2011).

Therefore schools (consequently their classrooms) are simply categorised as noisy and quiet schools. Table 1.1 shows aircraft noise level in each school.

Schools	Cranford	Grove Rd	STM&M	Orchard	Wellington	Andrew Ewing	Rosary	Heston	Hounslow	Feltham	Pools	Ambler	Norwood	Lady	Hungerford	Colerain	St Gildas	Green Church
Aircraft noise level LEG	>57									<57								
Schools' region	Noisy									Quiet								

Table1.1: Aircraft noise level in each school

As building factors such as thermal mass and solar gain have impacts on indoor temperature, in this study, it is tried to select schools from a wide range (in terms of thermal mass and solar gain) to provide a chance to assess their impact on indoor temperature. The schools range from Victorian to modern with different building specifications.

In order to assess the impact of aircraft noise on classrooms' indoor temperature and air quality as the main and first hypothesis of this research, this study is conducted in three parts as follow:

- Part 1: Impact of high level of aircraft noise on indoor temperature
- Part 2: Impact of high level of aircraft noise on window status
- Part 3: Impact of high level of aircraft noise on air quality

Each part contains a specific methodology. The methodology employed uses an objective survey to monitor temperature, air quality and noise; and subjective surveys.

Three objective measurements carried out in this study are noise, thermal and air quality measurements during the hottest period of the UK academic year (June and July). The noise and air quality measurements were carried out in 2008 and temperature measurement was carried out for three years: 2005, 2007 & 2008.

Subjective surveys were carried out by interview and questionnaires. Questionnaires and interviews with teachers and students are suitable means of evaluating classrooms' environmental conditions as they spend more than half of their days inside these classrooms.

In the 'first stage' of the subjective survey, the perception of teachers and students about the classrooms' environmental conditions are questioned in various interviews, in order to investigate the significant problems that the teachers and students face. The results of the interviews are used to select a questionnaire to look at the problems in depth, in the following stage. Following the authors personal communication with 'Usable Buildings Trust', the research questionnaire was designed based on their questionnaires set out to evaluate the environmental conditions in offices. Their questionnaire is selected as this is the most successful and relevant (considering the fact that the activities in offices and schools are both sedentary) questionnaire that can reflect the occupants' feelings regarding internal environment [Usable Buildings Trust].

In the 'second stage' of the subjective survey, a questionnaire was designed to be filled out by the teachers. The teachers' perceptions of the classrooms are questioned in three sections, in order to enable a more in depth evaluation of the classrooms' conditions:

- Section 1: Acoustic comfort, thermal comfort, air quality and lighting comfort.
- Section 2: Overall comfort, productivity and health rate.
- Section 3: The level of control on each of the comfort factors mentioned above.

Ninety three (93) questionnaires were filled by the teachers and helpers of 70 classrooms of 15 naturally ventilated schools in two consequent years of 2007 and 2008. Between one to seven questionnaires were filled out in each school. Unfortunately, the teachers of some schools refused to fill out the questionnaires both in 2007 & 2008. A sample of the questionnaire is found in the Appendix 2.1.

In the 'third stage' of the subjective survey, two types of questionnaires were designed for two age groups based on the interviews that had been carried out with students:

Group 1: Allocated to the students of years 1 to 3. Students of this group are incapable of filling out complicated questionnaires. Therefore, a simpler questionnaire was designed to be read out by teachers and the students were asked to express their views by raising their hands. Two hundred and forty (240) students from 9 classrooms of 2 naturally ventilated primary schools, located under the flight path, participated in this survey in the summer of 2008. Sample of the questionnaire can be found in Appendix 2.2.

Group 2: Allocated to the students of years 4 to 6. A more inclusive questionnaire was designed for the students of this group in order to collate more accurate results. The teachers were asked to brief the students on the aim of the questionnaires and guide them through to completion.

Four hundred and fifty (450) questionnaires were filled out by the students of 18 classrooms from 2 free-running primary schools, located under the flight path in summer 2008. A sample of the questionnaire can be found in the Appendix 2.3.

The summary of the above data collection can be seen in the following table (Table 1.2):

Classrooms Name	Objective survey						Subjective survey			
	Thermal objective Survey			Noise objective Survey		Air objective Survey	Thermal, Noise & Airquality subjcetive survey			
	2008	2007	2005	2008		2008	2008	2007	2008	
	Thermal measurment			Aircraft noise measuremnet	Activity noise measurmnet	CO2 measurmnet	Teachers and their helper are questioned		Students are questioned	
	Numbers of surveyed classrooms	Numbers of surveyed classrooms	Numbers of surveyed classrooms	Numbers of surveyed days	Numbers of surveyed days	Numbers of surveyed days	Numbers of filled questionniars	Numbers of filled questionniars	Numbers of students questionned (Y1 to Y3)	Numebers of filled questionnairs (Y4 to Y6)
Hounslow	4	4	3	_	_	_	1	0	_	_
Wellington	3	3	_	_	_	_	3	3	_	_
Cranford	3	3	_	_	_	_	3	6	_	_
Grove road	8	8	_	3	6	9	5	6	84	83
Andrew	5	5	3	3	3	3	5	8	155	80
Stmm	3	4	_	_	_	_	3	6	_	_
Heston	3	3	_	_	_	_	3	0	_	_
Rosary	3	3	_	_	_	_	2	0	_	_
Feltham	3	3	_	_	_	_	4	6	_	_
Pools	3	3	3	_	_	_	4	0	_	_
Ambler	3	3	3	_	_	_	5	0	_	_
Norwood	3	3	_	_	_	_	3	5	_	_
Lady	3	3	_	_	_	_	0	3	_	_
Hungerford	7	3	3	_	_	_	3	4	_	_
Colrain	3	3	_	_	_	_	2	0	_	_
Orchard	1	3	_	_	_	_	0	0	_	_
Green chuch	_	_	4	_	_	_	_	_	_	_
St Gildas	_	_	3	_	_	_	_	_	_	_

Table 1.2: Summary of data collection

As it was explained earlier, this study is carried out in 3 main areas (i.e. overheating, acoustic and air quality) each of which contain their own methodology as follows:

1.4.1. Overheating methodology :

Overheating is located in chapter 3 of this thesis. Part One concentrates on the impact of high aircraft noise on overheating. In summery the methodology of this part can be discussed around literature review, data collection and analysis of data.

A) Literature review: A comprehensive literature review is conducted in this stage regarding different overheating criteria and different factors that can have an impact on indoor temperature. The overheating chapter looks at thermal comfort and overheating criteria and the methods of controlling solar overheating in primary school classrooms.

B) Data collection: Two types of data are collected in this stage: objective data and subjective data:

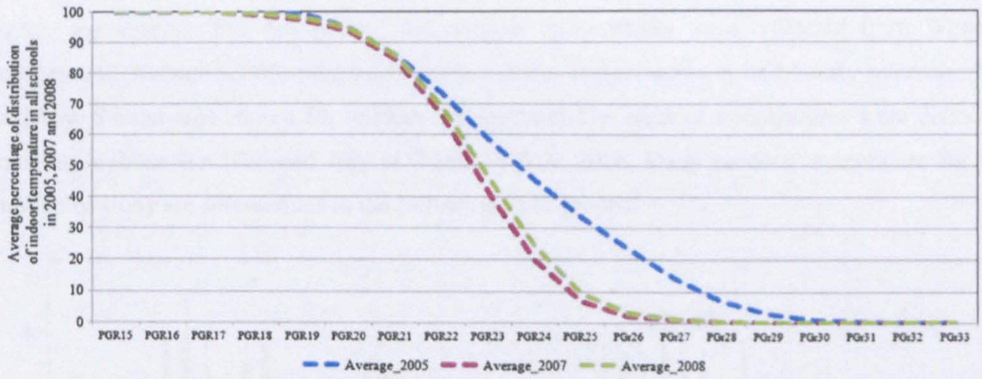
B1- Objective data**:** Climate and buildings factors are the two main factors that have impacts on indoor temperature. Therefore data collection can be divided into three parts: indoor temperature, climate and building data. Each part is divided in various stages as follow:

- Indoor tempter data:

- *Indoor temperature:* The indoor temperatures of 70 classrooms from 18 primary schools were recorded every half an hour with the accuracy of 0.5 degree C using a device called 'I Button' during the hottest period of the academic year (Jun & July) for the years 2005, 2007 & 2008. The indoor temperatures of 3 to 8 classrooms were recorded at each school. The indoor temperatures of each classroom were recorded 1 to 3 times during these 3 years. Two thermometers were placed in each classroom at a suitable height and far from direct solar gain in order to have an accurate result. Indoor air temperatures of classrooms were measured with a special thermometer called I-Button. This device contains a computer chip which is covered in a rugged steel can with the thickness of 16mm. The durable cover means that the updated information is portable and is safe if it is left in a rough environment (I-Button touch the future, 2006).

Figure 1.1: I-Button (Cited in I-Button touch the future, 2006)

Graph 1.1 Shows the average percentage distribution of indoor temperature in all schools in 2005, 2007 and 2008.



Graph 1.1: Average percentage distribution of indoor temperature in all schools in 2005, 2007 and 2008.

- Building data:

In order to assess the share of building impact on indoor temperature in each classroom, solar gain should be calculated and thermal mass should be assessed.

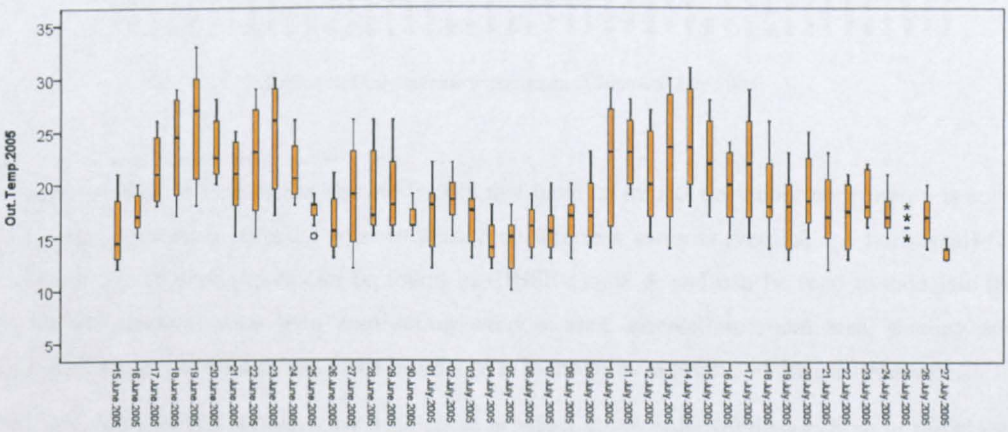
- *Solar gain calculation:* Solar gain refers to the increase in temperature as a result of solar radiation. The amount of solar gain (as one of the factor that has an impact on indoor temperature) in each classroom depends on the following factors: orientation, area of windows, classrooms' dimension (i.e. window area, floor area), type of shading and possible overshadowing (CIBSE TM36, 2006). Each orientation has a specific solar irradiance that can be found in CIBSE Guide A. In this guide, the design 97.5 percentile of beam and diffuse irradiance solar data on horizontal and vertical surfaces for London are shown for a 12 month period from sunrise (3:30 am solar time) to sunset (20:30 solar time) at hourly intervals (Appendix 3). It should be noted that only the data for June and July are used in this study. It should be considered that the solar irradiance data available in this guide is the 'maximum potential solar irradiance' for the peak day of each month under clear sky. The amount of solar gain that is calculated based on 'maximum potential solar irradiance' is maximum solar gain that a classroom could receive on each day during months of June and July.

- *Thermal mass evaluation:* Thermal mass is the ability of material to store heat. In order to study thermal mass (as one of the factor that have impact on indoor temperature), date of construction, construction material and detail and the percentage of each material for external wall(s), internal wall(s), ceiling and floor are assessed for each classroom.

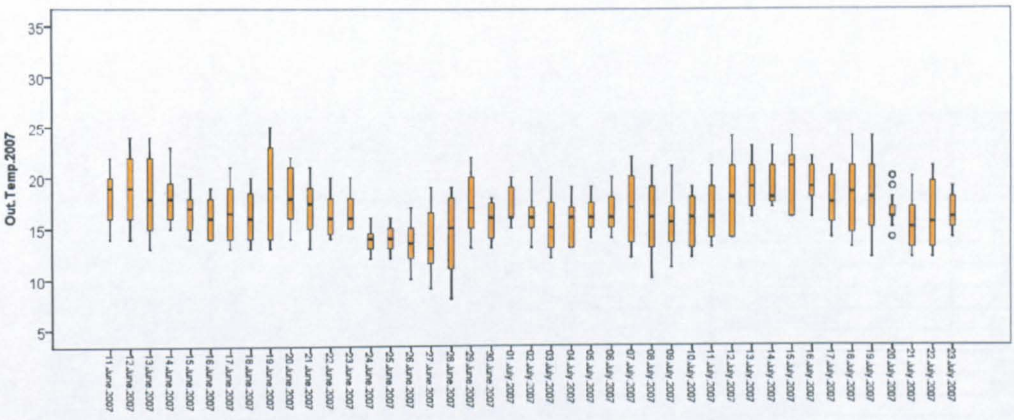
• Climate data:

Climate conditions: This can be discussed around outdoor temperature and solar irradiance.

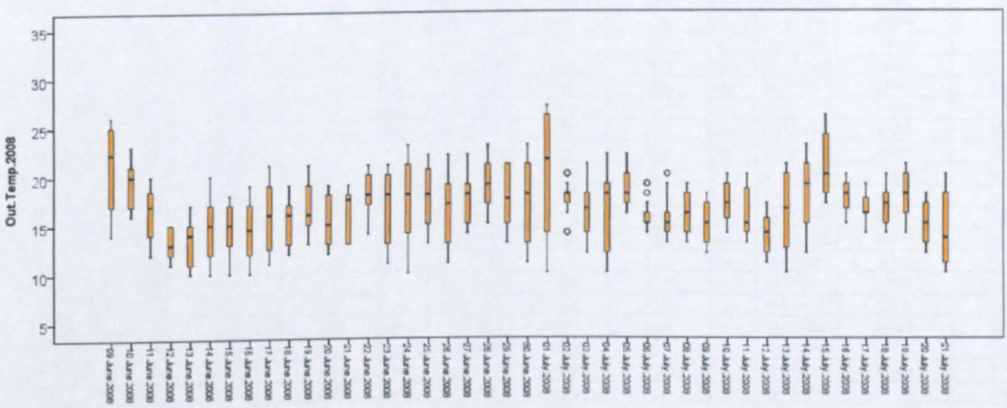
- *Outdoor temperature*: One of the climate factors that have an impact on indoor temperature is outside temperature. For this reason, the outdoor temperatures were collected from Weather Underground Website (2008) which shows the outdoor temperatures in half hourly intervals. The Heathrow Station was chosen for outdoor temperature. The outdoor temperatures were collected from this website for June and July of 2005, 2007 & 2008. Daily outdoor temperature for the duration of study are summarised in the following three graphs.



Graph 1.2: Daily outside temperature in June and July 2005



Graph 1.3: Daily outside temperature in June and July 2007



Graph 1.4: Daily outside temperature in June and July 2008

- *Solar irradiance*: One of the climate factors that have an impact on indoor temperature is solar irradiance. Maximum potential solar irradiance on different surfaces (vertical and horizontal) for the peak day of each month can be found in CIBSE Guide A and can be used to calculate the maximum potential solar gain considering window area, orientation, room area, shading and overshadowing on each surface. Solar irradiance is in the form of beam and diffuse irradiance.

The sum of beam and diffuse solar irradiances is called global solar irradiance. Sum of the global solar irradiance for a day is called daily global solar irradiance. Generally, the metrological offices around the world (e.g. Met Office), only record the 'daily global solar irradiance' on horizontal surfaces which vary according to the sky condition (cloudy or sunny).

Various complicated methods are proposed to convert the actual daily solar irradiance on horizontal surfaces to vertical surface. In this study the actual solar irradiance on horizontal surfaces is obtained from the UK Met Office for the duration of study which can be found from table 1.4.

2008	Date	Radiation - Daily global amount (KJ/m^2)	Radiation - Daily global amount (W/m^2)	2007	Date	Radiation - Daily global amount (KJ/m^2)	Radiation - Daily global amount (W/m^2)	2005	Date	Radiation - Daily global amount (KJ/m^2)	Radiation - Daily global amount (W/m^2)
Mon	09/06/2008	26911	7475	Mon	11/06/2007	10990	3053	Wed	15/06/2005	13311	3698
Tue	10/06/2008	23640	6567	Tue	12/06/2007	18697	5194	Thu	16/06/2005	7833	2176
Wed	11/06/2008	17962	4989	Wed	13/06/2007	21927	6091	Fri	17/06/2005	18730	5203
Thu	12/06/2008	15025	4174	Thu	14/06/2007	12374	3437	Sat	18/06/2005	28214	7837
Fri	13/06/2008	21961	6100	Fri	15/06/2007	18457	5127	Sun	19/06/2005	29475	8188
Sat	14/06/2008	21955	6099	Sat	16/06/2007	18202	5056	Mon	20/06/2005	17820	4950
Sun	15/06/2008	22828	6341	Sun	17/06/2007	17681	4911	Tue	21/06/2005	27043	7512
Mon	16/06/2008	24194	6721	Mon	18/06/2007	13449	3736	Wed	22/06/2005	28241	7845
Tue	17/06/2008	23251	6459	Tue	19/06/2007	22477	6244	Thu	23/06/2005	24918	6922
Wed	18/06/2008	11181	3106	Wed	20/06/2007	23995	6665	Fri	24/06/2005	19420	5394
Thu	19/06/2008	25986	7218	Thu	21/06/2007	20768	5769	Sat	25/06/2005	4156	1154
Fri	20/06/2008	15501	4306	Fri	22/06/2007	14999	4166	Sun	26/06/2005	18344	5096
Sat	21/06/2008	7003	1945	Sat	23/06/2007	14928	4147	Mon	27/06/2005	28035	7788
Sun	22/06/2008	26884	7468	Sun	24/06/2007	9563	2656	Tue	28/06/2005	23264	6462
Mon	23/06/2008	27376	7604	Mon	25/06/2007	13617	3783	Wed	29/06/2005	17714	4921
Tue	24/06/2008	23719	6589	Tue	26/06/2007	18390	5108	Thu	30/06/2005	7587	2108
Wed	25/06/2008	23147	6430	Wed	27/06/2007	15097	4194	Fri	01/07/2005	14829	4119
Thu	26/06/2008	24329	6758	Thu	28/06/2007	17700	4917	Sat	02/07/2005	7048	1958
Fri	27/06/2008	14233	3954	Fri	29/06/2007	20496	5693	Sun	03/07/2005	10441	2900
Sat	28/06/2008	26700	7417	Sat	30/06/2007	5745	1596	Mon	04/07/2005	17642	4901
Sun	29/06/2008	18598	5166	Sun	01/07/2007	20123	5590	Tue	05/07/2005	11887	3302
Mon	30/06/2008	26511	7364	Mon	02/07/2007	14388	3997	Wed	06/07/2005	14512	4031
Tue	01/07/2008	29702	8251	Tue	03/07/2007	17297	4805	Thu	07/07/2005	11511	3198
Wed	02/07/2008	11138	3094	Wed	04/07/2007	17565	4879	Fri	08/07/2005	10615	2949
Thu	03/07/2008	16987	4719	Thu	05/07/2007	13660	3794	Sat	09/07/2005	12368	3436
Fri	04/07/2008	25285	7024	Fri	06/07/2007	15053	4181	Sun	10/07/2005	27373	7604
Sat	05/07/2008	20826	5785	Sat	07/07/2007	26585	7385	Mon	11/07/2005	24047	6680
Sun	06/07/2008	11043	3068	Sun	08/07/2007	25572	7103	Tue	12/07/2005	27107	7530
Mon	07/07/2008	12697	3527	Mon	09/07/2007	20624	5729	Wed	13/07/2005	23003	6390
Tue	08/07/2008	20490	5692	Tue	10/07/2007	14794	4109	Thu	14/07/2005	25534	7093
Wed	09/07/2008	5773	1604	Wed	11/07/2007	13948	3874	Fri	15/07/2005	20563	5712
Thu	10/07/2008	18483	5134	Thu	12/07/2007	11592	3220	Sat	16/07/2005	27272	7576
Fri	11/07/2008	17638	4899	Fri	13/07/2007	14036	3899	Sun	17/07/2005	27914	7754
Sat	12/07/2008	15025	4174	Sat	14/07/2007	19898	5527	Mon	18/07/2005	21179	5883
Sun	13/07/2008	22327	6202	Sun	15/07/2007	13687	3802	Tue	19/07/2005	18237	5066
Mon	14/07/2008	21486	5968	Mon	16/07/2007	17022	4728	Wed	20/07/2005	25765	7157
Tue	15/07/2008	18522	5145	Tue	17/07/2007	20439	5678	Thu	21/07/2005	19844	5512
Wed	16/07/2008	16939	4705	Wed	18/07/2007	21915	6088	Fri	22/07/2005	11426	3174
Thu	17/07/2008	7566	2102	Thu	19/07/2007	15528	4313	Sat	23/07/2005	9500	2639
Fri	18/07/2008	7706	2141	Fri	20/07/2007	12732	3537	Sun	24/07/2005	7565	2101
Sat	19/07/2008	19625	5451	Sat	21/07/2007	17360	4822	Mon	25/07/2005	7415	2060
Sun	20/07/2008	17515	4865	Sun	22/07/2007	23148	6430	Tue	26/07/2005	13250	3681
Mon	21/07/2008	23864	6629	Mon	23/07/2007	5629	1564	Wed	27/07/2005	3016	838

Table 1.3: Actual daily solar irradiance' on horizontal surfaces (received from UK Met Office)

B2- Subjective data: A subjective survey is also carried out in order to test the results which are achieved from the objective survey. As a part of the teachers' questionnaires, teachers were asked to rate different environmental noise sources (e.g. aircraft, lorries, cars etc.) and thermal comfort. In the questionnaires, teachers were requested to rate thermal comfort and different noise sources level from 1 to 7 as follows:

Noise from	Cars	Too little	1	2	3	4	5	6	7	Too much
Noise from	Aircraft	Too little	1	2	3	4	5	6	7	Too much
Noise from	Lorries	Too little	1	2	3	4	5	6	7	Too much
Noise from	Buses	Too little	1	2	3	4	5	6	7	Too much
Noise from	Railway	Too little	1	2	3	4	5	6	7	Too much
Noise from	Other	Too little	1	2	3	4	5	6	7	Too much
Thermal comfort		Uncomfortable	1	2	3	4	5	6	7	Comfortable

Figure 1.2: Part of questionnaire

C) Analysis:

The analysis based one objective data: To study the impact of high levels of aircraft noise on indoor temperature, comparisons are carried out between the indoor temperatures (which are assessed based on different overheating criteria) of classrooms with similar properties (i.e. thermal mass, solar gain potential) with the same climate conditions (i.e. on days which have similar solar irradiance and outside temperature) but located either in noisy or quiet areas.

The analysis based one subjective data: Regression analysis is carried out between teachers' perceptions regarding environmental noise and thermal comfort in schools.

1.4.2. Acoustic Methodology

Acoustic study (located in chapter 4 of the research) concentrates on the impact of high aircraft noise on occupants' reactions toward high level aircraft noise. In summery the methodology of this part can be discussed around literature review, data collection and analysis of data.

A) Literature review: A comprehensive literature review is conducted in this stage regarding the requirements of acoustic comfort in school classrooms. In literature review, the factors that can have negative impacts on acoustic requirements inside a classroom are discussed.

B) Data collection: Two types of data are collected in this stage: objective data and subjective data:

B1- Objective data: In order to assess the relation between aircraft noise level and occupants' reactions toward windows, data should be collected in three stages: Activity noise measurement, Aircraft noise measurement and recording the window status when occupants are occupied with different activities.

- *Activity noise measurement:* The level of noise that students produce during different activities is measured on the days that the level of outside noise is negligible (i.e. when aircraft paths are diverted or when there is no disturbance from playgrounds or communal halls). For the purpose of the noise level study, the activities carried out in each classroom are divided to the following categories: 'Activity 1: Silent', 'Activity 2: One person speaking', 'Activity 3: Individual' and 'Activity 4: Group'. The activity noise measurements were carried out in seven classrooms (Y2-Y6) of two primary schools within close proximity to Heathrow Airport, for nine days in June and July 2008. The monitoring was carried out for a day or more.

- *Aircraft noise measurements:* In order to investigate the level of aircraft noise inside classrooms, courses of 30 minutes noise measurements were carried out when the schools were un-occupied, both when the windows were open and closed. The aim is basically to find out how closing a window would be of help in attenuating the aircraft noise inside a classroom. According to Building Bulletin 93, the background noise level should be no more than 35dB LAeq in unoccupied teaching spaces.

The aircraft noise measurements were carried out for six days in three classrooms of two primary schools within close proximity of Heathrow Airport in June and July 2008 in two situations of when windows were open and closed. In some classrooms, the monitoring was carried out for more than a day.

The classrooms' ambient noise levels were measured with a system called Symphonie manufactured by O1dB. The software package of Symphonie can be used for different purposes such as environment, industry and building acoustic. In this study, the dBTRAIT32, which is adapted for environment, is used (Symphonie User Guide Manual, n.d). The Symphonie hardware package contains the following devices (ibid):

- A powerful acquisition unit powered by the Notebook PcCard (PCMCIA) interface.
- A microphone
- A preamplifier

Figure 1.3: Symphonie system (Cited in Symphonie User Guide Manual, n.d)

- *Recording window status:* In order to assess the occupants' reactions toward aircraft noise, windows status were recorded during different sessions. The recordings provide the author with an opportunity to study the relation between windows statuses with the activity which is running inside classroom while an aircraft flies over a school building.

B2- Subjective data: Two types of subjective study are carried out in this stage:

- *Teacher's subjective study:* A subjective survey is carried out in order to test the results achieved from the objective survey. As a part of questionnaire, teachers were asked to rate ventilation control level and aircraft noise level from 1 to 7 as follow:

Ventilation	No Control	1	2	3	4	5	6	7	Full Control
Aircraft	Too little	1	2	3	4	5	6	7	Too much

Figure 1.4: Part of questionnaire

- *Students' subjective study:* Based on the student subjective study, the probabilities of closing windows due to the high level of aircraft noise are tested. In this study, students' perception regarding the high level of aircraft noise, their annoyance level, the extent to which they are used to aircraft noise and their reaction toward the high level of aircraft noise are questioned.

C) Analysis: The main aim of this part of the research is to evaluate whether occupants tend to close classrooms' windows when they are engaged with different types of activities, in order to provide a better acoustic condition inside the classrooms. In this chapter, pilot studies are carried out followed by detailed and observation studies. In the pilot studies, the aircraft and students' activity noise levels in two situations i.e. when window is open and when it's closed are compared in order to have a preliminary idea of the activities during which aircraft may cause a problem. Aircraft noise, through its nature, has two negative impacts on occupants: annoyance and speech intelligibility. For this reason, in detailed study, the impact of aircraft noise on classrooms annoyance level and speech intelligibility are assessed based on different benchmarks to evaluate the classrooms in terms of meeting the recommended acoustic criteria while windows are open and closed, and then, the situations in which it is more likely that occupants close windows are predicted. This study is followed by real observations mainly concentrating on the occupants' reactions toward the high level of aircraft noise when they are engaged with different types of activities inside classrooms in order to assess the assumptions made in pilot and detailed study.

1.4.3. Air quality Methodology:

Air quality study (located in chapter 5 of this research) concentrates on the impact of high aircraft noise on air quality. In summary, the methodology of this part can be discussed around literature review, data collection and analysis of data.

A) Literature review: A comprehensive study is carried out regarding the requirements of ventilation rate for two purposes of thermal comfort and air quality followed by various factors that cause poor air quality. Different air quality guidelines are studied.

B) Data collection: Two types of data are collected which are objective and subjective.

B1- Objective data: Occupancy and ventilation supplied through windows are the two main factors that have impacts on indoor air quality. Data are collected as follows:

- *CO_2 measurement*: In order to study the overall indoor air quality in schools which are located under the Heathrow flight path, CO_2 monitoring was carried out in eight classrooms (Y2- Y6) of two primary schools within close proximity of Heathrow Airport, for 12 occupied days during June and July (cooling season) of 2008. In some classrooms, the monitoring was carried out for more than a day.

The CO_2 level was monitored at 1 to 2 min intervals in classrooms at locations close to occupied zones at seated head height. The CO_2 levels were monitored with Telair 7001 (accuracy of +/- 50 ppm or 5% of reading up to 5000 PPM) [Figure 1.5]. The CO_2 reading range for this sensor (Figure 1.3) is between 0 to 10,000 ppm with the accuracy of ±50 ppm. Telaire 7001 is manufactured by Madge tech (Telaire 7001 User Guide Manual, n.d.). The readings are stored in a device called Tiny Tag. This is a data logger which is located in a compact film container (Figure 1.6), which has a memory capable of storing up to 16,000 readings (Gemini data loggers, n.d.).

Figure 1.5: Telaire 7001 (Cited in Telaire 7001 User Guide Manual, n.d.)

Figure 1.6: Tiny Tag (Cited in Gemini data loggers, n.d.)

- *Occupancy pattern:* As occupancy is one of the factors that have an impact on indoor Co2 level, the occupancy of classrooms are recorded in order to assess that how occupancy can impact air quality.

- *Window status pattern:* As ventilation provided through windows is one of the factors that have an impact on indoor CO_2 level, the opening statuses are recorded in order to asses that how the status impacts air quality.

B2- Subjective data: A subjective survey is also carried out in order to test the results achieved from the objective survey. As a part of questionnaires, teachers were asked to rate air quality and aircraft noise levels from 1 to 7 as follow:

Aircraft	Too little	1	2	3	4	5	6	7	Too much
Air quality	Fresh	1	2	3	4	5	6	7	Stuffy

Figure 1.7: Part of questionnaire

C) Analysis: The first part of analysis is carried out based on objective data. In this analysis, the recorded CO_2 levels are compared with the occupancy and opening status in order to evaluate that how these two factors impact indoor air quality. Furthermore, the recorded CO_2 levels are compared with air quality benchmarks in order to assess indoor air quality.

The second part of analysis is carried out based on subjective data. For this, a regression analysis is carried out between the teachers' perceptions regarding aircraft noise and air quality.

Second hypothesis methodology:

1.4.4. Overheating reliable benchmark methodology:

The second hypothesis of this research is that the use of relaxed environmental benchmarks can be one of the main reasons for poor environmental conditions in classrooms. In this study, the current air quality and thermal benchmarks which are used in refurbishing and designing schools are compared with other available benchmarks set for schools. The study is carried out in the following three parts:

A) Literature review: A complete literature review is carried out regarding different types of overheating benchmarks.

B) Data collection: Two types of data are collected which are objective and subjective.

Objective data: In order to assess this hypothesis, the indoor temperatures collected to assess the first hypothesis are used in this stage.

Subjective data: subjective surveys were carried out in 2007 & 2008. In these surveys, the teachers were requested to score their comfort level during summer terms (June & July) on a 7 scale Likert scale (One representing comfortable and seven representing uncomfortable).

Thermal comfort	Uncomfortable	1	2	3	4	5	6	7	Comfortable

Figure 1.8: Part of questionnaire

C) Analysis: This part of study is carried out in three stages in order to identify the most reliable overheating models. For this reason firstly, the current UK thermal comfort design guidelines are compared with each other, using the collated indoor temperature data from 140 classrooms in 18 schools during 2005, 2007 and 2008. Secondly, the relation between occupants' perceptions of thermal comfort are compared with adaptive and fixed thermal comfort. Finally, the percentages of dissatisfaction from overheating are calculated for each school, as one of the most reliable tools to assess overheating in schools.

1.5. Thesis structure:

This thesis is divided into seven chapters. The overview of each chapter is as follows:

- Chapter One - Introduction: This chapter provides an overview on the author's motivations and provides the background of the research problems. In this chapter, the research questions and aims are highlighted followed by the outline of the thesis structure and methodology.

- Chapter Two - UK School design: This chapter provides an overview of comfort conditions in schools. The impact of environmental conditions on students' performances and health are assessed followed by the evaluation of the school design in the UK from the Victorian era up to present day, with a focus on classroom comforts requirements such as lighting, ventilation and thermal comfort. These studies are followed by assessing the conflict between comfort factors in the schools built in each era. In this chapter, the guidelines requirements for comfort in schools are studied. Thus, a comprehensive background study regarding overheating and air quality benchmarks is carried out. The conflict between benchmarks for environmental conditions (in current design guidelines) as one of the factors that schools fail to maintain a good environmental condition are studied in this part based on literature review and collected data. Also, the impacts of environmental conditions on classrooms' occupants are assessed based on a further survey.

- Chapter Three - The principles of solar overheating controls (i.e. solar gain, internal gain, thermal mass and ventilation) are discussed in this chapter. The main aim of this part of the research is to highlight the impact of building and climate factors, on indoor temperature and, to compare the overheating levels in classrooms located in noisy regions with those in quiet areas in order to evaluate whether the schools which are located in noisy regions have a higher likelihood of experiencing overheating, as they may have a lower potential for having natural ventilation due to a high level of background noise. This chapter also provides an overview of the impact of climate and building factors (rather than ventilation) on indoor temperature.

- Chapter Four - Acoustic comfort: This chapter provides an overview of the principles of acoustic comfort in primary school classrooms and studies the reaction of occupants to the high level of aircraft noise in schools located under Heathrow airport flight paths. The main aim of this part of the research is to evaluate whether occupants tend to close classrooms' windows when they are engaged with different types of activities, in order to provide a better acoustic condition inside the classrooms.

- Chapter Five - Air Quality: This chapter provides an overview of different factors that have an impact on air quality. One of the main roles of natural ventilation is to provide fresh air and maintain air quality. Environmental noise is one of the obstacles that prevent a building from having the benefits of natural ventilation. The main aim of this part of the research is to assess whether aircraft noise is an obstacle to have the benefit of natural ventilation and to evaluate whether the schools which are located in noisy regions have a higher likelihood of experiencing poor air quality, as they may have a lower potential for having natural ventilation due to the high level of background noise.

- Chapter Six - Discussion: This chapter highlights the problems and findings of the previous chapters. The limitations which the author of this research is faced are explained followed by making suggestions for further research.

- Chapter Seven - Conclusion: This chapter discusses the conclusions of this research followed by making suggestions to overcome the identified problems.

1.6. Key phases of research project

The following flowchart shows the key phases of this research:

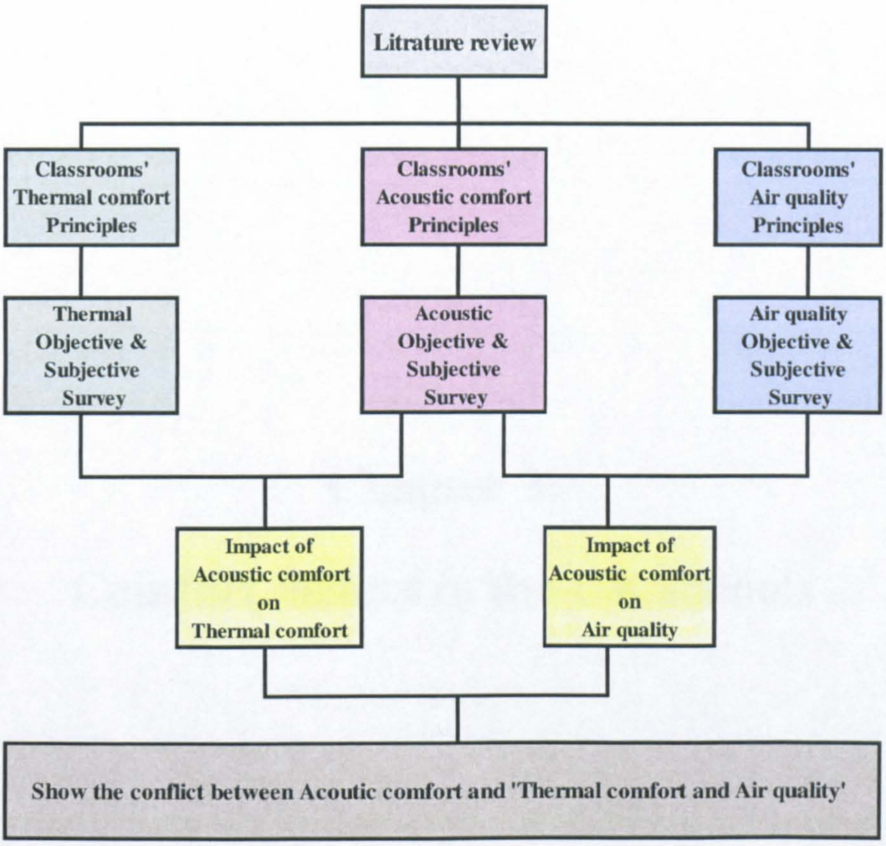


Figure 1.5: key phases of the research

Chapter 2:

Comfort factors in the UK schools

Chapter: 2.1. Literature review

Overview:

This chapter is conducted in four parts. The impact of environmental conditions on students' performances and health are assessed based on literature review in part one. The evolution of the school design in the UK from the Victorian era up to present day, with a focus on classroom comfort requirements such as lighting, ventilation and thermal comfort and conflict between comfort factors in the schools built in each era are studied in part two. The guidelines' comfort requirements in school design are studied in part three. In part four, a comprehensive background study regarding overheating and air quality benchmarks are carried out and various thermal and air quality benchmarks are compared with each other. Part five covers the conclusion of all parts.

2.1.1: Part One - The impact of poor environmental conditions on students' performance and health

The environmental factors in this study refer to thermal, lighting, acoustic and air quality. The aim of this part of the research is to study the impact of environmental factors on students' performances and their health. From the available literature, it can be seen that most of the researchers focus on the environmental issues in schools individually and not as a combination. Poor temperature control, lighting, air quality and acoustics have significant negative impacts on teachers and students, on their concentration, mood and attendance and consequently on their academic achievement (Higgins et al, 2005).

According to Earthman (2004), thermal comfort and air quality are the most important environmental issues that have impacts on students' achievements. However the lack of acoustic and lighting comfort have particular impacts on students which are discussed further in this chapter.

Students' age group is a significant factor that can influence the level of impact from the environment. This is due to the fact that the younger children have a higher concentration to their immediate environment while the older ones focus on a wider social and special environment. This can be explained by the students' physical and psychological make-up at the commencement of the primary school age (ages 4 to 5), which is different to the end of the primary school age (ages 11 to 12). Students become more mature and independent by the ages of 11 and 12 in comparison to when they start primary school (Dudek, 2000).

Earthman (1997) suggests that children, who are not in comfortable environments, feel disoriented and bored at school and face higher difficulty in their learning ability. In contrary, the ones who are in highly comfortable learning environments have higher learning abilities (Lackney, 1998). Poor environmental condition in classrooms not only affects the students' learning ability but also has a negative impact on teachers' health and their ability to teach and deliver the materials (Schneider, 2003, p.4).

The impacts of environmental conditions on students are discussed in the following as follows:

2.1.1.1. The impact of poor acoustic comfort on students' health and performance

Poor acoustic comfort is mainly related to the high level of background noise and long reverberation time. A classroom's background noise is affected by the noise from inside and outside of the classroom. The noise from outside a classroom can be either from inside or outside of school.

According to Baumann & Neiderstatter (Dudek, 2007), one of the most serious acoustic problems in a classroom is the long reverberation time experienced in old Victorian and open-plan schools. In their study, students reported comfort in the classrooms that were acoustically designed based on the classrooms' function. It has been found that noise interferes with students' learning both while it occurs as well as after noise has abated (Gifford, 1987). It is crucial to have good acoustic classrooms for all age groups (Dudek, 2007) since acoustic comfort is one of the major factors that have an impact on students' academic performance (Schneider, 2003). For this reason, various solutions to overcome long reverberation time and high level of background noise are proposed by different researchers in this regard. Some of the examples of these solutions are as follows:

- Increased carpeting as proposed by Tanner & Langford (2002)
- Increased acoustic tiles to dampen reverberation (Maxwell & Evans, 2000)
- Creating different zones which can offer a variety of acoustic characteristics according to the relevant activities such as silent, quiet, eating, singing, making music zone (Dudek 2007).

It should be noted that the above solutions improve the acoustic comfort inside a classroom only if the environmental noise is minimum. The presence of environmental noise such as noise from aircraft, rail and road traffic has a significant impact on the background noise level inside a classroom.

In the following pages, the negative impact of noise (i.e. environmental noise & classroom noise) on children's academic health and performance are discussed.

a) The effect of environmental noise on children

Many studies have been carried out to assess the impact of each of the environmental noise sources individually on students' performance. The most chronic environmental noise sources are noises from aircraft, train and traffic. The impacts of each of these environmental noises are explained below:

Aircraft noise:

The aircraft noise due to its intermittent characteristics (i.e. typically more intense, less predictable and peak level) causes more distraction compared to road noise, because children are more habituated to the road noise and are not distracted by it. This can be attributed to the continuing nature of road noise (Jones, 2010; British Standard 4142: 1997). It has been shown that aircraft noise has more impact on children compared to the noises from other sources [(Crook and Lagdon, 1974), (Cohen et al, 1980), (Cohen et al, 1981), (Hygee et al, 2002), (Haines et al, 2001), (Haines et al, 2002)].

Since aircraft noise causes a higher level of distraction than other environmental noise sources such as road noise, within the last three decades significant studies have been carried out on the impact of high level of aircraft exposure on children studying near eight airports around the world. The summary of these studies is given below. It should be noted that children's health and performance is related to many factors such as socioeconomic status, occupation of the household, parental education, family size, subsidised lunch programs, ethnicity, the percentage of pupils with English as a second language etc [(Evans et al,1995), (Evans and Maxwell, 1997)].

In each of the following studies (Jones, 2010), other than aircraft noise, all factors which have some impact on the children are kept constant to evaluate the main impact of aircraft noise on students. Alternatively samples which are compared with each other are chosen in such a way that they share all but one condition (aircraft noise).

- **Impact of Japan airport:** In 1975 Ando et al studied the impact of aircraft noise on students' performance by comparing 1144 elementary school pupils in schools around an airport in Japan with the ones in quiet regions. According to this study, pupils who were exposed to a high level of aircraft noise showed *lower performance* as their average rate of work was slower than average.

- **Impact of Los Angeles International Airport:** In 1980 Cohen et al studied the impact of aircraft noise on students' performance and health by comparing elementary students from four schools which were located around Los Angeles International Airport with three schools which were located in quiet areas. Based on this study, students located in the schools around the airport experienced a *higher level of health problems* (because they experienced a higher blood pressure) and a *lower performance* (because they failed on the cognitive tasks and were more likely to give up before the allocated time to complete tasks) as they were exposed to a high level aircraft noise.

• **Impact of Taiwan Airport:** In 1993 Chen and Chen studied the impact of aircraft noise on students by comparing the hearing ability of 228 students who were attending a school near an airport in Taiwan with 151 students attending schools further away from the airport. Based on this study, students of the school located under the flight path had a *lower level of health* due to a lower hearing level.

• **Impact of Munich International Airport:** In 1995 Evans et al studied the impact of aircraft noise on students' performance and health by comparing 135 students with the average age of 10.78 who were at Yr3 and Yr4. They were living in two different noise level neighbourhoods: noisy (24-hr Leq= 68.1dBA; peak=79.8dBA) and quiet neighbourhood (24-hr Leq=59.2dBA; peak=69.0dBA) around Munich International Airport. Based on this study, it was found that students who lived under the flight path had a *lower level of health* as their adrenaline, noradrenalin and systolic blood pressure were higher in comparison with the students who lived in quiet regions. In addition the students who lived under the flight path experienced a *lower performance* as they had poorer reading abilities and long-term memory required to recall tasks. The authors suggested that children may cope with adverse noise by developing coping strategies such as 'tuning out' ambient noise, which may have implications on language acquisition and speech processing.

• **Impact of New York Metropolitan Airport:** In 1997 Evans and Maxwell studied the impact of aircraft noise on students' performance by comparing 116 of Yrl & Yr2 from two elementary schools, one of which was located in a noisy neighbourhood (within the 65Leq flight counter) of New York Metropolitan Airport, while the other was located in a quiet neighbourhood. Based on this study, it was found that students from the school which was located in the noisy neighbourhood had a *lower reading score and reading ability* in comparison with the students of the school located in the quiet neighbourhood.

• **Impact of new Munich Airport:** In 1998 Evans et al studied the impact of aircraft noise on students' performance and health over a two-year period before and after the opening of the new Munich Airport by comparing 217 elementary school children from Yr3 & Yr4 with average age of 9.90 living close the airport. The schools noise exposure increased in both quiet (from 53dB to 55dB L_{eq}) and noisy (from 62 to 73 dB L_{eq}) neighbourhoods as the result of opening the airport.

Students' health and performance samples were collected six months prior to the opening of the airport (Wave 1), 6 months after opening (Wave 2) and after 18 months after the opening (Wave 3). Post Wave 1, the children's health became poorer as their blood pressure, adrenaline and noradrenalin increased in the noisier neighbourhood while it remained stable in the quieter area. In addition their quality of life decreased in the noisier neighbourhood while it remained stable in the quieter area. Bollinger et al (1999), based their research on Evans et al and reported that motivational deficits were seen in those children exposed to aircraft noise after the opening of the airport in comparison to the children living in the quieter areas.

• **Impact of London Heathrow Airport:** In 2001 Haines et al studied the impact of aircraft noise on students' performance and health by comparing 340 school children aged 8-11 around London Heathrow Airport. Children in four schools exposed to outdoor Leq>66dBA were compared with those in lower noise areas, with outdoor Leq<57dBA. The results indicated that chronic noise exposure was associated with higher levels of noise annoyance and impaired reading comprehension, but there was no effect on mental health problems. Matsui et al in (2004), studied the impact of aircraft noise on students' performance by comparing children from 10 schools which were located in high-aircraft noise areas (L_{eq}> 63dBA) with children from 10 schools in low-aircraft noise areas (L_{eq}< 57dBA). This study showed that the students from schools which were located in high-aircraft noise had delayed recalling abilities.

• **Impacts of Heathrow, Netherlands and Spain Airports:** The RACH project (Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health) by Stansfeld et al (2005) was one of the most extensive studies done on aircraft noise and children's learning carried out betweenApril to October 2002. A total of 2844 children were studied in primary schools near Schiphol (Netherlands), Barajas (Spain) and Heathrow (UK). The results indicated that exposure to chronic aircraft noise was associated with a significant impairment in reading comprehension. The study shows that a 5dB increase in aircraft noise is equivalent to a 2-month reading delay in the UK, and a 1-month delay in Netherlands. No national data was available in Spain.

Matheson et al in 2003 summarised findings from 1980 onwards and explained that the high level of aircraft noise exposure caused raised annoyance level, raised blood pressure, increased stress response level, impaired motivation, increased sense of helplessness, lower reading ability, attention and memory in children.

Majority of the children who were exposed to a high aircraft noise expressed disruption while thinking or doing school work (Haines et al, 2003). Three types of coping strategies have been seen among the children who are exposed to a high level of aircraft noise. The first one which is the most popular method is the covering of ears, the second one is do nothing (no activities while the noise is present) and the third one is ignoring.

Road & rail noise:

After aircraft noise, road noise is found to be the most distracting noise. In the European Union countries, about 40% of the population are exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dB(A) during daytime and 20% are exposed to the levels exceeding 65 dB(A) (Berglund et al, 1995).

Road noise is the predominant noise source in urban areas. Car noises can be heard in 86% of London primary schools as per the study carried out by Sheild and Dockrell (2004b). Road traffic has negative effect on children such as affecting their reading ability (Lukas et al, 1981), their concentration [(Sanz et al, 1993) and (Romero et al, 1995)] and also a higher level of complaints when the noise levels exceed 60 dB (A) (Sargent et al 1980). It has been found that typical road traffic noises are around 70dB (A) (Shield and Dockrell, 2008).

Traffic noise does not have any impact on children's memory according to the study carried out by Bowman (2004). In his study, the impact of traffic noise on memory on children age 13-14 years was assessed. For this reason, three equal groups of 32 pupils were chosen to be exposed to three different noise conditions. It was found that there was no significant relation between noise and memory processing.

Another study by Bronzaft and McCarthy (1975) shows that the children who were exposed to train noise of up to 89dB(A) achieved lower reading scores than the ones located on the quiet side of the school. It was also found that the difference in the scores could be eliminated by a noise reduction programme.

b) The effect of classroom noise on children

In the last few years, the most research on the effect of noise on children has concentrated on environmental noises rather than classroom noise. Recently, researchers have shown a higher interest in classroom noises and have studied the impact of internal noise on children's reading, numeracy and overall academic performances [Shield et al (2002), MacKenzie (2000), Maxwell et al (2000) & Lundquist (2000)].

As per the study carried out by Hetu et al (1990), there is a significant relationship between children's learning and consequently their performance, with the background noise level interfering with their speech. Children's performances in an acoustically treated room were compared with the non-acoustically treated rooms by Mackenzie (2000) and the results revealed that children show a higher performance in word intelligibility in the acoustically treated rooms. In addition, a recent study by Shield and Dockrell (2003b) shows a significant relation between internal classroom noise and their performance. The student performances were assessed by Standard Assessment Task (SAT) score results. This study confirms that not only the environmental noise but also the classrooms' noise level has a significant impact on students' performance. It should be noted that in some cases, the classrooms' background noise level is deeply related to the underlying classrooms' noise levels when classrooms are unoccupied. This result proves the importance of environmental noise as a deterrent to students' health and academic performance.

2.1.1.2. The impact of poor air quality on students' health and performance

Poor air quality in a classroom has a negative impact on students' performance, health and also teachers' productivity according to various studies that are explained further. For this reason, guidelines have been put in place to provide good indoor air quality in classrooms. These guidelines are explained in Chapter 5. In general, the factors that influence indoor air quality are outdoor pollution, ventilation rate, furnishings, occupants' activities, length of the occupancy and the number of occupants. Several researches have been carried to assess indoor air quality in school classrooms as well as the impact of poor air quality on occupants' health and performance.

Coley and Beisteiner (2000) and Lugg (1999) carried out studies in some of the naturally ventilated UK schools and suggest that school classrooms are unable to provide good air quality for students. Furthermore, a large detailed study was carried out to assess the ventilation and indoor air quality inside 16 classrooms of eight primary schools across the UK. As per the results of the study, the ventilation levels in classrooms were frequently below the minimum recommended levels when occupied (Ajiboye et al, 2006).

Further study was conducted on the impact of poor air quality on the students themselves. A series of studies have been conducted around the world to study the impact of poor indoor quality on occupants and specifically its impact on school buildings, students and teachers.

- **Dutch study:** This study was carried out by Dijken et al (2005) on homes and schools. It was discovered that there was a significant relation between poor air quality and students' health. This study shows that 10 out of the 11 classrooms that were chosen as samples suffered from poor air quality and experienced a CO_2 level of above 1000 ppm.

- **Scandinavian study:** This study confirmed that students' performance decreases as a result of poor air quality and vice-versa (Myhrvold et al, 1996; Wargocki et al, 2007).

- **European study:** This study was carried out on 800 students from eight schools. The results show that lower ventilation rate and consequently high CO_2 levels cause lower concentration and increase health symptoms (EPA, 2003).

- **Norway study:** Following the concern on the increase of allergy and asthma among the Norwegian children, a plan was put in place to renovate schools in order to provide a better indoor environment and elevate the students' health and performance. In order to test the impact of air quality on students, surveys were carried out in 35 classrooms from eight schools before and after the renovation and the results show that the students' performance increased in the new indoor environment as a result of the renovation (Myhrvold et al, 1996).

- **UK Studies:** David and Coley (2004) carried out a study on students between the ages of 10 to 11 from one primary school that was identified as a poorly ventilated school by Coley and Beisteiner (2002). This research shows that student concentration become significantly lower as a result of high CO_2 levels inside the classrooms. In another study carried out in the UK, Clements-Croome et al (2006) focused on 20 primary schools (mixture of old and new) located in Southern

England (Reading). This study shows that the school performance improved by 14.5% by doubling the ventilation rate to 10 l/s. This improved by 3.5% by reducing the temperature by 1°C.

As a result of the requirement of reducing CO_2 emission levels by 2030, UK schools have shown a tendency to reduce their ventilation rate in order to reduce energy consumption. Reducing the ventilation rate in schools had an adverse effect on students' learning and achievements due to a higher level of CO_2 inside classroom.

Poor indoor quality can have a significant effect on students' health and consequently effect on their learning both directly and indirectly. Poor indoor air quality *directly* affects the occupants learning ability by impairing their concentration and memory and *indirectly* by causing health problems. For example, indoor pollutant in classrooms causes diseases such as asthma and allergy among students. This could lead to absenteeism and use of medication, both of which have a negative impact on their academic achievement. Among chronic illnesses, asthma has been found to be responsible for 20% of absents in primary and secondary schools (Richards 1986 cited in Mendell et al, 2005, p.5).

2.1.1.3. The impact of poor thermal comfort on students' health and performance

The principles of thermal comfort and various guidelines in place regarding them are discussed in the literature review of Chapter 3.

Most of the research regarding the impact of environmental factors on students' performances in the UK concentrate on the impact of acoustic comfort, lighting comfort and air quality rather than thermal comfort. According to the available evidence, British schools are not thermally comfortable and as shown by the studies of Leaman & Bordass (cited in Woolner 2010, p.24), occupants have a high level of complaint regarding classroom thermal comfort. Under the Building Schools the for Future (BSF) scheme, some schools awaited refurbishment due to heating and cooling problem. In these schools, the negative impact of the lack of thermal comfort on students' achievement were reported by the schools' staffs (ibid).

The negative impact of thermal discomfort on students can be divided into two categories: students' poor performance and students' health. Thermal discomfort is typically associated with either overheating or cold temperature. Generally warm temperatures cause sluggishness, tiredness while cold temperature can affect students' dexterity (Lackney, 1999).

Studies carried out around the world looked at the negative impact of thermal discomfort on students' performance and health:

- **Thermal discomfort and student's health:** As per the study on the negative impact of thermal discomfort on students' health by Jago and Tanner (1999), it was demonstrated that when the classrooms' indoor temperature exceeds 23.9C°, students' respiration rate increases and this also provides the condition for some diseases.

• **Thermal discomfort and students' performance:** A study was conducted in Swedish schools looking at whether high indoor temperature has a negative impact on specific mental attainments. Low mental attainment causes poorer performance especially in adding and multiplying. This has been confirmed by Wargocki (2005), who suggests that increased temperature has significant negative impact on students' performances while carrying out different tasks such as adding, multiplying, reading etc.

According to a study by King and Maran (1979 cited in Zeiler et al 2009, p.2308), students reported discomfort as temperature and humidity increased. In this study, the students had a lower task-performance as an outcome of low attention given to providing thermal comfort. As a support to this, a more recent study by Wargocki and Wyon (2007) demonstrates that providing the classrooms with a comfortable indoor temperature improves students' performances. For example, according to their research, the students' performances on 'numerical tasks' and 'language-based tasks' improved when the indoor temperature in the classroom was decreased from 25° C to 20°C in late summer.

Hence it can be suggested that thermal discomforts have a negative impact on both students' health and academic performance. The student's academic attainments and health can be improved by improving thermal comfort.

2.1.1.4. The impact of poor lighting comfort on students' health and performance

Similar to the factors explained earlier, the lack of lighting comfort can negatively affect students' health and performance. Lighting comfort mainly refers to providing a sufficient level of illuminance considering the type of activity being carried out, and also providing adequate light control to ensure a correct level of light distribution so that no glare is caused.

Since lighting is one of the fundamental characteristic of a classroom, many research focus on the impact of lighting on students (Earthman, 2004). Lighting design is a broad subject that covers both natural and artificial design. As mentioned above, there have been studies carried out that examine the impact of lighting comfort on students' performance and health.

• **Poor lighting comfort on students' health:**

A study by Taylor and Gousie (1988) suggests that lack of lighting comfort (in terms of level, glare, spectrum etc) has a negative effect on students' physiological and psychological functions such as neuron doctrine functions, hyperactivity and task behaviour.

Good natural lighting can only be achieved by combining direct and indirect lighting (Barnitt, 2003; Butin, 2000) and lighting controls such as blinds to provide an opportunity for adjusting lighting levels in classrooms (Butin, 2000). One of the main benefits of natural light is that it consists of all light spectrums (full spectrum). Natural daylight has a positive impact on bodily and mental well-being of all humans. This is why school design should maximise the level of daylight, which also helps reducing the cost of artificial lighting (Walden.R, 2008). Lack of adequate level of light can increase fatigue, headaches and also damage to eyesight, also a light which is too bright has a negative impact on well-being. Glare can lead to diminished vision, indisposition, and headaches resulting from overexerting the eyes (CIBSE KS6, 2006).

It has also been found that illness and mental fatigue can be reduced by the use of full spectrum natural light especially on children with hyperactivity disorder (Dunn et al., 1985). The study discovers that students are healthier under the full florescent lamp with improved ultraviolet artificial light. They seem to have fewer dental cavities, have better growth and also better attendance and development in comparison with students studying under other artificial lighting sources. Florescent lighting is also found to increase hyperactivity among children as compared to full spectrum lighting (Jago and Tanner 1999)

- **Poor lighting comfort on students' performance:**

Performance improves in the presence of daylight, and its positive effects are manifested in better social behaviour. There is a significant relationship between students' academic attainment with natural daylight. Children's attention increases (Ott, 1976) and student absenteeism decreases (London, 1988) as a result of full spectrum natural light. According to the study carried out by (CHPS, n.d), students in well-lit classrooms had higher scores (up to 26%) on the New Stanford Achievement Test in comparison with the ones in poorly lit classrooms.

Hence it can be inferred that lighting discomforts have negative impact on students' health and academic performance. The student's academic attainments are improved by making improvement to lighting comfort.

2.1.1.5. Result:

As a result of the literature review, it can be concluded that there is a significant relationship between various environmental factors and students' academic achievements as well as health. This research studies their relationship based on the teachers' perceptions (self-assessment through questionnaires) in the analysis section.

2.1.2. Part Two - Evolution of comfort requirements in UK school design from Victorian era to the present day

Over the past two centuries, the design of school buildings in the UK has been affected by various factors such as social, economic, architectural educational etc. (Woolner, 2010). Not only have the schools layouts changed, but the comfort requirements have also been improved since the Victorian area in order to provide better environmental conditions for students. As far as the comfort factors requirements are concerned, the history of the UK school construction is divided into five time periods - the Victorian, open air, after World War II, after the oil crisis and after Primary Capital Programme (PCP) / Building School for Future (BSF) schemes, which are explained in this part . In each of these periods, the level of lighting, ventilation requirements and the type of constructional materials (which have a significant impact on heating and cooling loads and consequently thermal comfort) are different. The requirements of each era are reviewed in this research. It should be noted that the schools which were built during the different periods mentioned above are still being utilised in London.

2.1.2.1. Victorian schools

Figure 2-1.1: Internal view of the first generation of a Victorian school

(Cited in Wu et al, 2002)

Victorian schools were built from 1837 to 1901 after the establishment of government-led educational system, transferring students from classrooms run in churches to schools (Chatelet, n.d). Victorian schools are divided into two generations: schools which were built before and those after due consideration was given to hygiene issues. These generations are named as the first and second generation of Victorian schools for the purpose of this study. It should be noted that the second generation of the Victorian schools are still being used.

In the first generation of Victorian schools, a large number of children were gathered in school houses which were divided into classrooms by curtains. During this period, a new English educational method (known as mutual education) was offered, which allowed a single teacher to manage hundreds of students by getting assistance from advanced students who were trained as tutors (Seaborne,1971).

Joseph Lancaster, one of the promoters of the mutual education method started debating about the classroom layouts with regards to the number of students and arrangement of furniture. Following his debate, the 'Hygiene issue' became prominent especially with regard to lighting, heating and classroom furnishing. One of the disadvantages of 'the first generation of Victorian schools' was the poor air quality and lack of fresh air as the windows were built high in the walls, to stop students from being distracted from their work by looking outside (Chatelet, n.d).

This style of school building spread quickly but disappeared almost instantly, as the school population in the UK rose, which resulted in classrooms being separated for children of different abilities and ages (Wu et al, 2002). Rule of hygiene was enforced and ratified between 1860 and 1880. As a result 'the second generation of Victorian schools' emerged. Built two or three floors high, these schools featured long central hallways with classrooms with high ceilings, typically on either side, making the depth of buildings greater than 20 meters (Chatelet, n.d).

a) Thermal comfort in Victorian schools

Victorian schools are found to be thermally comfortable during summer but not in winter (BB73, 1991). These schools have low cooling demand during summer and maintained indoor temperature during summer because of the following reasons:

- The heavy thermal mass materials which were used in construction of these schools absorb extensive solar gain during summer and prevent classrooms from being overheated. The main construction of Victorian schools is solid brickwork. The pitched roofs in these buildings are covered with slate (BB73, 1991).

- The main faces of the classrooms are towards the North which results in the classrooms receiving a lower level of solar gain than from any other direction.

- The high ceiling and sash windows create the stack effect which has an impact on indoor temperature and air quality during cooling seasons (summer).

Hence it can be concluded that the occupants of Victorian schools have the benefit of good thermal comfort in summer but these schools struggle to provide thermal comfort during winter as the heating demand in Victorian schools is high. This is due to the fact that the solid brick walls in these schools have a U value of around 2.05, which is extremely high, in comparison with the current recommended U value of 0.25 as per the current building regulation. The high U value causes an increased heating demand and consequently creates problems in maintaining indoor temperature during heating seasons (winter) in classrooms.

The following techniques can be adopted to provide a better thermal comfort during winter in Victorian classrooms (BB73, 1991):

a) Insulation: In order to decrease the U value and the heating demand in Victorian classrooms, insulation (preferably external) should be added to the solid brick walls.

b) Suspended ceiling: The height of classrooms in Victorian schools is between 3.1m to 3.5m. This height could be reduced to 2.4m. In order to prevent reducing day lighting and ventilation, the ceiling should be flared up in places at 45°, to meet the window heads. This prevents the classrooms from losing the privilege of having natural ventilation through sash windows.

c) Add window: Generally, the windows in Victorian buildings are single glazed sash windows with timber frames. As the majority of Victorian schools are listed buildings and their façades are required to be conserved as they are, a new double glazed window could be added to the slate edge of existing windows (Figure 2-1.2).

Figure 2-1.2: Double glazed window in a Victorian school (taken by the author)

a) Lighting comfort in Victorian schools

The Victorian classrooms are generally prevented from glare and excessive heat as they face the North (Robson, 1972). It should be noted that North facing windows receive less luminance when compared with the South orientated ones. Generally in Victorian times, the requirements of lighting levels were less in comparison with the present days (BB90, 1999). Please note that although classrooms facing north may have some glare due to sunrise/sunset, this does not cause any problems for occupants as schools are closed during these times.

b) Acoustic comfort in Victorian schools

The reverberation time and background noise level in Victorian schools is higher than modern schools due to the higher classrooms' volume with a corresponding increase in the amount of reflective surfaces. Acoustic tiles can be added to the Victorian classrooms' surfaces to decrease the reverberation time. It should be noted that by adding acoustic tiles to the classrooms' surfaces, the classrooms' capability for maintaining indoor temperature during summer would be decreased, as heavy thermal mass surfaces would be covered with these materials. In addition, Victorian schools do not suffer from environmental noises such as cars and lorries as much as modern schools, since they are mainly surrounded by large grounds and playgrounds which separate them from the nearest road (Shield et al., 2004b).

c) Air quality in Victorian schools

For the following reasons, the Victorian classrooms may have a better indoor air quality:

- Victorian schools do not have any restriction for opening windows as they are usually set back from busy roads and consequently receive a lower level of environmental noise.
- Sash windows together with high ceilings in Victorian schools offer stack ventilation.

d) Conflict between comfort factors in Victorian schools:

Two types of comfort factor conflicts are experienced in Victorian schools:

- On the one hand, Victorian schools have the privilege of having stack effect due to sash windows and high ceilings and consequently the ability to maintain indoor air quality during summer. On the other hand, the occupants of these schools suffer from high reverberation times and consequently a higher level of noise due to their high ceilings. This is a conflict between air quality and acoustic comfort in Victorian schools.
- In Victorian schools acoustic tiles could be added to reduce the reverberation times, but acoustic tiles cover the heavy thermal mass surfaces and reduce the building's capability to maintain indoor temperature during summer.

Figure 2-1.3: View of a Victorian school

(Taken by the author)

2.1.2.2. Open-air schools

In the early part of the 20th century, concern over the spread of tuberculosis was brought up in the international congress held in Nuremberg in 1904. In this congress, the lack of ventilation issue was discussed as one of the reasons of spread of tuberculosis. Doctors advised provisions of a higher ventilation level and natural light inside the schools, in order to react against the tuberculosis break out. Thus, from 1900 up to the 1930s, an open air school movement became the dominant idea to decrease the risk of tuberculosis. This idea was extended afterwards until mid post war (Chatelet, n.d).

Architects proposed single floor schools located at garden sites in which the classrooms' windows could be opened, so that they could provide a higher level of ventilation. The innovation of construction technology (i.e. steel framing) made it possible to maximum the use of glazed areas in these schools. These schools became known as open air schools (Wu et al., 2002).

a)Thermal comfort in open air schools before modification

At the time of their construction, the open air schools were thermally comfortable during summer but not winter. These schools had the benefit of cross ventilation, as large windows and doors could be fully opened to maintain indoor temperature and to remove excessive heat during cooling seasons (summer). Although these schools had the benefit of a high level luminance, good level of natural light and thermal comfort during summer, a large amount of heat was lost during winter due to their large openings (conflict between thermal comfort in winter and summer).

Figure 2-1.4: View of an open air school before modification
(cited in Wu et al, 2002)

b) Thermal comfort in open air schools after modification

The open corridors in open air schools were covered up (using glass enclosures) in order to improve environmental conditions. By covering up the corridors, these schools lost the benefit of cross ventilation.

As can be seen, the closed corridors were added to the buildings (Figure 2-1.4 & 5).

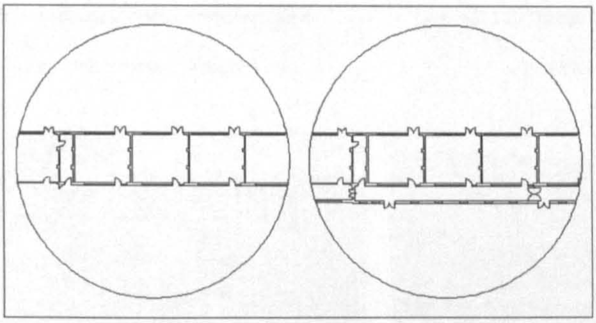


Figure 2-1.5: Part of the school plan before (left) and after (right) modification

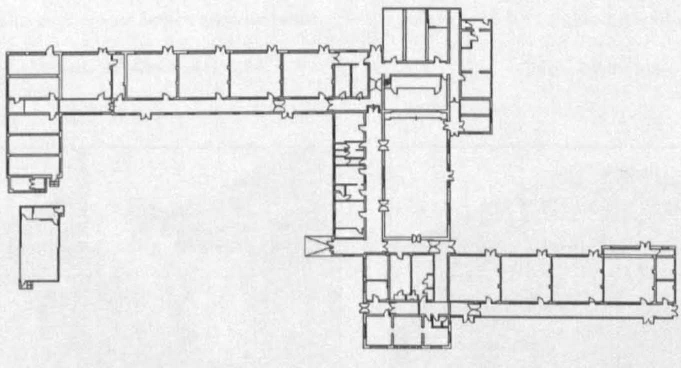


Figure 2-1.6: School plan after modification

The following photos show the Heston (Built 1936), Wellington (Built 1930-1935) & Cranford (1937) as open air primary schools both at the time of their construction and also after the implementation of the proposed modifications (provision of enclosed corridors).

Figure 2-1.7: Heston school before improvements

(Cited in Friends Reunited website)

Figure 2-1.8: Heston school after improvements

(Taken by the author)

Figure 2-1.9: Cranford school before improvements

(Cited in Friends Reunited website)

Figure 2-1.10: Cranford school after improvements

(Taken by the author)

Figure 2-1.11: Wellington school before improvements

(Cited in Friends Reunited website)

Figure 2-1.12: Wellington school after improvements

(Taken by the author)

After the modifications were made, classrooms have had a lower risk of heating loss during winter, however they have had a higher risk of experiencing overheating during summer as the benefit of cross ventilation was reduced to a single sided ventilation (conflict between thermal comfort in winter and summer).

2.1.2.3. Post World War II schools

Due to the baby boom after the destruction caused by World War II and the growing need for the schools at the beginning of fifties (1945-1970) prefabrication technology was developed and lightweight construction was applied to the construction of many schools to increase the speed of the construction (Woolner, 2010).

Figure 2-1.13: View of a low thermal mass school

(Cited in Friends Reunited website)

Figure 2-1.14: View of a prefabricated classroom

(Taken by the author)

a) Thermal comfort in post war schools

A large number of schools built in the 1950s and 60s were constructed using System Methods (i.e. structural steel frames support the internal fabric and external curtain walls of these buildings). Unfortunately, many of these buildings are thermally inefficient and they have lightweight structures which are neither heavy thermal mass nor thermally insulated (BB73, 1991). As a result, the schools which were built in this time period are not thermally comfortable. The problem was expressed by the teachers in primary schools built in the 1970s as 'freezing in winter and boiling in summer' in energy surveys (Woolner, 2010). BB73 suggests different techniques that can be applied to provide better thermal conditions during winter.

b) Lighting comfort in post war schools

Daylight is the main source of illumination in post war schools according to 'the lighting of buildings' which has been published regarding the post-war buildings. The BS regulations in place at the time of construction recommended a minimum of 2% daylight factor with the possibility to increase to 5%. For this reason, the windows had to be large enough to meet the 2% daylight factor. These large windows cause many problems such as glare, overheating in summer and heat losses in winter (Wu et al., 2002).

c) Conflict between comfort factors in post war schools

One the one hand, the post war classroom have a high level of natural light due to the large windows but on the other hand, these classrooms produce excessive glare and receive a high amount of solar gain during summer that cause overheating during summer and heat loses during winter. This is the conflict between lighting and thermal comfort in post war primary school classrooms. It should be noted that the poor thermal comfort is not only related to the large windows but also to the lightweight construction materials used in these buildings.

2.1.2.4. Energy efficient schools

The school construction in this period was affected by two phenomena i.e. the energy crisis and sick building syndrome.

In 1970, following the OPEC embargo, there was a concern over oil supplies and designers tried to construct more energy efficient buildings. They tried to minimize the energy usage by the following techniques:

- 1st technique: Doors and window frames were sealed and buildings were made air tight as much as possible.

- 2nd technique: The requirements for outside fresh air for each occupant inside a building was 15 cubic feet per minute (cfm) in early and mid 1900's which was reduced to 5 cubic feet per minute after the 1973 oil crisis.

After the oil crisis and the subsequent attempts by designers to increase the buildings' energy efficiency, the World Health Organization reported Sick Building Syndrome in 1984 for 30% of newly remodelled buildings worldwide. Sick Building Syndrome is the combination of ailments and associated with an individual's places of work. The main causes of sick building syndrome are mechanical air conditioning systems and lack of sufficient ventilation. After buildings started experiencing Sick Building Syndrome that caused short and long term health problems, a greater consideration was given to providing good environmental conditions whilst minimising the usage of energy (Edward, 2010).

Followed by the oil crisis and sick building syndrome, the open-plan space school concept was introduced in the United State in 1970 and the idea spread to Europe and especially to the UK. This trend reached its highest level in 1976 when 10% of all the UK primary schools were constructed based on this concept (N. Bennet et al, 1980). The main advantages of the open plan school concept was the privilege of having cross ventilation for providing good air quality, which protected the schools from the phenomena of the sick building syndrome, as well as providing indoor thermal comfort.

In summary, in this period, there was a great concern regarding fuel saving and providing comfort for occupants. Therefore, the UK Building Regulation Act 1984 allocated two clauses to fuel saving and occupants' needs. These clauses are under the title of 'Furthering the conservation of fuel and power' and 'Securing the health, safety, welfare and convenience of persons in buildings' (Building Regulation Act, 1984).

In addition, a tool for measuring the sustainability of new non-domestic buildings such as schools was established in the UK in 1990. The tool was called BREEAM (BRE Environmental Assessment Method) which has been updated regularly in line with the UK building regulations (Part L). Following BREEAM, the need to address the 'three Es' (i.e. energy, environment and ecology) in conjunction with each other was agreed as the crucial part of the design in Rio de Janeiro in the UN Earth Summit in 1992 (Edwards, 2010). The 'three Es' suggests deliberate designing to:

E1 employ low-energy design by different techniques
E2 provide healthy and comfortable environment
E3 reducing the impact of design to the ecological system

Comfort issues and possible conflict between them for this duration are discussed as follows:

a) Thermal comfort in the schools after the oil crisis

In this duration, a new vision was established towards energy efficiency and occupant's satisfaction concept inside buildings. So new rules were incorporated to building regulations to achieve better environmental conditions and comfort situations. Open plan classrooms which were proposed in this era offered the benefit of having cross ventilation in order to maintain comfortable temperature and air quality in the summer.

b) Air quality in schools after the oil crisis

After the Sick building syndrome phenomenon, open plan classrooms became a predominant solution to providing good air quality with the aid of cross ventilation.

c) Acoustic comfort in schools after the oil crisis

Open plan classroom suffer from poor acoustic comfort as they have a higher noise level and reverberation time. For this reason, teaching activities had to be carefully planned and organised in order for the open design to work successfully (Tate-Harte and Shield, 2006).

d) Conflict between comfort factors in schools after the oil crisis

Open-plan schools had the privilege of having cross ventilation to maintain classrooms' indoor temperature and air quality during summer but they were highly noisy and were not acoustically comfortable. As a result, there was a conflict between acoustic comfort and 'thermal comfort / air quality' in these kinds of schools. Therefore, the open plan classrooms were converted to cellular classrooms to overcome the acoustic problem (Figure 2-1.15). As a result of this conversion, classrooms lost their opportunity for having cross ventilation in cooling seasons (summer) and having less energy consumption during cooling seasons.

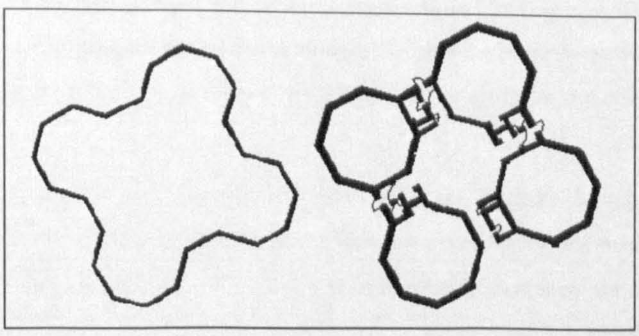


Figure 2-1.15: Open plan layout before modification (left), cellular layout after modification (right)

The following photos shows the classrooms in Andrew Ewing primary schools which were built based on open plan classroom concept but were converted to cellular classrooms in order to overcome the acoustic problem some years after construction.

Figure 2-1.16: Andrew primary school. View from inside a classroom (left) hall (right) (Taken by the author)

2.1.2.5. BSF & PCP schools

In 1992, the UK government adopted a policy for financing public services including the building and refurbishment of schools via 'Public-Private Finance Initiative' (PFI) (Burke and Grosvenor, 2003). Besides, in February 2003, an investment scheme [Building School for the Future (BSF)] was proposed. This scheme was a long-term programme of investment and change in England that would help the education for secondary age students to be transformed (DCSF, 2008). The aim of this scheme was to rebuild or renew nearly every secondary school in England by 2016.

It needs to be mentioned that primary schools were not included in BSF, but there was a separate programme under the name of Primary Capital Programme (PCP) announced in March 2006 intended to renew or remodel at least half of all primary school buildings by 2022-23 (Every Child Matters: Primary capital programme,2006). Although the above investments were stopped in 2008 due to the economic recession, some schools underwent construction or remodelling between 2003 and 2008.

BSF & PCP schools mainly refer to the schools built under the Primary Capital Programme (PCP) and Building School for Future (BSF) schemes which were announced for primary and secondary schools in 2003 & 2006 respectively. The PCP and BSF programmes were the first wave of school construction/refurbishment since the huge Victorian and post-war building programmes. One of the aims of constructing these schools was to provide the best environmental conditions for schools' occupants.

Based on these programmes, the Department for Children, Schools and Families (DCSF) expected all new schools to meet high standards of sustainability and energy efficiency. New school buildings and refurbishment projects were required to achieve at least the 'Very Good' rating for schools according to BREEAM. As part of the schemes, the Department expected all new school buildings to reduce carbon emissions by at least 60 percent relative to those constructed and designed as per the 2002 building regulations (Part L). A simple piece of software, the 'carbon calculator' was developed to assist the selection of measures to reduce carbon emissions (Carbon calculator, nd.).

It was hoped that in the longer term (by 2016), new school buildings would be zero carbon. A Task Force was appointed to advice on the implementation of this challenging goal demonstrating the Government's commitment to significantly reduce carbon emissions (DCSF, 2008). Unfortunately these investment programmes were stopped due to the lack of funding as a result of the recession in 2008.

BSF and PCP design programmes had to meet a variety of requirements. One of the requirements was to provide comfortable environments in schools. Based on these programs, there was a hope that a new generation of classrooms would be created to provide better classrooms with the highest level of comfort. Although the main principle of constructing these schools is to provide comfortable environmental, these schools still fail to provide comfortable environment in some cases due to the conflict between comfort factors.

a) Conflict between comfort factors in PCP and BSF school

Mumvic et al. (2009) studies the winter indoor air quality, thermal comfort and acoustic performance of a newly built secondary school in England followed by BSF investment. Based on this research, complex interactions between thermal comfort, ventilation and acoustic comfort are studied. Two types of conflict are shown in the research:

- Conflict between acoustic comfort and air quality: Schools in this research are equipped with mechanical ventilation to maintain indoor air quality. The noise level measured inside the classrooms when occupants were occupied with a quiet test exceeded 50dB (A), which is far above the requirement proposed by BB93. This is due to the result of noise produced by the mechanical ventilation. This shows one kind of conflict between air quality and acoustic comfort.

- Conflict between air quality and thermal comfort: The mechanical ventilation installed to provide good air quality, in this situation should provide 8l/s per person fresh air but produces cold droughts that have a negative impact on thermal comfort.

Hence it can be seen that although the school has recently been built based on the BSF programme, it does not provide a comfortable environment as the comfort factors conflict with each other.

The BSF and PCP programmes adopted Building Bulletins' environmental comfort guidelines and benchmarks in design and refurbishment of schools. The Building Bulletins were published by Department for Education and Skills and proposed benchmarks for thermal, lighting, acoustic comfort and air quality. In the next pars, the benchmarks prescribed by Building Bulletin are discussed and compared with the ones suggested by other guidelines used for schools such as

CIBSE. Based on a private communication between the author and a representative of National Union of Teacher (NUT), some secondary schools built based on BSF programme have failed to provide comfortable (i.e. temperature over 38°C measured by NUT) conditions for occupants.

2.1.2.6. Result:

Providing comfortable classrooms has always been a matter of concern for building designers during and even after the construction of schools. However their attempts have not been completely successful through history. This has mainly been a result of comfort factors conflicting with each other for various reasons. The two main causes of conflict is summarised as follows:

1. Conflict between comfort factors as they are considered separately.
2. Conflict between comfort factors due to change of conditions over the life of buildings

2.1.3. Part Three: The requirements of environmental comfort in school design guidelines

This part of the research concentrates on the requirements of environmental comfort in various school design guidelines.

2.1.3.1. Consideration of the environment and comfort factors in PCP and BSF programmes

As part of the BSF programme, 'School Design Assessment Panel' was intended to help local authorities to evaluate the quality of design proposals, support bidders in meeting briefing requirements and refining their proposal, and ensuring that design quality remains consistently high. The following ten points were proposed by 'Commission for Architecture and Built Environment' for a well designed school (CABE, 2007) in a publication called 'Creating Excellent Secondary School'. Two of these points (numbers 2 and 8) focused on sustainability and good environmental conditions:

1. A High-quality that inspire users to learn.
2. *A sustainable approach design, construction and environmental servicing.*
3. Good use of the site, balancing the need of pedestrians, cyclists and cars and enhancing the school's presence in the community.
4. Buildings and grounds that are welcoming to both the school and the community while providing adequate security.
5. Good organization of spaces in plan and section, easily legible and fully accessible.
6. Internal spaces that are well proportioned, fit for purpose and meet the needs of the curriculum.
7. Flexible design to allow for short term change of layout and use, and for long term expansion on contraction.
8. *Good environmental conditions throughout including optimum level of natural light and ventilation for the different activities within the buildings.*
9. Well-design external spaces offering a variety of differing settings for leisure, learning and sport.
10. A simple palette of attractive material, detailed carefully to be durable and easily maintained.

The Design Quality Indicator (DQI) was designed to assists building procurement teams for defining and checking the evolution of design quality at key stages in the development process (CABE, 2005). The DQI for schools is a version of this tool which is intended to be more applicable to the needs of schools and has been adapted from DQI by Department for Education and Skills (DfES) to be used on all types of school projects. The use of DQI for school (DQIfS) was mandatory in BSF. DQI for schools (DQIfS) consists of 111 statements under three main headings and subheadings one of which is focused on building quality:

- Functionality concerning the way in which the school building is designed to be used, and is split into Access, space and use
- Build Quality related to the performance of the school building fabric and split into performance, Engineering Service and Construction
- Impact refers to a building's ability to create a sense of place, and to have a positive effect on local community and environment

Focus on the two factors of environmental condition and energy efficiency in school design has a specific position in both school design programme and tool (i.e. 'ten points for a well-designed school' and DQIfS) which were proposed following the PCP and BSF programmes. Additionally, these two factors have a specific position in other schools design programmes which are explained below.

2.1.3.2. Consideration of the environment and comfort factors in other school design programmes

Sanoff assessment tools: Sanoff et al (2001) introduce two school building assessment tools for schools which are the 'Six Factor School Building Assessments' and 'the School Building Rating Scale'.

- The Six Factor School Building Assessment offers individuals and groups a procedure for taking a structured walk through and round a building. Observers using this checklist appraise visual and special quality in terms of six key elements one of which is comfort. The other elements are context, massing, interface, way finding and social space.

- The 'School Building Rating Scale' is organised into ten categories that are essential components for meeting the demands of optimum learning environments. One out of the ten components is the study of comfort factors in learning environments. The other components are physical features, outdoor areas, social areas, media access, transition spaces, circulation routes, visual appearance, safety and security.

Lang assessment tool: Lang (1996) proposed six general categories including the criteria that are essential components for meeting demands of schools. Three out of six categories are allocated to the comfort factors which are:

- Acoustical Quality and Noise control
- Illumination and Views
- Temperature, Humidity and Ventilation

School design pattern: In addition to the assessment tools discussed earlier, Nair and Fielding (2005) in their book, 'The Language of School Design', introduce 25 patterns for design of schools in the twenty-first century. These patterns could work as a framework (or generative tool) for school design. Two out of the 25 patterns were allocated to comfort factors e.g. day lighting and natural ventilation (Nair et al, 2005).

2.1.3.3. Result:

As a result, it can be concluded that the consideration of environmental conditions has always had a specific position in all school design guidelines. However, there is no consideration regarding the potential conflicts between comfort factors. It is therefore suggested that the environmental sections of school design guidelines to be expanded in order to consider the conflict between comfort factors.

2.1.4. Part Four: Comfort benchmarks

2.1.4.1. Use of Building Bulletin benchmarks in PCP and BSF programmes

After reviewing the literatures on school designs tools and programmes, it can be concluded that all the assessment tools and programmes were greatly concerned about the necessity of providing the comfort factors in order to provide a good and comfortable internal environment.

It should be noted that necessity of providing comfort factors is not sufficient, but selecting a reliable benchmark is also important in order to provide comfort in classrooms. Different guidelines for Environmental Design in schools were published by Departments of Education and Skills under the names of Building Bulletin 87 (2003), Building Bulletin 101(2006), Building Bulletin 93(2003), Building Bulletin 90(2003), etc to help classrooms to meet the required comfort levels in the UK. Some of these guidelines are as follows:

- Building Bulletin 87: Guidelines for Environmental Design in Schools
- Building Bulletin 90: Lighting Design for Schools
- Building Bulletin 93: Acoustic design of Schools
- Building Bulletin 101: Ventilation of school buildings (updated BB87)

The above Building Bulletin's guidelines proposed for design of schools are utilised to design and refurbish many schools in the UK, including those constructed under PCP and BSF programmes. It should be noted that the above guidelines are not the only guidelines available for school design but more are proposed by CIBSE (2006), BS (2007), and BSRIA (2003) published in UK.

The differences between Building Bulletins benchmarks (which are widely used) and other benchmarks are discussed further in this part.

2.1.4.2. Overheating and different guidelines

A range of overheating guidelines has been in place for a number of years which can be explained as follow:

a) BB87

According to BB87 which was published in 2003 for school building, a classroom is defined as overheated when the internal air temperature exceed 28°C. The guideline allows flexibility of up to 80 occupied hours in a year, normally in the non-heating periods of May to September excluding August.

b) BB101

These overheating criteria will ensure that the design of future schools is not dictated by a single factor, unlike BB87, but by a combination of factors that will allow a degree of flexibility in the design of the school. These criteria are only applicable for the cooling season for the occupied period (i.e. 9:00-15:30, Monday to Friday from 1st May to 30th September excluding August which is school summer holiday). These criteria are in compliance with Approved Document L2 for summertime overheating for teaching and learning areas and are as follows:

a) There should be no more than 120 hours when the air temperature in the classroom rises above 28°C.

b) The average internal to external temperature difference should not exceed 5°C (i.e. the internal air temperature should be no more than 5°C above the external air temperature on an average).

c) The internal air temperature when the space is occupied should not exceed 32°C.

In order to show that the proposed school will not from suffer overheating, two of these three criteria must be met.

c) CIBSE

Two temperature thresholds have been defined by CIBSE Guide A (2006) for schools: a lower temperature threshold, which is taken to indicate when occupants will start to feel 'warm' (above 25°C) and higher threshold temperature, which is taken to indicate when occupants will start to fill 'hot' (above 28°C). However, to define a fixed measure of 'overheating' an excess of more than 1% of occupied hours in a year over the higher temperature benchmark is adapted to indicate a failure of the building to control overheating risk (CIBSE Guide A, 2006).

The formation of an overheating taskforce by CIBSE is in part a recognition that there are problems with the use of a fixed, nationwide threshold temperature and 'hours over' criterion, which are as follows :

- According to Humphreys and Nicol (1998), comfort adaptive temperature varies in accordance to outdoor running mean temperature and therefore is not fixed.
- The CIBSE criteria fail to recognise the severity of overheating which is as important as its occurrence (Nicol et al, 2009).
- Two criteria were developed by CEN Technical committees in BS EN15251 (2007) which considers both discomfort occurrence and severity: cooling degree-hours measure and a weighted measure based on Predicted Percentage Dissatisfaction (PPD). However, the PPD has been argued to be an unreliable indicator in naturally ventilated buildings according to Humphrey and Nichol (Nicol et al, 2009).
- As overheating evaluation for buildings is based on a fixed threshold depending on the number of occupied hours above threshold, therefore by changing the number of occupied hours, the result can be altered to solve the overheating problem, which is totally unrealistic (Nicol et al, 2009) and deceiving.
- Based on the fixed temperature threshold, it is debateable whether overheating should be measured over a whole year or a shorter period during a year (Nicol et al, 2009). For example, based on the CIBSE overheating is measured over a whole year and based on BB101 and BB87, it is measured on the duration of cooling seasons (May to September excluding August).

For all above reasons, some other criteria are presented that are explained as follows:

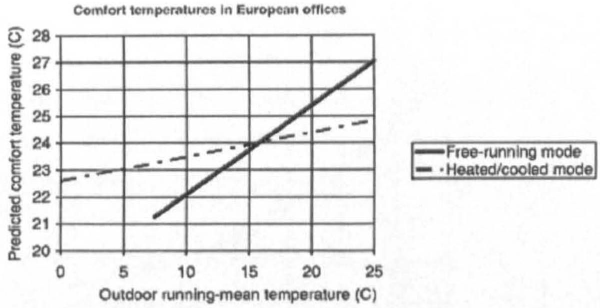
d) British Standard

Alternative criteria are presented by British Standard [based on survey of thermal comfort in European buildings and first proposed in CIBSE Guide A (2006)] for thermal comfort in naturally ventilated building using an adaptive thermal comfort model.

According to these criteria, thermal comfort is not a fixed temperature and varies according to recent climate conditions (e.g. over selected previous days). The criteria links comfort temperature to 'running mean temperature' (Trm). The running mean is calculated from the external temperature over the preceding days, with weightage taking into account the greater influence of the most recent day, using the formula below where the mean outdoor temperature exceeds 10°C.

$$Tc=0.33Trm + 18.8$$

The following graph (Graph 3-1.3) shows the comfort temperatures as a function of outdoor temperature (CIBSE, 2006):



Graph 2-1.1: Comfort temperature as a function of outdoor running means temperature (CIBSE, 2006)

British Standard proposes that there is a maximum allowable difference from comfort temperature as it is shown in the following table (Table 3-1.2).

Category	Explanation	Suggested accaptable range
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	±2K
II	Normal expectation (for new buildings and renovations)	±3K
III	Moderate expectation (used for existing buildings)	±4K
IV	Values outside the criteria for the above categories (only acceptable for a limited periods)	
Source: British Standards (BSI) (2007e).		

Table 2-1.1: Suggested applicability of the categories and their associated acceptable temperature range. (British Standard 2007)

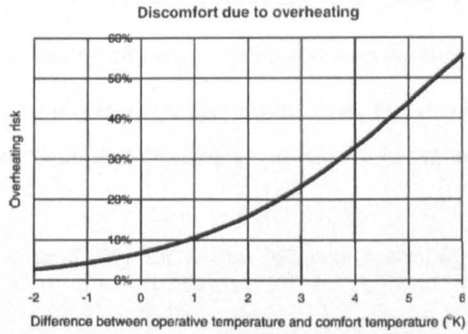
e) Percentage of discomfort by occupants

Nicol and Humphreys (2007) suggest that occupants' discomfort is related to ΔT by applying a weighting factor which reflects the non-linear relationship between heat discomfort (percentage of overheating by occupant) and departure from the comfort temperature which is observable in the following graph (Graph 3-1.4). The percentage of discomfort can be calculated from the following formula:

$$P = \frac{e^{(0.4734^{*}\Delta T - 2.607)}}{\{1 + e^{(0.4734^{*}\Delta T - 2.607)}\}}$$

In the above formula, ΔT refers to the differences between recorded temperature and calculated 'Tc=adaptive thermal comfort'. Tc is affected by 'thermal running mean temperature' and calculated from the equation Tc=0.33Trm+18.8. 'Trm' refers to the thermal running mean temperature and CEN Standard EN15251 (2009) gives an approximate calculation method (for Trm) using the mean temperature for the last 7 days (α = 0.8).

Trm = (Tod -1 + 0.8 Tod -2 + 0.6 Tod -3 + 0.5 Tod -4 + 0.4 Tod -5 + 0.3 Tod -6 + 0.2 Tod -7)/3.8



Graph 2-1.2: The proportion of subjects voting warm or hot on the ASHRAE scale as a function of the difference between the indoor operative temperature and CEN comfort temperature, (Nicol et al, 2009)

This alternative criterion proposed by British Standard and further developed by Nicol regarding the percentage of overheating by occupants is only valid for spaces engaged in mainly sedentary activities such as offices, classroom etc (Nicol et al, 2009).

In summary, the guidelines can be divided into two different categories: Adaptive & Fixed approach.

- Fixed approach for thermal comfort is the more popular approach. This approach considers 28°C as a benchmark for overheating in a classroom. CIBSE, BB101 and BB87 all accept this threshold as an overheating benchmark however each define different conditions which are to be met before a classroom can be considered as overheated.

- Adaptive approach for thermal comfort is the most recent approach which shows that the temperatures at which majority of people are comfortable varies with the running-mean of the external temperature.

2.1.4.3. Comparing UK overheating guidelines for school:

Below, the BB101 overheating criteria are compared with the BB87 and CIBSE:

In the UK, primary school children attend school from Monday to Friday between 0900 to 1530 hours. The number of hours that children go to school during an academic year is calculated as follow:

The following table (Table 2.1) shows the holidays according to the Student Calendar in an academic year.

Autumn term	Spring term	Summer term
1 week off as half term 2 weeks off as Christmas holiday	1 week off as half term 2 weeks off as Easter holiday	1 week off as half term 2 weeks off as Summer holiday

Table 2-1.2: Holidays according to the Student Calendar in an academic year

Based on Table 2.1, it can be concluded that students in a London Primary School have 13 weeks off during an academic year. There are 52 weeks in a year. As the result students attend school for over 39 weeks (Table 2.2).

Weeks off	Weeks spent at school
13	39

Table 2-1.3: Number of the weeks that children spend at school

Number of the days that children attend school in one academic year can be calculated by multiplying 39 (i.e. number of the weeks that children attend schools) by 5 (i.e. Number of days that children attend school in a week) which come up to 195 days. Number of hours that students attend school in one academic year can be calculated by multiplying 195 (i.e. number of hours that children attend schools in one academic year) by 6.5 (i.e. number of hours that children spend at school in a day) which result in 1274 hours.

Numbers of hours students spend at school in an academic year: 1274 hrs

Total number of hours that children attend school in May and September excluding August is 422.5.

Numbers of hours students spend at school in May-Sept excluding August: 422.5

As mentioned earlier, if 1% of indoor occupied hours in a year exceed 28°C in schools, the school has failed to control the overheating risk. One percent of indoor occupied hours is nearly 13 hours (12.74). In the other words, if the indoor temperature exceeds the threshold for only 13 hours during one academic year, the school suffers from overheating based on CIBSE criteria. In contrast, if the indoor temperature of a classroom exceeds 80 hours during summer term (May-Sep excluding August), the classroom experiences overheating based on BB87, while this amount increases to 120 hours based on BB101. Although, BB101 is the updated version of BB87, it is more flexible.

2.1.4.4. Air quality and different guidelines

A variety of air quality guidelines has been in place for a number of years in the UK which are as follows:

BB87/BB101: According to BB87 which was published in 2003 for school buildings, a classroom is naturally ventilated if the minimum ventilation rate is 3 l/s/p with the capability of reaching 8 l/s/p (BB 87). The BB101which is the updated version of BB87 and was published in 2006 added one more condition to the previous conditions. This is the provision of the minimum daily average of 5 l/s/p (BB101). BB101 is currently used to design and refurbish schools in the UK. The minimum 3 l/s/p ventilation rate is open to misinterpretation as it does not confirm the circumstances and the type of activity for which this rate is required (Lugg & Batty, 1999).

CIBSE: The CIBSE Guide B is a clearer guideline regarding the ventilation rate and clarifies the relationship between the type of activity and requirement of ventilation rate. According to the CIBSE Guide B published in 1986, the recommended ventilation rate for schools is at least 8.3 l/s/p. However, this benchmark was amended in the updated version published in 2005 and became more relaxed as the minimum ventilation requirements was confirmed to be 3l/s/ person with the capability of 8l/s/ person (CIBSE Guide B, 2005).

BSRIA: According to The Building Services Research and Information Association (BSRIA) Guide 4th edition published in 2003, the requirement of ventilation rate is 8 l/s/person (BSRIA, 2003).

CO_2 maybe regarded as an alternative indicator of ventilation rate, in some cases the above guidelines are proposed based on the CO_2 level in the air. For example, based on BB101 criteria, classrooms should meet all the following criteria in order to be identified as classrooms having good air quality: Firstly, the average concentration of CO_2 should not exceed 1500 ppm during occupied hours. Secondly, the maximum concentration of CO_2 should not exceed 5000 ppm during a teaching day. Thirdly, at any occupied time, the occupants should be able to reduce the concentration of CO_2 to 1000ppm. Based on the BSRIA, the threshold level for an acceptable indoor air quality is 800ppm without mentioning the type of usage.

By caparisoning DfEE guidelines (BB 87 & BB101) with CIBSE Guide B and BSRIA, it can be concluded that the BB87 and its updated revision BB101 which are currently used in refurbishment and redesign of schools are the most relaxed benchmarks regarding the air quality.

2.1.4.5. Result:

It can be seen that BB101 is more flexible than BB87 in terms of overheating criteria, and BB87 is a more flexible than CIBSE. In the analysis part of this study, these criteria are compared with each other based on real data. In addition, the DfES guidelines (BB79 & BB101) are more flexible than the CIBSE and BSRIA Guidelines in terms of air quality criteria. Construction and refurbishment of schools' classrooms based on BB101 could be the reason that they experience overheating and poor air quality. In other words, there is a risk that newly constructed or refurbished schools based on BB101 could suffer from overheating and poor air quality as the Building Bulletin criteria (BB101) is the most relaxed criteria in comparison with the others.

2.1.5. Part five - Conclusion:

As explained in the first part of this chapter, thermal, lighting and acoustic comfort, and air quality have significant impacts on students' health and academic performances. In the second part of this chapter, it was explained that classrooms could not have offered all of the comfort conditions simultaneously in the UK school construction history, as there are conflicts between different comfort conditions.

In the third part, it was explained that environmental conditions have always been considered in all school design guidelines however no reference has been made to the potential conflicts between comfort factors.

In the fourth part, it was explained that one of the reasons that classrooms cannot offer a good environmental conditions may be that the relaxed benchmarks have become the basis for school design.

As a result of this part, the causes of poor environmental condition can be summarised as follows:

- Poor environmental conditions as a result of conflict between comfort factors
- Poor environmental conditions as a result of using relaxed benchmarks

2.1.5.1. Poor environmental condition as a result of conflict between comfort factors

The causes of conflict between comfort factors which lead to unpleasant environmental conditions are summarised and solutions are discussed as follows:

a) Conflict between comfort factors as they are considered separately

One of the reasons for conflict between comfort factors is that they are usually considered separately while comfort factors are interrelated. So it can be concluded that to overcome the conflict between comfort factors, they should be assessed from all aspects and in conjunction with each other in the early stages of building design. Oral et al (2004) propose the following design process which can be used to overcome the conflict between comfort factors:

Figure 2-1.17: Design process of the building envelope with respect

to thermal, acoustic and lighting comfort (Oral et al, 2003)

b) Conflict between comfort factors due to the change of conditions over the life of the building

The lack of appropriate forecasts and estimation and failure to review the environmental changes and their impact on classrooms' indoor environment in the long run is another reason for conflict between comfort factors and consequently the lack of long term comfort conditions. The following examples highlight some of the conflicts:

- Example 1: Schools which were built 70 years ago (circa 1930's) in the Hounslow area relied on the use of natural ventilation through windows at the time of construction. At that time, the Heathrow airport was not as busy as it is nowadays and occupants of these schools could easily rely on this means of ventilation. However at the present time, these schools cannot rely on opening windows for natural ventilation as Heathrow Airport has been expanded and produces a high level of aircraft noise in this region.

- Example 2: Current schools will have the potential to experience overheating in coming decades due to the impact of global warming. Constructing a school based on the weather data of the current decade may result in overheating in the following decades. Hence schools should be designed in such a way that they can be compatible for future climates.

It is recommended that in the first stage of design, excessive care should be taken in order to estimate the impact of developing infrastructures and changing environment on classrooms' indoor environment for the life time of the buildings.

2.1.5.2. Poor environmental conditions as a result of using relaxed benchmarks

The third important factor that should be taken into account is the use of relaxed benchmarks, which are used to design schools in order to provide comfort conditions. Designing a building based on relaxed benchmarks could be the reason that a building loses its capability to provide good environmental conditions for occupants. For example, based on the discussions in the previous section, the BB101 which is currently used to design school buildings is found to be the most relaxed benchmark in comparison with other benchmarks. Therefore, the schools which are designed for thermal comfort and air quality based on this guideline may not provide good conditions for their occupants and hence they may be required to be revised. It should be noted that guidelines regarding acoustic comfort which were proposed in BB87 were revised under the Building Bulletin 93. The BB93 proposes stricter guidelines in comparison to BB87.

Chapter: 2.2. Analysis:

Overview:

This chapter is conducted in two parts. Part one studies the importance of comfort factors and its relation with teachers' and students' health based on teachers' perception. Part two focuses on identifying the most reliable overheating models for the UK schools design.

2.2.1. Part one: The importance of comfort factors in classrooms based on teachers' perceptions.

Analysis - The relationship between various environmental factors with students and teachers' health and also students' academic achievements based on the subjective survey

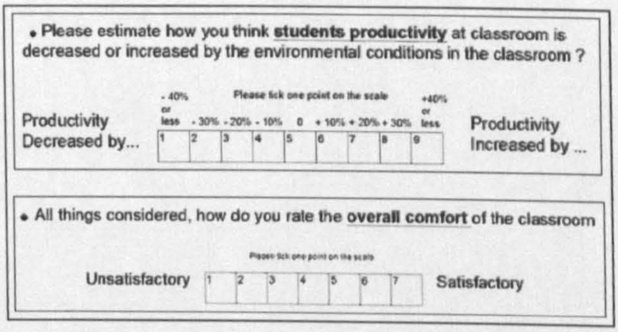
As per the discussion in the literature review in the previous sections, it can be concluded that environmental conditions have a significant impact on the occupants' performance and health. A pilot subject study is carried out in order to re-assess this fact in this study.

Through questionnaires (Appendix 2.1) filled out by teachers, classrooms' comfort level, teachers' and students' productivity and also teachers' health were evaluated based on the teachers' perceptions (self-assessments) in the summer of 2007 & 2008.

In the following section, the relationship between overall comforts inside the classrooms is studied against the students' and teachers' productivity and also teachers' health.

2.2.1.1: Students' productivity versus Classrooms' overall comfort

In the questionnaires, teachers were asked to rate the students' productivity from one to nine and also the classrooms' overall comfort from one to seven (Figure 2-1.18).


• Please estimate how you think **students productivity** at classroom is decreased or increased by the environmental conditions in the classroom ?

Please tick one point on the scale

Productivity Decreased by...	- 40% or less	- 30%	- 20%	- 10%	0	+ 10%	+ 20%	+ 30%	+40% or less	Productivity Increased by ...
	1	2	3	4	5	6	7	8	9	

• All things considered, how do you rate the **overall comfort** of the classroom

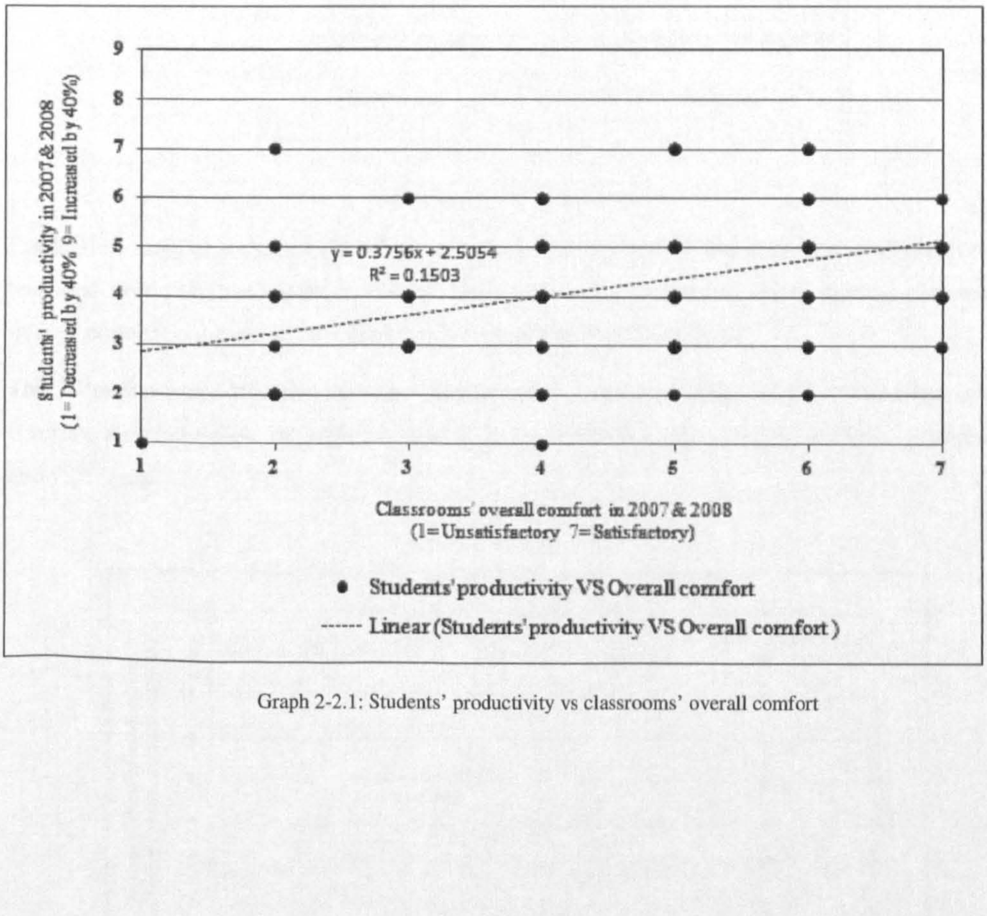
Please tick one point on the scale

Unsatisfactory	1	2	3	4	5	6	7	Satisfactory

Figure 2-1.18: Part of questionnaire

Regression analysis is carried out between teachers' perceptions of classrooms' overall comfort and students' productivity (Appendix 10.1.a). The result of the regression shows that the classrooms' overall comfort can be one of the predictors for students' productivity (P<0.05, r=0.388).

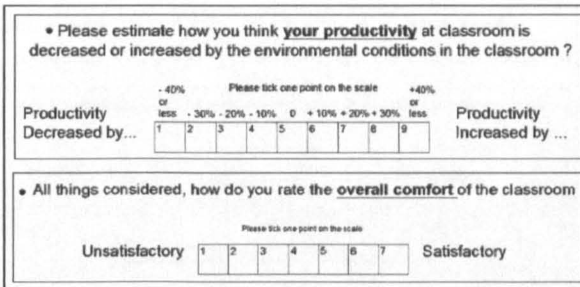
The following graph (Graph 2.1) shows the students' productivity against the classrooms' overall comfort. As it can be seen, the higher overall comfort, the higher the perceived students' productivity and vice versa.



Graph 2-2.1: Students' productivity vs classrooms' overall comfort

2.2.1.2: Teachers' productivity versus Classrooms' overall comfort

In the questionnaires, teachers were asked to rate their productivity from one to nine and also the classrooms' overall comfort from one to seven (Figure 2-1.19).


• Please estimate how you think **your productivity** at classroom is decreased or increased by the environmental conditions in the classroom ?

Please tick one point on the scale

Productivity Decreased by... | - 40% or less | - 30% | - 20% | - 10% | 0 | + 10% | + 20% | + 30% | +40% or less | Productivity Increased by ...

1 2 3 4 5 6 7 8 9

• All things considered, how do you rate the **overall comfort** of the classroom

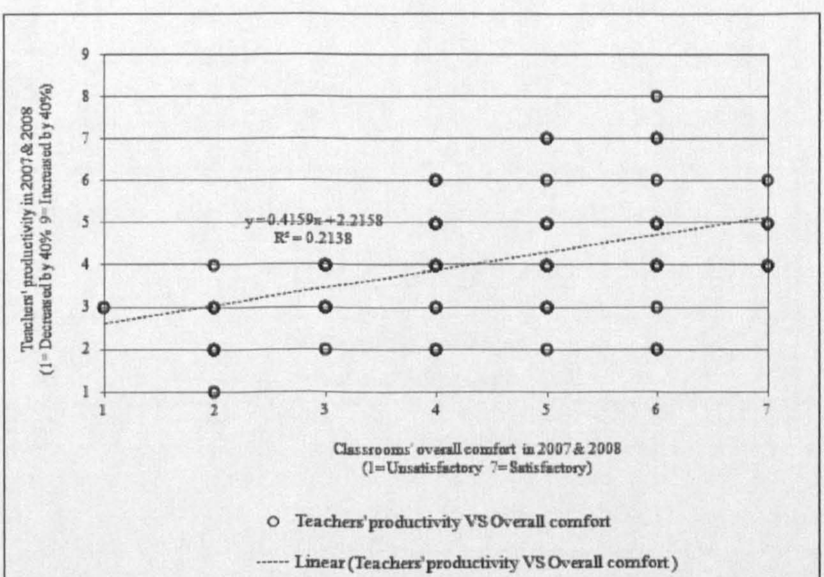
Please tick one point on the scale

Unsatisfactory 1 2 3 4 5 6 7 Satisfactory

Figure 2-1.19: Part of questionnaire

Regression analysis is carried out between teachers' perceptions of classrooms' overall comfort and teachers' productivity (Appendix 10.1.b). The result of the regression shows that the classrooms' overall comfort is a predictor for students' productivity (P<0.05, r=0.462).

The following graph (Graph 2.2) shows the teachers' productivity against the classrooms' overall comfort. As can be seen, the higher overall comfort, the higher the perceived teachers' productivity and vice versa.



Graph 2-2.2: Teachers' productivity vs classrooms' overall comfort

2.2.1.3: Teachers' health versus Classrooms' overall comfort

In the questionnaires, teachers were asked to rate their health from one to seven and also the classrooms' overall comfort from one to seven (Figure 2-1.20).

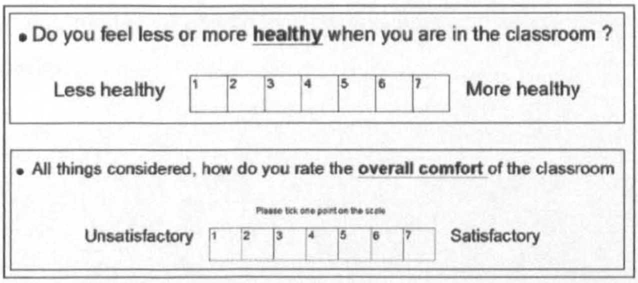
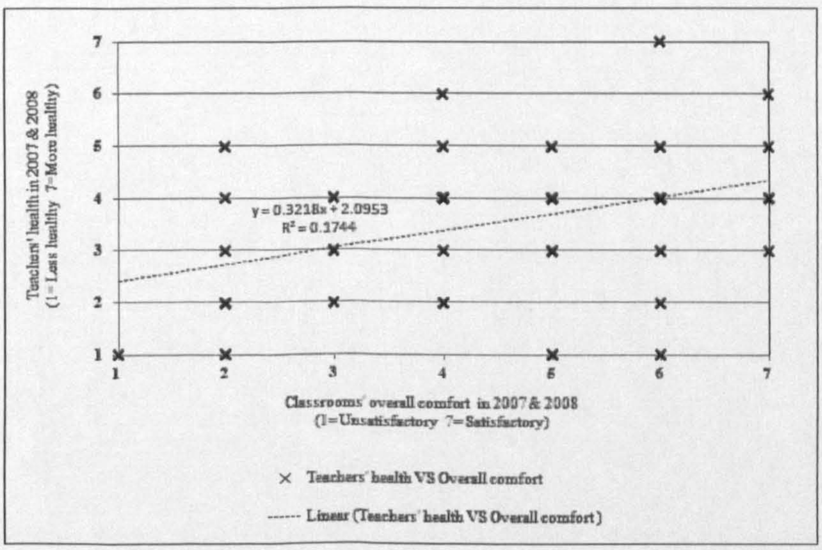


Figure 2-1.20: Part of questionnaire

Regression analysis is carried out between teachers' perceptions of classrooms' overall comfort and teachers' health (Appendix 10.1.c). The result of the regression suggests that the classrooms' overall comfort is one of the predictors for students' productivity (P<05, r=0.418). The following graph (Graph 2.3) shows the teachers' health against the classrooms' overall comfort. As can be seen, the higher the perceived overall comfort, the healthier are the teachers and vice versa.



Graph 2-2.3: Teachers' health vs. classrooms' overall comfort

2.2.1.4: Result - Summary of the relationship between students' academic achievement and wellbeing with environmental conditions

From the literature review and the subjective survey carried out using real data, it can be concluded that the classrooms' environmental condition plays a crucial role on the occupants' performances and also teachers' health.

2.1.2. Part two - Identifying the most reliable overheating models

The aim of this part of the research, which is carried out in three parts, is to compare the overheating models with each other in order to identify which one of them is more reliable and represents the occupant's voice. For this reason, firstly the current UK design guidelines for thermal comfort are compared with each other using real data (indoor temperature data) which have been collected from schools. Secondly, the relationship between occupants' perceptions regarding thermal comfort are compared with the adaptive and fixed thermal comfort models. Finally, the percentages of dissatisfaction from overheating are calculated for each school as one of the most reliable tools to assess overheating.

2.1.2.1: Stage one: Comparing the current UK design guidelines for thermal comfort

In this part, a comparison is carried out between the fixed overheating models which are proposed by Building Bulletin (i.e. BB101& BB87) and Charted Institution of Building Services Engineers (CIBSE).

In order to compare different overheating models with each other, the risk of classrooms from various schools being overheated according to fixed models (i.e.BB87, BB101 and CIBSE) are calculated for the duration of the study (Appendix 4). Table 2-2.1 shows the duration of studies in 2005, 2007 & 2008. The amounts of occupied hours within these durations are 202 hours for each year.

Table 2-2.2 shows the risk of classrooms (total on 139 classrooms) from various schools being overheated according to different fixed models. As can be seen from this table, none of the classrooms are overheated based on BB101. Overheating experiences vary according to BB87 and CIBSE. As can be seen from Table 3, in the years of 2007 and 2008, only 'one out of seventeen' school is overheated when evaluated on CIBSE, and non when evaluated on BB87 and BB101; in 2005, 'six out of eight' schools when evaluated based on CIBSE and 'one out of eight' when evaluated based on BB87 and none based on BB101.

2008							
Month	Days						
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jun	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
July	30	1	2	3	4	5	6
	7	8	9	10	11	12	13
	14	15	16	17	18	19	20
	21						

2007							
Month	Days						
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jun	11	12	13	14	15	16	17
	18	19	20	21	22	23	24
	25	26	27	28	29	30	1
July	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23						

2005							
Month	Days						
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jun	15	16	17	18	19	20	21
	22	23	24	25	26	27	28
	29	30	1	2	3	4	5
July	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
	27						

Table 2-2.1: Duration of study in year 2005, 2007 & 2008

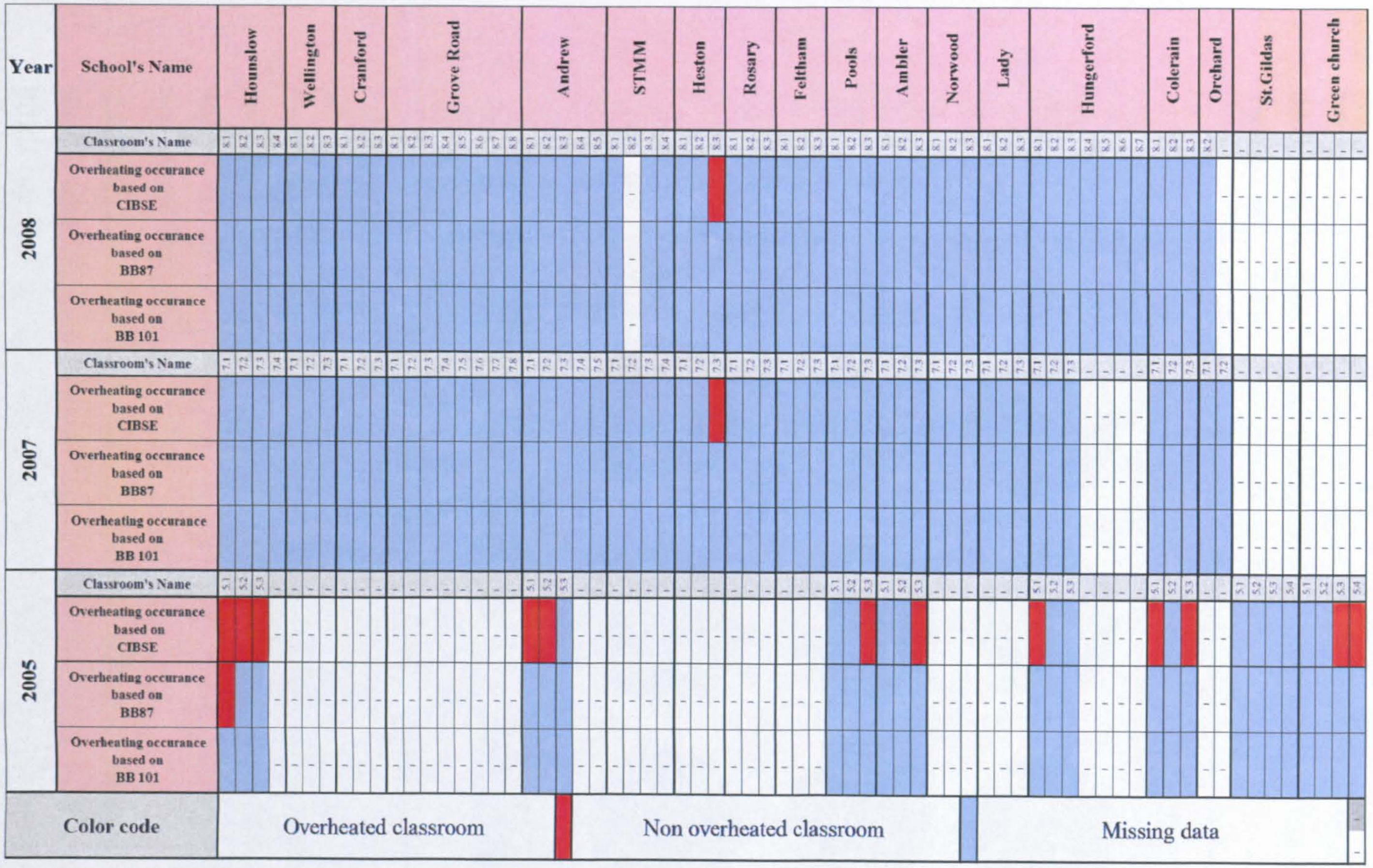
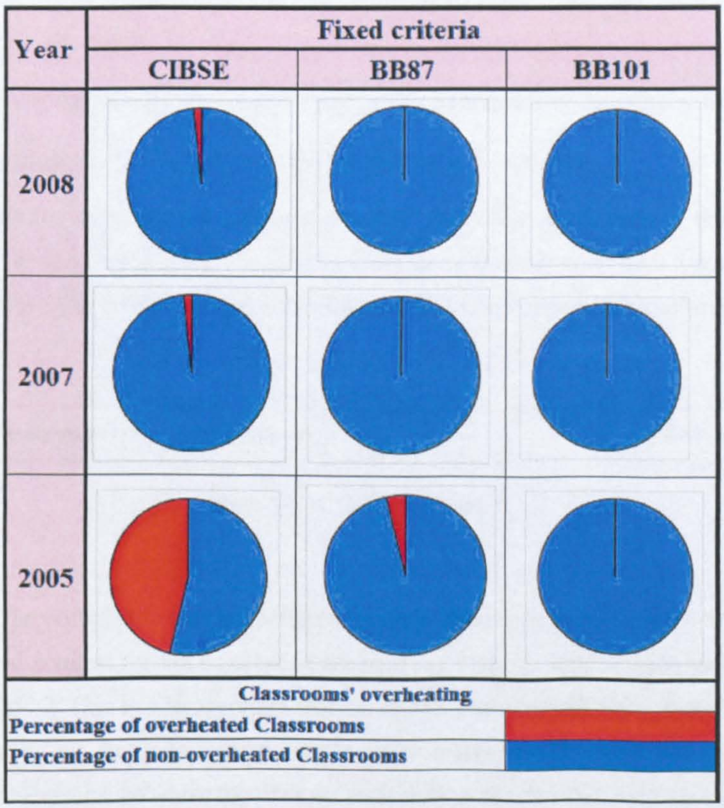


Table 2-2.2: Study of the classrooms' indoor temperature based on Fixed models in various schools

Cold summer of 2007& 2008 (when compared with 2005) was the reason for a big gap between occurrences of overheating in 2005 and 2007/2008. The following pie-charts (Graph 2-2.4) show the share of occurrence of overheating in different schools based on Fixed models (derived from Table 2-2.2).



Graph 2-2.4: Percentages of overheated and non-overheated classrooms

As per Graph 2-2.4, it can be concluded that the Building Bulletin criteria (BB101) which is currently used as the design benchmark for schools is the most relaxed criterion. CIBSE is the most stringent one among the fixed models. In fact, BB101 is more relaxed than BB87, and BB87 is more relaxed than CIBSE.

This could be one of the reasons that the classrooms which are designed/ refurbished based on this criterion could experience overheating. Based on this part of the study, it can be suggested that BB101 benchmark should be revised. As there are two models for assessing thermal comfort (i.e. fixed and adaptive), the next stage focuses on the assessment of the models to identify those which are closer to occupants' feeling.

2.1.2.2: Stage two: Study the relationship between the adaptive and fixed thermal comfort models with schools occupants' perceptions regarding thermal comfort

In this part, a comparison is carried out between the teachers' perceptions of classroom overheating against the evaluation of overheating based on fixed and adaptive models, in order to establish the accuracy level of the models. In this part, two methods are applied to determine which of the overheating models are closer to the teachers' votes (perception) regarding thermal comfort and consequently is more reliable.

- **First Method: Compare the teachers' votes with overheating dissatisfaction**

This section of the research was carried out in the following 3 sections:

Section One: Subjective survey was carried out in 2007 & 2008. In these surveys, the teachers were requested to score their comfort level during summer terms (June & July) on a 7 scale Likert scale for their classroom. One representing comfortable and seven representing uncomfortable.

Thermal comfort	Uncomfortable	1	2	3	4	5	6	7	Comfortable

Figure 2-1.21: Part of questionnaire

Section Two: The occupied indoor temperature for each classroom is compared with the fixed and adaptive thermal comfort for the duration of the study in 2007 & 2008. Fixed thermal comfort is considered as 25°C. This is a temperature that occupants starts to feel warm according to CIBSE criteria. The occasions that indoor temperatures for each day in each classroom exceed 25°C are calculated and the results are added together for each classrooms and then for each school.

The adaptive thermal comfort varies for each day. The adaptive thermal comforts for each day in 2007 and 2008 which is calculated from the following formula are shown in Table 2-2.3.

$$Tc = 0.33\ Trm + 18.8$$

The occasions that an indoor temperature for each day in each classroom exceeds above the adaptive thermal comfort are calculated and the result are added for each classrooms and then for each school.

2008	Day	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon
	Date	09/06/2008	10/06/2008	11/06/2008	12/06/2008	13/06/2008	16/06/2008	17/06/2008	18/06/2008	19/06/2008	20/06/2008	23/06/2008	24/06/2008	25/06/2008	26/06/2008	27/06/2008	30/06/2008
	Mean Tout	21.0	19.2	16.4	13.2	13.4	14.4	16.0	15.4	17.0	15.3	16.7	17.4	17.8	16.4	17.5	17.4
	Trm	16.7	17.5	17.9	17.6	16.7	15.6	15.3	15.5	15.5	15.8	16.3	16.3	16.5	16.8	16.7	17.3
	Tc	24.3	24.6	24.7	24.6	24.3	23.9	23.9	23.9	23.9	24.0	24.2	24.2	24.3	24.3	24.3	24.5
2007	Day	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon
	Date	11/06/2007	12/06/2007	13/06/2007	14/06/2007	15/06/2007	18/06/2007	19/06/2007	20/06/2007	21/06/2007	22/06/2007	25/06/2007	26/06/2007	27/06/2007	28/06/2007	29/06/2007	02/07/2007
	Mean Tout	18.4	18.6	18.2	18.1	17.1	16.0	18.6	18.1	17.0	15.7	13.8	13.5	14.1	14.8	17.3	16.0
	Trm	17.5	17.7	17.9	17.9	18.0	17.2	17.0	17.3	17.5	17.4	16.3	15.8	15.4	15.1	15.0	16.0
	Tc	24.6	24.6	24.7	24.7	24.7	24.5	24.4	24.5	24.6	24.5	24.2	24.0	23.9	23.8	23.8	24.1

2008	Day	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon
	Date	01/07/2008	02/07/2008	03/07/2008	04/07/2008	07/07/2008	08/07/2008	09/07/2008	10/07/2008	11/07/2008	14/07/2008	15/07/2008	16/07/2008	17/07/2008	18/07/2008	21/07/2008
	Mean Tout	20.3	17.5	16.3	16.4	15.1	16.0	15.1	17.2	16.0	18.4	20.6	17.7	16.4	16.9	16.0
	Trm	17.4	17.9	17.9	17.5	17.1	16.7	16.6	16.3	16.5	15.9	16.4	17.3	17.3	17.2	16.9
	Tc	24.5	24.7	24.7	24.6	24.4	24.3	24.3	24.2	24.2	24.1	24.2	24.5	24.5	24.5	24.4
2007	Day	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon
	Date	03/07/2007	04/07/2007	05/07/2007	06/07/2007	09/07/2007	10/07/2007	11/07/2007	12/07/2007	13/07/2007	16/07/2007	17/07/2007	18/07/2007	19/07/2007	20/07/2007	23/07/2007
	Mean Tout	15.5	15.5	16.1	16.3	14.8	15.3	16.7	18.3	19.0	19.4	17.4	18.1	17.5	16.8	16.0
	Trm	16.0	15.9	15.8	15.9	16.1	15.9	15.7	15.9	16.4	17.8	18.1	17.9	18.0	17.9	16.9
	Tc	24.1	24.0	24.0	24.0	24.1	24.0	24.0	24.1	24.2	24.7	24.8	24.7	24.7	24.7	24.4

Table 2-2.3: Mean outside temperature, Mean runing temperature and thermal comfort for the duration for duration of study

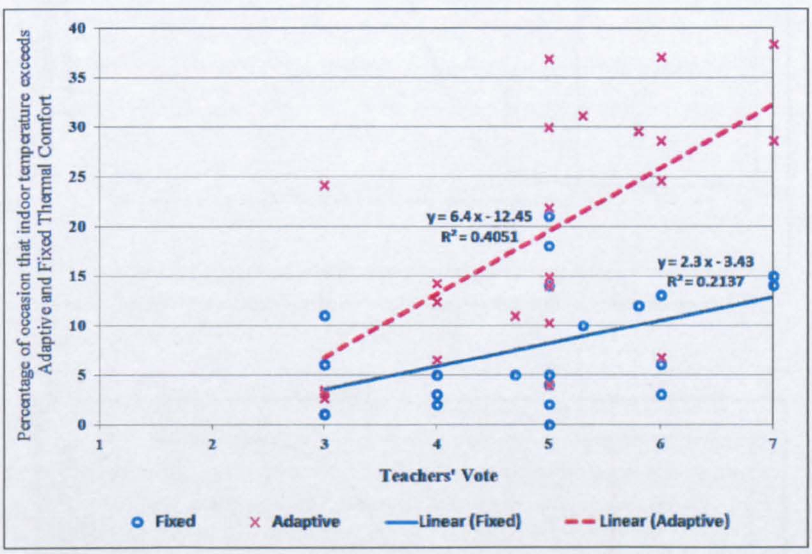
Section Three: Two regression analyses were carried out between the results of the above:

- Between the teachers' votes and the percentage of occasions that indoor temperatures exceed the fixed thermal comfort (i.e. greater than 25°C) for 2007 & 2008.
- Between the teachers' votes and the percentage of occasions that indoor temperatures exceed the adaptive thermal comfort (Tc = 0.33 Trm +18.8) for 2007 & 2008.

The results show that the teachers' votes on their satisfaction with indoor temperature (comfortable and uncomfortable) have a correlation (R) of 0.64 where the indoor temperatures exceed the adaptive thermal comfort, while this correlation is reduced to 0.46 when the indoor temperature exceed the fixed thermal comfort in the years of 2007 & 2008 (Appendix 10.2).

In other words, a regression analysis between the teachers' votes on the indoor temperature with the occurrence of overheating based on different overheating criteria shows that there is a higher relation between teachers' votes with the adaptive thermal comfort than the fixed thermal comfort.

Graph 2-2.5 shows the correlation between teachers' votes and the percentages of occasions that indoor temperatures exceed adaptive and fixed thermal comfort.



Graph 2-2.5: Relation between teachers actual feeling with the occasions that indoor temperature exceeds adaptive and fixed thermal comfort

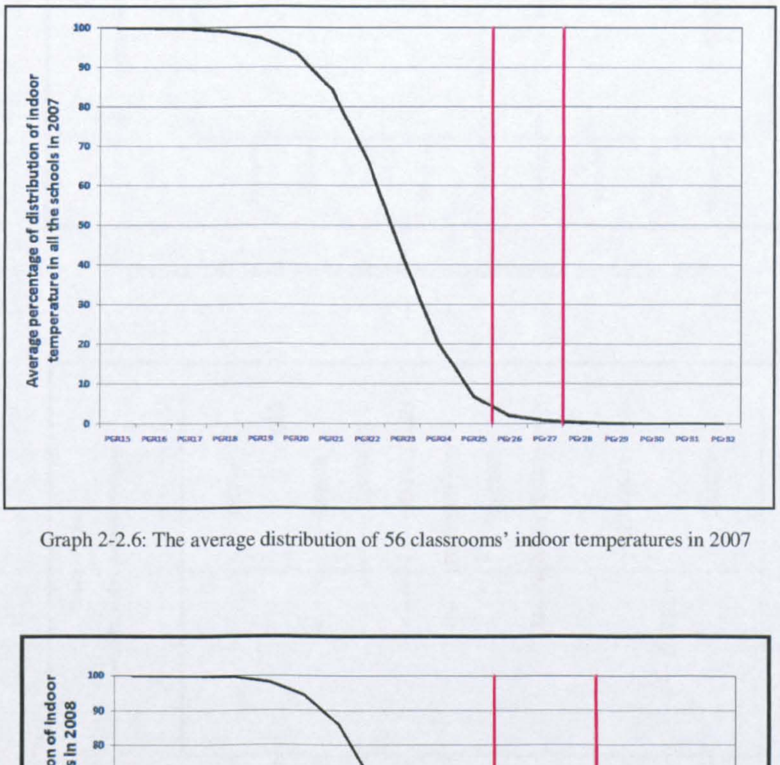
As it can be seen from Graph 2-2.5, there is a higher correlation between the percentage of occasions that exceed adaptive thermal comfort (R=0.64, P<0.05) than the fixed thermal comfort (R=0.46 , P<0.5).

- **Second method: Distribution of indoor temperature**

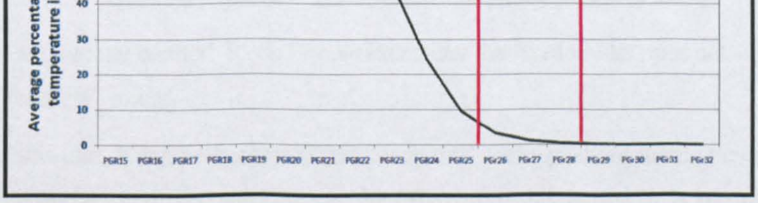
The first method has proven that the adaptive model is a better criterion than the fixed model for assessing overheating in classrooms.

The distribution of indoor temperature is an alternative way to compare the teachers' votes on overheating with the fixed and adaptive model.

The average distributions of 15 schools' indoor temperatures are shown in the Graph 2-2.6 and Graph 2-2.7 for the years of 2007 & 2008. As can be seen, only a small portion of the indoor temperatures exceeded 25°C (7% in 2007 and 10 % in 2008) & none exceeded 28°C for the duration of the study.

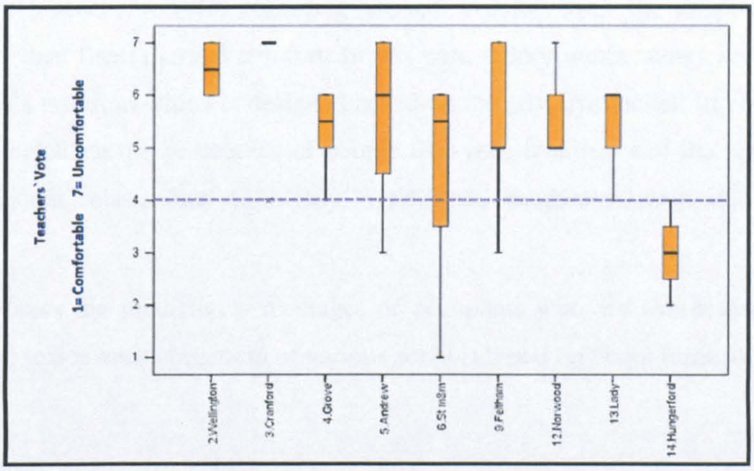


Graph 2-2.6: The average distribution of 56 classrooms' indoor temperatures in 2007

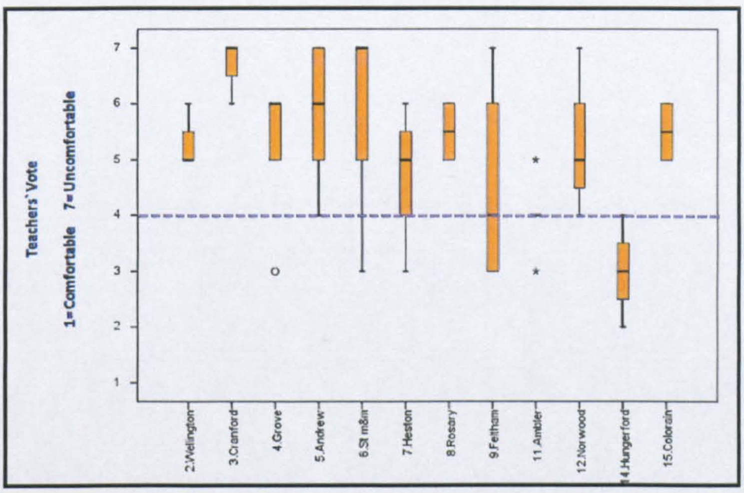


Graph 2-2.7: The average distribution of 58 classrooms' indoor temperatures in 2008

Consequently, the occupants of these schools should not significantly have felt thermally uncomfortable if evaluated on the basis of the fixed model. But the results of the questionnaires on thermal comfort show that the teachers were significantly thermally uncomfortable in June and July of the years 2007 & 2008 based on the Graph 2-2.8 and Graph 2-2.9. The graphs show a tendency towards uncomfortable in 8 out of 9 primary schools which proof of this claim (above the scale of 4).



Graph 2-2.8: Teachers' comfort level toward thermal comfort in 2007



Graph 2-2.9: Teachers' comfort level toward thermal comfort in 2008

From the first and second method, it can be concluded that the fixed model does not significantly represent the teachers' voices.

As a result of this part, it can be suggested that occupants' feelings about thermal comfort is more related to the adaptive thermal comfort rather than fixed. For this reason, it is recommended that thermal comfort benchmarks to be revised based on adaptive model rather than fixed model.

2.1.2.3: Stage three: Comparing the indoor temperatures with adaptive model

As it is shown in the first part of the study, the current UK thermal comfort benchmark for school (BB101), is the most relaxed one among the fixed thermal comfort benchmarks (BB87 and CIBSE). In the second part of this study, it is shown that there is a higher relation between teachers' votes regarding thermal comfort with the adaptive thermal comfort rather than fixed thermal comfort. In this part, indoor temperatures are compared with the Nicol's criterion which is designed based on the adaptive model. In his theory, it is possible to calculate the percentage of people who may overheat and the result can be used to categorise classrooms to highly overheated, moderate overheated and low overheated.

Table 2-2.4 shows the predicted percentages of occupants who are overheated (thermal dissatisfaction) inside each classroom of various schools based on Nicol formula.

School's Name	2008 Classroom's Name	2008 Mean	2008 Max	2007 Classroom's Name	2007 Mean	2007 Max	2005 Classroom's Name	2005 Mean	2005 Max
Hounslow	8.1	8	41	7.1	7	36	5.1	13	78
	8.2	4	23	7.2	3	18	5.2	12	85
	8.3	4	14	7.3	2	14	5.3	11	73
	8.4	6	30	7.4	4	22	-	-	-
Wellington	8.1	3	15	7.1	2	10	-	-	-
	8.2	5	16	7.2	4	12	-	-	-
	8.3	4	16	7.3	5	20	-	-	-
Cranford	8.1	7	22	7.1	6	26	-	-	-
	8.2	7	25	7.2	5	15	-	-	-
	8.3	6	25	7.3	6	22	-	-	-
Grove Road	8.1	7	19	7.1	6	18	-	-	-
	8.2	8	25	7.2	5	18	-	-	-
	8.3	6	23	7.3	6	22	-	-	-
	8.4	7	25	7.4	5	18	-	-	-
	8.5	6	19	7.5	6	18	-	-	-
	8.6	8	24	7.6	5	15	-	-	-
	8.7	5	15	7.7	6	18	-	-	-
	8.8	4	13	7.8	4	18	-	-	-
Andrew	8.1	3	9	7.1	4	17	5.1	7	46
	8.2	6	14	7.2	4	12	5.2	9	33
	8.3	6	17	7.3	4	20	5.3	8	35
	8.4	12	35	7.4	5	18	-	-	-
	8.5	5	18	7.5	5	24	-	-	-
STMM	8.1	6	15	7.1	6	16	-	-	-
	8.2	-	-	7.2	7	22	-	-	-
	8.3	6	13	7.3	6	17	-	-	-
	8.4	7	15	7.4	5	17	-	-	-
Heston	8.1	4	16	7.1	4	11	-	-	-
	8.2	4	21	7.2	3	10	-	-	-
	8.3	11	74	7.3	9	64	-	-	-
Rosary	8.1	4	15	7.1	3	11	-	-	-
	8.2	4	20	7.2	3	12	-	-	-
	8.3	3	8	7.3	3	29	-	-	-
Feltham	8.1	3	10	7.1	4	10	-	-	-
	8.2	7	26	7.2	6	12	-	-	-
	8.3	3	9	7.3	3	8	-	-	-
Pools	8.1	5	16	7.1	4	12	5.1	7	35
	8.2	6	18	7.2	5	14	5.2	6	31
	8.3	7	21	7.3	5	15	5.3	7	31
Ambler	8.1	5	14	7.1	5	30	5.1	6	31
	8.2	4	14	7.2	5	18	5.2	6	24
	8.3	3	6	7.3	4	10	5.3	10	45
Norwood	8.1	5	22	7.1	4	15	-	-	-
	8.2	5	25	7.2	5	17	-	-	-
	8.3	12	46	7.3	9	42	-	-	-
Lady	8.1	3	6	7.1	3	8	-	-	-
	8.2	7	26	7.2	4	10	-	-	-
	8.3	5	27	7.3	4	11	-	-	-
Hungerford	8.1	4	8	7.1	4	8	5.1	8	37
	8.2	4	16	7.2	4	15	5.2	4	18
	8.3	3	9	7.3	3	6	5.3	5	25
	8.4	3	9	-	-	-	-	-	-
	8.5	3	12	-	-	-	-	-	-
	8.6	2	7	-	-	-	-	-	-
	8.7	4	10	-	-	-	-	-	-
Colerain	8.1	2	14	7.1	3	12	5.1	10	58
	8.2	2	8	7.2	2	47	5.2	5	37
	8.3	5	19	7.3	3	14	5.3	9	49
Orchard	8.2	2	19	7.1	3	15	-	-	-
	-	-	-	7.2	5	39	-	-	-
St.Gildas	-	-	-	-	-	-	5.1	5	29
	-	-	-	-	-	-	5.2	6	35
	-	-	-	-	-	-	5.3	6	35
	-	-	-	-	-	-	5.4	-	-
Green church	-	-	-	-	-	-	5.1	5	18
	-	-	-	-	-	-	5.2	4	39
	-	-	-	-	-	-	5.3	8	54
	-	-	-	-	-	-	5.4	8	48

Color Code	
Highly overheated ≤%10	(red)
Moderate overheated %6 ≤ & < %10	(orange)
Low overheated <%6	(light yellow)
Missing data	(grey)

Table 2-2.4: Study of the percentages of occupants' dissatisfaction from overheating based on Adaptive model in various schools

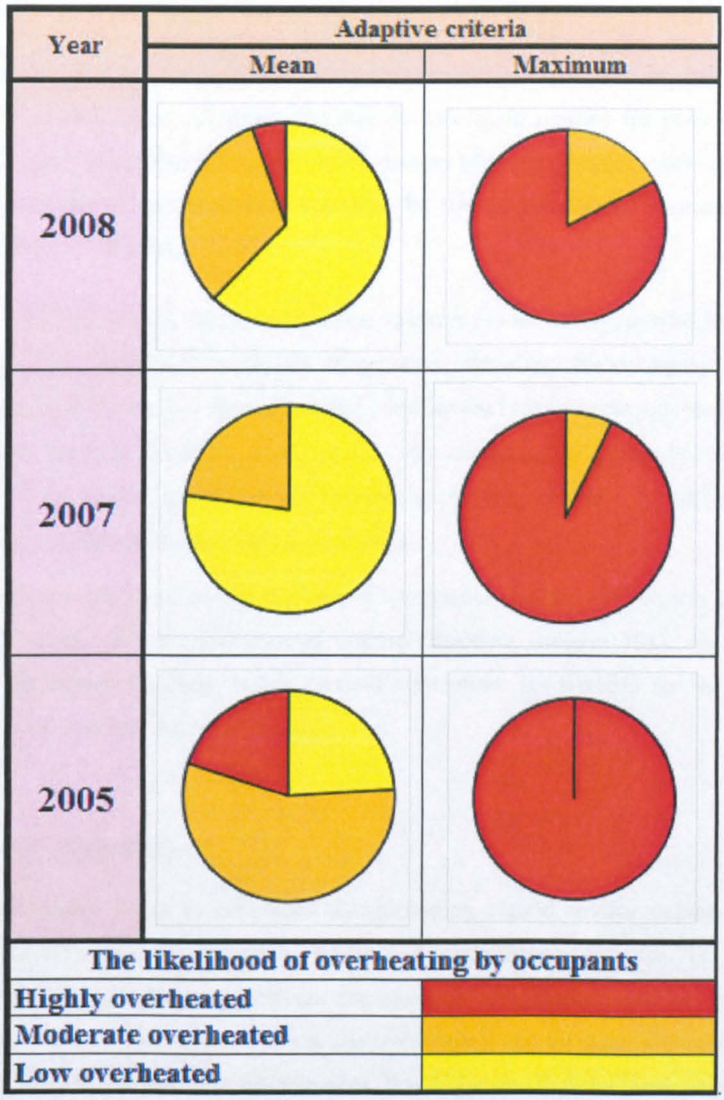
As can be seen from Table 2-2.4, classrooms are categorised into the following groups based on the percentage of occupants' dissatisfaction from overheating.

- Highly overheated classroom: refers to the classrooms in which more than 10% of occupants feel overheated.
- Moderately overheated classroom: refers to the classrooms in which 6% to 10% of occupants feel overheated.
- Low overheated classroom: refers to the situation in which less than 6% of occupants feel overheated.

The above is based on normal level of expectation in new or renovated building with occupants who are not sensitive and fragile (i.e. handicapped, sick, very young children and elderly persons).

In a condition that a classroom is occupied by very sensitive and fragile persons with special requirement like handicapped, sick children, a higher level of expectation is required. In this condition, a classroom is highly overheated if only 6% of occupants feel overheated.

In the following pie-charts (Graph 2-2.10), the percentage of classrooms which are classed as overheated (in different level of highly, moderate and low) in 2005, 2007 and 2008 are summarised.



Graph 2-2.10: The summary of evaluating classrooms' indoor temperatures based on Adaptive and Fixed model

As it can be seen, the number of schools (consequently their classrooms) which are highly overheated in 2005 is more than 2007 and 2008 (seen Mean column). All schools, therefore classrooms, have at some points, been highly overheated (see the Maximum column).

2.1.2.4: Result:

As a result of this study, it can be suggested that the two main reasons for poor environmental conditions are: firstly the conflict between comforts factors (thermal, lighting, acoustic comfort and air quality) as they are interrelated and secondly, the use of the relaxed thermal, air quality, acoustic and lighting benchmarks.

Nicol thermal criteria is not only designed based on adaptive model which has a better relation with occupants feeling, but also provides detailed information regarding overheating by predicting the percentage of people that may feel overheated and consider the type of occupants inside classroom, while overheating criteria based on fixed model only determine whether the classrooms are overheated or not. As a result, there is a gap between predicting thermal comfort (based on fixed model) and actual occupants feeling inside a classroom.

Based on this study, it can be suggested that one of the reasons that the UK schools are overheated is the use of the most relaxed fixed thermal criteria (Building Bulletin 101). As a result, it is suggested that the current building design thermal benchmark (i.e.BB101) for the UK primary schools to be revised considering Nicol formula.

2.1.3. Part Three - Conclusion:

As a result of this study, it can be concluded that providing a good environmental condition can have positive impacts on school occupants' health and academic performance. To provide good comfort conditions, school design guidelines are required to include a section to address the conflicts between comfort factors. In addition, the overheating and air quality benchmarks should be revised with the strangest and most reliable ones. It is suggested that the overheating benchmark (Building Bulletin 101) should be revised considering Nicol formula which is designed based on adaptive requirements.

Chapter 3: Overheating

Chapter 3.1: Literature Review: Principles of overheating control:

Chapter Overview:

This section looks at the definition of thermal environment followed by the reasons from overheating. The principles of solar overheating controls (i.e. solar gain, internal gain, thermal mass and ventilation) are discussed in this chapter.

3.1.1. Thermal environment

Thermal environment is divided into three broad categories:

- Thermal comfort is where there is broad satisfaction with the thermal environment
- Thermal discomfort is where people start feeling being uncomfortable.
- Thermal stress is where thermal environment causes potential harmful medical conditions e.g. dehydration or heat exhaustion.

The various types of overheating criteria are explained in Chapter Two. In this chapter the principles of overheating control are discussed.

3.1.2. Reasons of overheating

The first purpose of buildings is to protect humans against climatic influence. Consequently there is a significant relationship between place, climate and human life. Failing in building design process against climate condition and climate change may lead a building to experience overheating. The main reasons of overheating are climate and building. Climate can be discussed under micro and macro climate.

- Climate and overheating
- Building design and overheating

3.1.2.1. Climate and overheating

Climate is not the same as weather. While weather is described as the atmospheric conditions at any given time, climate is the average of these weather and atmospheric conditions over a number of years. Climate change has been mentioned as one of the greatest threats for environment, society and economy facing our planet. Climate change is developing dangerously year on year. The World Health Organisation (cited in Site Layout and Building Design, n.d.) estimates over 25,000 people died in Europe during summer 2003 due to the heat-wave in July and August. This subject can be discussed around macro and micro climate:

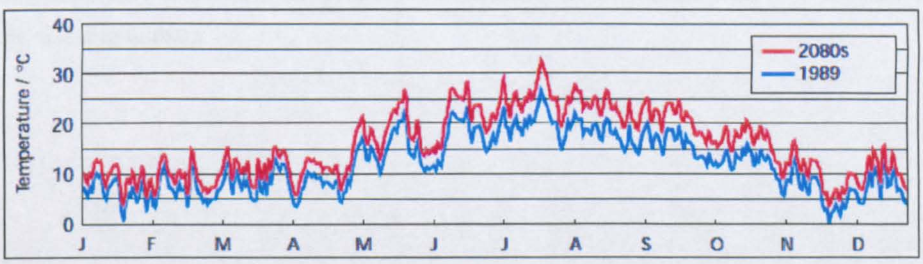
a) Macro climate and overheating

A number of factors band together or individually makes up the observed climate. Influencing factors are to name a few, wind speed, sea level, rain and snow, dry bulb temperature and solar radiations. Our climate is changing and there exists compelling scientific evidence indicating the same.

According to CIBSE (TM 37, 2006), a several degree increase in average temperature over the coming century is a probability and dry bulb temperature, solar radiation, and wind speed will play a cardinal part as climate variables.

The CIBSE Guide A (2006) reports that dry bulb temperature will affect the UK climate by between 2ºC to 3.5ºC by 2080s. This guide predicts that the South East of the UK will experience greater warming that the North West, with summer and autumns experiencing greater warming than winter and spring. Freezing winters will be a rarity whilst sweating summers more the norm. Prediction of the guide indicates that the 1995 August which gave the UK a 3.4°C warmer than average weather will occur 20 percent of every five years by 2050 and up to 60 percent in every five years by 2080s.

Graph 3-1.1 is a depiction of daily average temperatures predicted for London in 2080 against the gathered data available for those of temperature in 1989. The guide forecasts that in the case of solar radiation, the UK, especially the South will see less cloud cover during the summer resulting in higher solar radiation levels. In winter, although changes in cloud cover is expected to be less in the South yet still 2-3% above the rest of the country, which will result in a relatively small decrease in solar radiation levels. The peak solar radiation levels are expected to almost remain stable.



Graph 3-1.1: Daily average temperature for 1989 and 2080s

The other major factor beings wind speed which is obviously extremely difficult to predict and forecast with the available weather models. Diligent work is needed and is being carried out to improve models for predictions of this factor and at best at the present time, it is estimated that wind speeds will remain the same.

Increase in temperature and solar radiation will dramatically affect the ambient weather feel within the UK buildings. Naturally ventilated buildings are normally more at risk of overheating. It is apparent that a less than well designed building will harbour higher temperature than those observed outside of the building during hot spells leading to overheating.

A well design building will prohibit its internal temperature to exceed that of the outside and a well thought out building design using thermal storage and solar shade properly will keep the buildings internal temperature close to or lower than the average temperature during a hot period.

b) Micro climate and overheating

Prevailing climate can be affected by different factors such as topography, vegetation, water and building and cause the climate to deviate between regions within a small distance. This forms a small scale pattern of climate called 'micro-climate'.

The Urban Heat Island effect is an example of micro climate. There is a significant difference between an urban climate and a rural climate as a result of the following factors in an urban area:

- More effective absorption of solar radiation in 'street gorges' and less effective long waves radiation cooling
- Reduced wind speed
- Less vegetation

This difference varies from 1 to 4.5 °C in cities and in London this difference reaches to 8K (Akbari, et al, 1992).

It can be concluded that indoor temperature is affected by micro climate such as heat island effect as well as macro climate.

3.1.2.2. Building design and overheating

The main aim of any architect is to design a comfortable and pleasing space for occupants. Architectural design demands complicated processes and there is still much debate about optimising building design. The main and initial step of building design is the climate study to provide comfort condition.

In the last few decades, different scientists in the thermal comfort field such as Macpherson, Olgyay, Givoni, Fanger, Nicol & Humphreys etc., have assisted architects by defining comfort zones and by providing advices on climate design. Failure to study and consider the scientists' advices in the design process may lead to a failure in providing thermal comfort and cause overheating.

Looking at the history of school building design in the UK (Chapter Two), it can be concluded that school classrooms have been experiencing overheating in different eras due to the following reasons:

- Using low thermal mass material is the main reason for overheating in the schools which were built after World War II.
- Excessive solar gain is the main reason for overheating in schools which were built considering the 5% daylight factor requirement (by increasing window area).
- Saving energy by making buildings to be air tight and reducing the ventilation requirements is one the main reasons for overheating in the schools which were built after the oil crisis.
- Excessive internal gain as a result of increased usage of technology inside classrooms may be another reason for experiencing overheating.

Hence it can inferred that the main reasons of overheating in school classrooms are the use of low thermal mass, excessive solar gain, lack of ventilation and excessive internal gain. The impact of global warming necessity the need for a higher attention to the control of excessive heat in London schools as the age of school buildings varies from Victorian to recent constructions, with different levels of thermal mass, solar gain, internal gain and ventilation. The CIBSE presents a guideline to control solar overheating as explained below:

- **The principles of solar overheating control**

Excessive solar gain can lead to overheating or the need for high air conditioning loads in summer.

CIBSE TM.37 criteria suggest controlling solar overheating by controlling the following factors:

- Solar gain
- Internal gain
- Thermal mass
- Ventilation

The following techniques can be employed to reduce the impact of solar overheating.

- Solar overheating can be controlled by selecting a suitable layout and orientation. Building spaces should be laid out in such a way that they allow the building to achieve a balance between the advantages and disadvantages of sunlight. For example, controlling solar gain by shading devices would be more efficient if the building spaces have windows faced to the north or south as opposed to the east or west.
- Solar overheating can be controlled by controlling the window area. Window area should be decreased in such a way as to control the solar heat gain, as the amount of solar heat gain is related (a function of) to the window area. As a window has an impact on daylight as well as view to the outside, its area should be minimized thoughtfully.
- Solar overheating can be controlled by choosing suitable solar shading. Solar shading can be in the shape of external, internal, mid-pane shading or solar control glazing.
- Solar overheating can be controlled by utilising the exposed thermal mass in a building structure. The exposed thermal mass absorbs excessive heat and decreases the peak inside temperature of hot days. To maximise the benefit of thermal mass, night time ventilation is considered to be beneficial.
- Solar overheating can be controlled by ventilation. Ventilation has two specific roles in a building: sustaining air quality and cooling effect. It should be noted that the ventilation rate which is required to remove excessive solar heat gain is higher than the ventilation which is required to maintain indoor air quality.
- Overheating can be controlled by internal gain. Internal gain depends on occupants, equipment and luminaries. In order to control internal gain, energy efficient equipments and luminaires should be utilised and they should be switched off when not required.
- Mechanical cooling and air-conditioning can be used to control indoor from overheating.

In order to have a better understanding of how to control the above factors in order to reduce overheating, the relationship between them and indoor temperature are explained below:

- Solar gain and indoor temperature
- Internal gain and indoor temperature
- Thermal mass and indoor temperature
- Ventilation and indoor temperature

a) Solar gain and indoor temperature

This section looks at solar gain as one of the factors that have a significant impact on indoor temperature and is followed by the development of solar gain calculation method. Different factors which have significant impacts on the amount of solar gain that a space receives are explained in this part. One of these factors is window. Window has two other roles (i.e. providing view and daylight) which are also explained in this part.

a1) Roles of a Window:

Generally, windows have three main roles in buildings which are to provide view to the outside, allow daylight to enter the building and solar gain.

- **Windows and view:** The first important role of a window is to provide a view to the outside. According to BS8206-2 (2008), the view from inside a building to the outside should be provided as it has a significant impact on occupants' refreshment and relaxation. In the situation where view to outside cannot be provided, an internal view to a space, which has the outside quality such as atrium, should be provided.

- **Window and daylight:** The second important role of a window is to provide daylight. Generally the quality and quantity of natural light in an interior space depend firstly on the design of the interior environment and secondly on the design of the external environment. The size and position of windows play an important role on the design of interior environment. The other factors that have impact on the design of interior environment are the depth and shape of room and colour of internal surfaces. Design of external environment is related to the external buildings and trees that can block sunlight completely (by buildings) or partially (by trees) for a specific duration of the year (depends of the distance and height of the adjacent building and tree to the main building).

- **Window and solar gain:** The third important role of a window is its impact on solar gain which is discussed in detail in this chapter. Solar gain which is also called 'solar heat gain' or 'passive solar gain' refers to the temperature increase in a space, which depends on the building's furniture, structure and the power of solar radiation (differs in each orientation). Window glass transmits short wave radiations in to the building's space and these short waves are absorbed by internal surfaces (structure and objects) and then reradiated in long-waves which are also called thermal radiation. The window glass cannot transmit the long wave radiation (thermal radiation) and therefore this energy is trapped indoor and raises the indoor temperature. This procedure is called the green-house effect. Within the comfort topic, direct radiation which falls on the occupants who sit near windows is more significant than the rising indoor temperature as the result of green-house effect (CIBSE Guide A, 2006). Although it can have a positive effect on indoor temperature during the heating season excessive solar gain has a negative impact on indoor temperature which causes overheating in summer and consequently requires high cooling loads (CIBSE.TM37, 2006). The unnecessary solar gain can be controlled and reduced by careful design including the selection of an appropriate window orientation, permanent or temporary shading device, suitable overshadowing under the condition that optimum daylight and ventilation for a space is provided (BB101, 2006) .

- **Window and ventilation:** The forth important role of a window is its use as a means of ventilation. The position of window in relation to the prevailing wind can have impacts on the amount of air that enters in to a space to remove heat or provide fresh air. Different types of windows have different air flow and ventilation control potentials. For example, an upper fanlight and outward opening casement can provide a good level of airflow with a very good ventilation control (BB101, 2006).

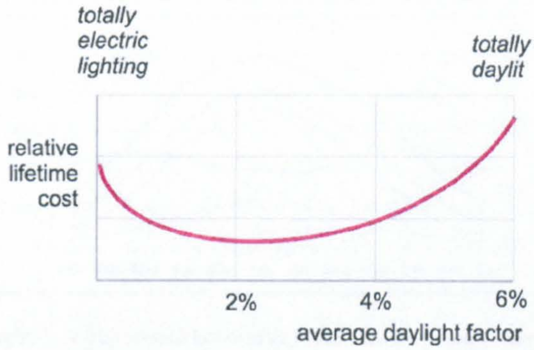
Excess care should be applied for selecting suitable windows so that there is no conflict between protecting inside from high level of background noise, pollution, rain, security etc.

a2) Solar gain factors:

The amount of solar gain that a building can receive depends on its location in the world and on the following factors:

- Window area
- Window orientation
- Obstructed solar gain

- **Window area:** Solar heat gain - as a result of direct solar gain through a window - is proportional to the window area of a space. High level of daylight which is provided by large window area is associated with excessive heat gain/loss and high building costs however reducing window area can limit daylight and restrict the view to the outside.The relationship between energy cost and window area is shown in the following graph (Graph 3-1.2) which is applicable to a majority of buildings (DETR, 1998).



Graph 3-1.2: Typical curve showing the effect of life time costs of the balance between daylights and electric lighting (Tregenza and Wilson., 2011)

The window area must be chosen in such a way that it provides an average daylight factor of 2%.

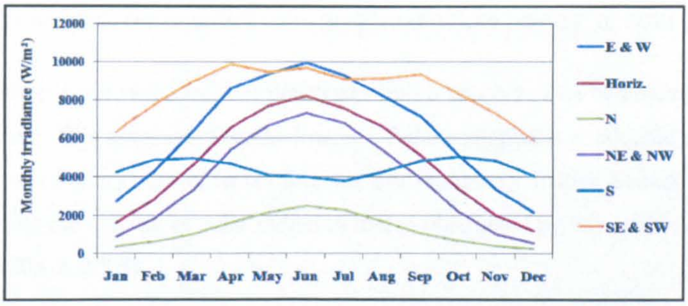
- If daylight factor falls less that 2%, the room looks gloomy and full electric lighting is needed during day time
- If daylight factor falls between 2% to 5%, the window provides large amount of daylight and only complementary electric lighting is needed
- If daylight factor goes more than 5%, a high level of daylight is provided in the room with little need of electric lighting, but the room would face serious thermal problems.

In order to provide 2% of daylight factor, an optimum window area needs to be chosen. BB87 suggests two different optimum levels for each kind of window (vertical & horizontal) which can satisfy and control both daylight and thermal performance. Vertical glazed areas should allocate maximum 40% of the internal elevation of the external wall to itself on an average.

Horizontal glazed areas should allocate maximum 20% of the roof area to itself on an average.

Using a passive daylight strategy may mean that the level of vertical glazed area may go above 40%, which can cause excessive heat loss and heat gain through a window (cause overheating), which can be compensated with a higher level of insulation to the building fabric. According to the case study undertaken by BRE, it is possible to increase the vertical glazed area by up to 50% with the cautious use of the external shading (e.g. deep eaves). Vertical glazed area below 20% makes the building too dark and gloomy inside and occupants lose their contact with the outside world, while vertical glazed areas above 40% causes overheating and glare as a result of increased solar gain (EnREI, 1995).

- **Window orientation:** The building orientation determines the amount of radiation it receives and this varies according to the time of the year. The maximum daily global solar irradiance for a peak day in each month for different directions received in London, UK (CIBSE Guide A, 2006) is shown in the following graph (Graph 3-1.3).



Graph 3-1.3: The relation between the maximum daily global solar irradiance for the peak day of each month and different directions
(Drawn by the author based on data derived from CIBSE Guide A – Appendix 6)

As can be seen from the above graph, solar radiation varies according to the direction and the time of the year. The following facts can be inferred from the above graph:

South facing windows usually receive a higher solar irradiance over a longer duration of the day in comparison with north facing windows. Although east and west facing windows receive the highest solar irradiance, they only receive solar irradiance over a shorter duration of the day (Littlefair, 1991).

If a building is carefully designed and oriented, solar gains can be made beneficial for much of the year. However, excessive solar gains may lead to overheating (BB101, 2006). For this reason, great care should be taken in designing the buildings' layout to increase the advantage of sunlight and decrease its disadvantages. Placing a building's main facade to the south allows the occupants to use winter solar gain, and block it by shading devices when needed during summer. Spaces that are critically overheated (e.g. computer sites) can be placed on the north side of the building (CIBSE TM 37, 2006) but if this is not possible, solar shading would be required (BB101, 2006).

- **Obstructing solar gain:**

• **Shading:** Solar gain can be controlled by shading. The variety of shading devices available are external shading, mid-pane blind and internal blind. Traditional low transmittance solar glazing will diminish light as well as solar gain. However, new types of coated glazing can give a high daylight transmittance with a lower solar gain. This might be the best method of reducing summer cooling loads where large areas of glass are needed for view or appearance (CIBSE.TM37, 2006).

In most buildings the need for shading changes through the year. It can vary according to the following factors:

- Seasonal requirements: overheating is a problem in summer, but winter solar heat gain can be welcome
- Daily weather: on dull days there is often little need for shading devices

- Occupant requirements: for some activities people need extra privacy, or extra control of glare.

- **Overshadowing:** solar radiation that penetrates into a space can be obstructed by any outside buildings, trees, etc. This is called 'overshadowing'. Solar radiation is a valuable source of heating in heating seasons (winter) but not in cooling seasons (summer). British Standard recommends a method to calculate the amount of solar radiation that is obstructed by any building or trees around a building (BS 8206-2, 2008).

Calculation of the percentage of over-shading in each space enables the determination of the amount of solar gain obstructed and the amount that penetrates into a building. Although overshadowing has a negative impact on the amount of heat and natural light coming into a building during winter, it can have a positive impact on controlling overheating during summer.

- **Overshadowing by building vs. trees:** If a building is overshadowed by another building, it may help to control summer overheating, but has a negative impact on winter heating load and natural light. Overshadowing by deciduous trees is a desirable method for obstruction of buildings, as deciduous trees shed their leaves during winter allowing the building to benefit from solar gain for heating loads. It is cautioned that care should be applied when choosing and planting trees. Trees obstruct different amount of solar gain according to their density. Table 3-2.1 shows the transmission percentage (shading coefficient) for various trees during summer and winter (McPherson, 1984).

	Shading coefficients (% transmission)	
Botanical name **Common name**	**Summer**	**Winter**
Pyrus communis Common Pear	.20(6)	.60(7)
Quercus alba White Oak	.25(6)	
Quercus palustris Pin Oak	.15(1), .30(3)	.63(3), .88(4)
Quercus robur English Oak	.19(6)	.83(6)
Quercus rubra Red Oak	.19(6)	.79(4), .81(6) .70(7)
Sapium sebiferium Chinese Tallow Tree	.17(1)	.63(1)
Sophora japonica Japanese Pagoda Tree	.20(1), .24(5) .22(6)	.35(1)
Tilia cordata Littleleaf Linden	.07(1), .13(5) .17(6)	.46(1), .70(6) .62(7)
Ulmus americana American Elm	.13(5)	.89(4), .63(7)
Ulmus pumila Siberian Elm	.15(1), .15(5)	.29(1), .50(4)
Zelkova serrata Japanese Zelkova	.15(1), .24(6)	.54(1), .78(6) .74(7)

To be continued

Botanical name **Common name**	**Shading coefficients (% transmission)** **Summer**	 **Winter**
Acer ginnala Amur Maple	.09(6)	
Acer platanoides Norway Maple	.14(1), .14(3) .10(5), .10(6)	.65(1), .75(6) .75(6), .61(7)
Acer rubrum Red Maple	.17(6)	.75(4), .82(6) .63(7)
Acer saccharinum Silver Maple	.18(1), .11(5) .21(6)	.66(1), .87(4) .59(7)
Acer saccharum Sugar Maple	.16(6)	.82(4), .56(7)
Aesculus hippocastanum Horsechestnut	.08(5), .15(6)	.73(4)
Albizzia julibrissin Silk Tree	.17(1)	.63(1), .73(7)
Amelanchier canadensis Shadblow	.23(6)	.57(7)
Betula pendula European Birch	.15(1), .20(5) .19(6)	.48(1), .60(2) .88(4), .52(7)
Carya ovata Shagbark Hickory	.23(6)	.66(7)
Catalpa speciosa Western Catalpa	.24(6)	.83(4), .52(7)
Celtis australis European Hackberry	.08(1)	.53(1)
Celtis occidentalis Common Hackberry	12(5)	
Crataegus laevigata English Hawthorn	.14(5)	
Crataegus lavallei Carrier Hawthorn	.11(5)	
Crataegus phaenopyrum Washington Hawthorn	.24(5)	
Elaeagnus angustifolia Russian Olive	.13(5)	
Fagus sylvatica European Beech	.12(6)	.83(5)
Fraxinus excelsior European Ash	.14(1), .15(5)	.59(1)
Fraxinus holotricha 'Moraine' Moraine Ash	.22(1)	.50(2)
Fraxinus pennsylvanica Green Ash	.13(5), .20(6)	.71(6), .70(7)
Ginkgo biloba Maidenhair Tree	.20(1), .16(5) .22(6)	.55(1), .72(6)
Gleditsia triacanthos inermis Honey Locust	.32(1), .30(5) .38(6)	.48(1), .85(2)
Gymnocladus dioicus Kentucky Coffee Tree	.14(5)	
Juglans nigra Black Walnut	.09(5)	.55(2), .72(7)
Koelreuteria bipinnata Chinese Flame Tree	.10(1)	.70(1)
Koelreuteria paniculata Goldenrain Tree	.25(1), .13(5)	.42(1)
Liquidamber styraciflua Sweetgum	.18(1)	.70(1), .84(4) .65(7)
Liriodendron tulipifera Tulip Tree	.10(5)	.78(4), .69(7)
Malus spp. Crabapple	.15(1), .15(5)	.85(1)
Parkinsonia aculeata Jerusalem Thorn	.15(1)	.27(1)
Pistachia chinensis Chinese Pistache	.15(1)	.38(1)
Platanus acerifolia London Plane Tree	.17(1), .14(3) .11(5)	.64(1), .46(3)
Platanus racemosa California Sycamore	.09(1)	.45(1), .60(2)
Populus deltoides Cottonwood	.15(6)	.68(7)

Table 3-2.1: Transmission percentage (shading coefficient) for different trees during summer and winter extracted from McPherson (1984)

a3) Solar gain calculation:

The solar load per unit floor area in a space is obtained by Qsl = (1/Ap) $\sum$ (Ag Qs geff)

- Qsl: is the solar load per unit floor area in a space (W/m²)
- Ap: is the perimeter zone floor area which is within 6 meters on plan from a window wall or roof light (m²)
- Ag: is the net area of glazing of each element in the perimeter zone for a particular orientation of an opening (W/m²)
- Qs: is the external solar radiation for a particular orientation of an opening which can be found from the CIBSE irradiance tables
- geff: is related to the window specification and type of shading

The summation sign indicates the summation of the glazing areas on each facade and the roof bounding the space in question. This formula is only applicable when the building is not overshadowed by other buildings and trees (CIBSE TM37, 2006).

b) Internal gain and indoor temperature:

This section focuses on internal gain as one of the factors that have a significant impact on indoor temperature and looks at internal gain calculation methods.

b1) Internal gain definition:

The heat produced from the following sources inside a building is called internal gain:

- Heat from the occupant
- Heat from the equipment
- Heat from lighting

b2) Internal gain calculation methods:

In order to calculate internal gain, CIBSE TM37 (2006) suggests two methods as follows:

- **Method A:** In this method, the standard casual gain is calculated as a standard figure W/m² for people, equipment and lighting. For example, Table 3-1.2 shows the standard internal gains in a primary school. The standard casual gain in this table is based on the activity schedule in SBEM (Simplifies Building Energy Model).

In this table, the level of standard casual gain in classrooms is shown.

Building type	Space type	Occupant gain (W/m²)	Equipment (W/m²)	Lighting (W/m²)	Display lighting (W/m²)
Primary school	Cellular office	32	9.1	18.8	0
	Classroom	22.8	4.5	11.3	0
	Common room/ Staff room/ Longe	0.8	4.4	7.8	0
	Dry sport hall	2.6	1.4	15.6	0
	Eating/ Drinking area	2.5	8.6	7.8	0
	Food preparation area	2.5	16.9	26.0	0
	Meeting room	9.1	4.5	11.3	0
	Open plan office	5.0	13.6	18.8	0
	Reception	1.0	4.5	10.4	9
	Swimming pool	5.2	2	15.6	0

Table 3-1.2: Standard casual gains in different parts of a primary school

(CIBSE TM37, 2006)

- **Method B:** In this method which is called 'detailed method', internal gain for each source (i.e. people, equipment and lighting) is separately calculated based on the occupancy and use of the space.

- **Occupant internal gain calculation:** Heat from the occupant is related to the following factors:

1. Heat emission per occupant:

Table 3-1.3 shows the sensible heat gain per person when undertaking a particular type of activity under heat wave conditions (i.e. 26°C ambient temperature). The latent heat produced in the form of moisture is not included as it is assumed to be removed by ventilation.

Heat emission from typical occupants under heat wave conditions	
Activity	Sensible heat gain per person under heat wave conditions/W
Seated, inactive	59
Seated, light work	63
Seated moderated work (e.g. office)	65
Standing, light work, walking (e.g. retail)	66
Light bench work	71
Medium bench work	85
Heavy work	105
Moderate dancing	85

Table 3-1.3: Heat emission from typical occupants under heat wave condition
(CIBSE.TM37, 2006)

2. Work station density:

The work station density represents the area per head in each space. For example, according to Neufert architect's data (Baiche and Walliman, 2000) the area per head for people inside primary schools is 2.00 to 2.20 m².

3. Probability people are present:

Heat emission from typical occupants under a heat wave condition (Factor 1) is divided by the average number of square meter per person in a perimeter zone on peak summer days. The average number of square meters per person in a perimeter zone on peak summer days is not always the same as the number of square meter per head (i.e. work station or desk). Therefore, this amount should be modified according to the probability that people will be present in the space on a hot summer working day.

4. Working hours per person & occupancy density:

The level of occupancy in each building is different from one building to another. Some buildings have a lower than average occupancy like primary school classrooms which have 6 hours occupancy per day in contrast to some buildings that have a higher than average occupancy like hotels and resorts which have 24 hours occupancy.

By finding the above 4 factors, the total internal gain from people can be calculated from the following formula:

Heat gain from people (W m^{-2})= (heat emission per occupant (W)/workstation density (m^2) x (probability people are present (m^2)) x (working hours per person/occupancy density(m^2))

- **Equipment internal gain calculation:** Heat from equipment is related to the following factors:

1. Power consumed by equipment:

The power consumption for equipment can be extracted from Appendix 7.1.
Some equipment like PCs have the 'stand-by' and 'sleep' modes when not in use. So the power which is consumed by this equipment can be calculated from the following formula:

Power consumed= (fraction of time in full operation x power in full operation) + (fraction of time in standby mode x power in standby mode) + (fraction of time in sleep mode x power sleep mode)

2. Fraction of heat that enters space:

Often all the heat generated by the equipment will end up in the space. However if there is a localised mechanical ventilation or passive venting of a particular equipment, most of the heat generated will usually be extracted. For the purposes of the Approved Document L2A calculation, heat gains from equipment for which there is a localised mechanical ventilation may be discounted.

3. Daily probability equipment will be switched on:

The daily probability that the equipment would be switched on is related to a working day in summer. If the equipment is associated with a particular person [e.g. personal computers (PCs)], the probability it would be switched on can be assumed to be equal to the probability that person is in the space on that particular day.

4. Hours equipment in use:

This is the number of hours that the equipment is in use.

By finding the above 4 factors, the total internal gain from the equipment can be calculated using the following formula:

Heat gain from equipment= (Power consumed by equipment) x (fraction of heat that enters the space) x (daily probability the equipment will be switched on) x (no. of hours equipment in use/10)

Electronic whiteboard projector, overhead projector, monitor, laptop etc. are the source of heat inside a classroom. Heat gain from these sources can be minimised by choosing energy efficient equipments. For example LCD screens reduce heat gain compared to conventional CRT monitors (BB101, 2006).

- **Lighting internal gain calculation:** Sources of heat from lighting are divided as follows:

1. Heat from general lighting:

General lighting is the light that is switched on when a space does not have enough daylight. The contribution of this kind of lighting on heat gain is zero if the space is adequately day-lit (no general lighting required). The amount of energy and heat which is distributed in a space is extracted from the lighting equipment's specification. See Appendix 7.2 for samples of specifications.

2. Heat from display lighting:

Display lighting mainly refers to a light which is left on during the occupied hours and include portable and tracked mounted lights. The level of energy and heat distributed from them depend on their specification. Heat from display lighting is calculated from the following formula:

Heat gain from display lighting= (Heat from display lighting in the perimeter zone) / (floor area of that zone).

In order to reduce the level of heat gained from 'electric lighting', care should be taken in order to design a space so that it receives adequate natural light without any difficulty. For example, in some classrooms occupants pull the blinds down in order to reduce glare and direct solar gain, consequently natural light is reduced and they have to turn on the electric light.

Summary of Method B: The sum of the calculation of occupants, equipments and lighting gains provides the total internal gain in any spaces.

c) Thermal mass and indoor temperature

In this section the definition of thermal mass is provided followed by the discussion of its differences with thermal insulation. Admittance value and decrement delay are the two factors that have impacts on thermal mass level. Some recommendations are made regarding the integration between heavy thermal and high insulation level. Utilisation of heavy thermal mass can be a suitable technique to control the indoor temperature in the UK as the country will experience warmer summers by the 2080s as a result of global warming. The roles of heavy thermal mass in the UK climate during summer and winter to control indoor temperatures are different which are explained in this section.

c1) Definition of thermal mass

Thermal mass is the ability of any material to store heat. Thermal mass is a concept in building design that protects the indoor temperature from high air temperature fluctuations. Materials, according to their 'Thermal storage' and 'Conductivity' are tabularised in different categories of Heavy, Medium and Low thermal mass (The Concrete Centre, 2009).

- **Thermal storage:** Thermal storage in a material is related to Density (kg/m) and Specific Heat Capacity (J/kg.k) of the material. Specific Heat Capacity is the amount of heat required to change a unit mass of a substance by one degree temperature in the unit of (J/kg.K) and Density refers to the mass per unit volume (kg/m).

- **Thermal conductivity:** Thermal Conductivity (K) is a 'material property' and means its ability to conduct heat through its internal structure. It depends on the temperature, the density and the moisture content of the material as a unit of (W/m K).

Table 3-1.4 shows thermal storage, thermal conductivity and thermal mass levels of some materials.

Material type	Density	Specifict Heat	Thermal storage	Thermal storage	Thermal condictivity	Themal mass level
	kg/m³	J/kg.k	J/m³.K	kJ/m³.K	W/m.k	
Timber	500	1600	800,000	800	0.13	Low
Steel	7800	450	3,510,000	3,510	50	Low
Light weight aggregate bloc	1400	1000	1,400,000	1,400	0.57	Meduim-High
Precast and in-situ concrete	2300	1000	2,300,000	2,300	1.75	High
Brick	1750	1000	1,750,000	1,750	0.77	High
Sandstone	2300	1000	2,300,000	2,300	1.8	High

Table 3-1.4: Thermal mass specification of materials (The Concrete Centre, 2009)

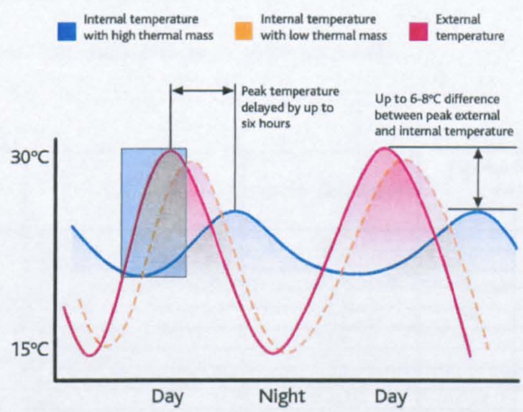
- **Timber:** As can be seen from the above table, timber is considered as a 'Low thermal mass' material for two reasons. Firstly, timber heat storage potential is low (it is approximately 800 kJ/m³k) and secondly, it is not a conductive material with only 0.13 W/m.k thermal conductivity. Therefore, timber cannot conduct heat to the depth of the material to be stored for later use.

- **Steel:** The above table shows that steel is counted as a Low thermal mass material. Although steel has a high storage potential of around 3510 kJ/m3k, it has a high conductivity of around 50 thermal conductivity, that can quickly transfer heat stored in the core of a material to the surface to be released to the environment.

- **Concrete, Brick and Sand stone:** As can be seen from the table, concrete, brick and sandstone are counted as Heavy thermal mass materials. This is because these materials have a high heat storage potential of 1750 to 2300 KJ/m³K and a moderate thermal conductivity of around 0.77 to 1.80 W/m.k allowing heat transfers to the depth of material.

Graph 3-1.4 shows the indoor temperature of two spaces built with two levels of thermal mass (i.e. heavy and low) against external temperature. As can be seen, the fluctuation of indoor temperature in a space with high thermal mass level is lower than the one built with low thermal mass material. In addition, the 'peak temperature delay' and 'peak temperature differences' in the space which is built with low thermal mass material is higher than the one built with heavy thermal mass material.

'Peak temperature delay' is related to a factor which is called 'Decrement delay'; and 'Peak temperature differences' is related to a factor called 'Admittance values'.



Graph 3-1.4: Stabilising effect of thermal mass on internal temperature

(The concrete centre, 2009)

- **Decrement delay:** Decrement delay factor refers to the length of time required for heat to get into the material from one side and out from the other side. In order to decrease the risk of overheating during summer, construction materials should be chosen in such a way as to provide a decrement delay of around 10 to 12 hours in order to delay the heat which gets into the material during the day until the late evening or night. Reducing the 'Decrement delay' from 10-12 hours to a lower rate is helpful but it will have a limited benefit if decreased to less than six hours.

- **Admittance value (W/m².k):** 'Admittance value' refers to the ability of a material or a construction such as a wall to exchange heat with the environment when it is subject to a simple cyclic variation in temperature. For buildings, cyclic variation is 24 hours.

c2) Differences between thermal mass and thermal insulation

It is important that the concept of thermal insulation is not confused with thermal mass. Thermal insulation is a building design concept that reduces heat flow from getting in or out of the buildings' envelopes while thermal mass allows heat to get in to the material and stores it for a specific period of time and then releases it. Therefore, heavy thermal mass material is not a good thermal insulation and vice versa.

Thermal insulation is shown with R-value (U = 1/ R) which measures the thermal resistance of materials. Under uniform conditions, it is the ratio of the temperature difference across an insulator and the heat flux (heat transfer per unit area, QA) through it (R= Δt/ QA).

The U value is the inverse of R value which is an important concept of building design and it represents the air-to-air transmittance of an element. The U value refers to how well an element conducts heat from one side to the other.

Table 3-1.5 shows the thermal conductivity of some materials.

Group	Material	Specific mass (kg/m³)	Thermal conductivity (W/mK)	
			Dry	Wet
Metal	Aluminium	2800	204	204
	Copper	9000	372	372
	Lead	12250	35	35
	Steel, Iron	7800	52	52
	Zinc	7200	110	110
Natural stone	Basalt, Granite	3000	3.5	3.5
	Bluestone, Marble	2700	2.5	2.5
	Sandstone	2600	1.6	1.6
Masonry	Brick	1600-1900	0.6-0.7	0.9-1.2
	Sand-lime brick	1900	0.9	1.4
Concrete	Gravel concrete	2300-2500	2	2
	Light concrete	1600-1900	0.7-0.9	1.2-1.4
	Pumice powder concrete	1000-1400	0.35-0.5	0.5-0.95
	Isolation concrete	300-700	0.12-0.23	
	Cellular concrete	1000-1300	0.35-0.5	0.7-1.2
	Slag concrete	1600-1900	0.45-0.70	0.7-1.0
Plasters	Cement	1900	0.9	1.5
	Lime	1600	0.7	0.8
	Gypsum	1300	0.5	0.8
Organic	Cork (expanded)	100-200	0.04-0.0045	
	Linoleum	1200	0.17	
	Rubber	1200-1500	0.17-0.3	
	Fibre board	200-400	0.08-0.12	0.09-0.17
Wood	Hardwood	800	0.17	0.23
Cavity isolation	Cavity wall isolation	20-100	0.05	
Water	Water	1000	0.58	
	Ice	900	2.2	
	Snow, fresh	80-200	0.1-0.2	
	Snow, old	200-800	0.5-1.8	
Air	Air	1.2	0.023	
Soil	Woodland soil	1450	0.8	
	Clay with sand	1780	0.9	
	Damp sandy soil	1700	2	
	Soil (dry)	1600	0.3	
Floor covering	Floor tiles	2000	1.5	
	Parquet	800	0.17-0.27	
	Cork	200	0.06-0.07	
	Wool	400	0.07	

Table 3-1.5: Thermal insulation specification of materials (LEARN website, n.d.)

From the explanation of thermal mass and thermal insulation, it can be concluded that these two concepts need to be considered carefully when being selected in the design of a building. Selecting the correct concept in any region depends on the prevailing climate for that region. For this reason a complete review is conducted in the next part about selecting the thermal mass or thermal insulation concept in each climate.

c3) Integrating the use of heavy thermal mass and high insulation level

Utilisation of correct thermal mass and insulation in a building helps to reduce the heating demand during winter and cooling requirement during summer and as well as to reduce the building's carbon footprint. Apart from this, care should also be taken regarding the form and orientation of buildings.

'Heavy thermal mass' is the main solution for hot climates that helps storing heat during the day on the external wall protecting the inside from overheating during the day (during midday), and transferring the stored heat to the inside during the night when the outside temperature cools down to freezing levels (during midnight), helping to protect the inside from cold temperature. A 'high insulation level' is the main solution for cold climates to prevent heat transfer from outside the building to the inside during day and night.

As each of the thermal mass and thermal insulation concepts has their own benefits, their careful integration can provide a better solution to reduce the building's energy demands and reduce their carbon footprint. Passive solar design with the aim of reducing heating and cooling demands and CO_2 emissions, use both 'heavy thermal mass' and 'high insulation' techniques to maintain indoor temperature during cold and warm seasons, with minimum requirements for energy loads.

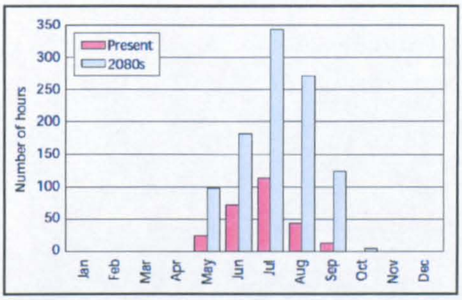
As mentioned earlier, good thermal mass is not a good thermal insulation, and therefore it is beneficial to combine thermal mass and thermal insulation for an effective passive design for climates such as in the UK. For this reason, the position of thermal insulation in relation to the thermal mass is very important. Thermal mass should be located inside the thermal insulation of the building envelope (Figure 3-1.1). In addition, the insulation for solid ground floors should be located under the slab. In such a situation, the thermal mass surfaces can store the solar gain themselves and radiate it to the building (not outside the building as building is covered with thermal insulation) after a specific period of time.

Figure 3-1.1: Integration of thermal mass & insulation

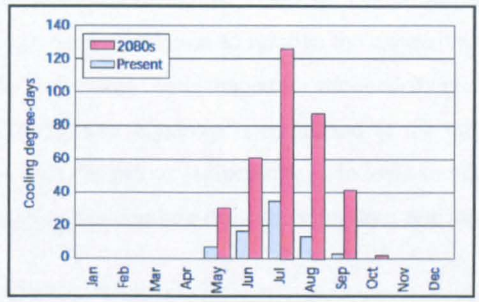
(Concrete centre, 2009)

c4) UK climate, global warming and utilisation of heavy thermal mass materials

According to the CIBSE, TM36 (2005), the UK will have warmer summers by the 2080s as a result of global warming. Graph 3-1.5 compares the monthly variation of hours exceeding 25°C forecasted for the 2080s with the present days, and Graph 3-1.6 compares the cooling degree days based on 22°C in 2080s with the present days.



Graph 3-1.5: Monthly variation of hours exceeding 25 °C for London (cited in CIBSE TM36 (2005))



Graph 3-1.6: Annual distribution of cooling degree-days referred to as 22 °C for London (cited in CIBSE TM36 (2005)

As can be seen from the above graphs, the number of hours during which the temperature exceeds 25°C will become significantly higher in the 2080s as compared to the present day. Similarly, the cooling degree-hours in the 2080s become significantly higher. It can be concluded that as a result of global warming, the free running buildings in the UK will experience higher indoor temperatures and therefore the risk of overheating will increase.

Careful design is necessary to reduce the risk of overheating in the future. Utilisation of heavy thermal mass materials in the UK building construction is one of the solutions suggested, to maintain indoor temperature and decrease the risk of overheating during summer.

c5) The impact of an integrated technique during both seasons:

In the following section, the role of heavy thermal materials in the UK climate during summer and winter are explained.

Summer: Indoor surfaces (i.e. floor, ceiling and internal wall) with heavy thermal mass materials store the solar gain during the day and protect the inside from overheating and excessive heat (Figure 3-1.2). The stored heat in the internal surfaces is released from the surfaces, usually after a cycle of 12 hours (in the night), when the outdoor temperature drops. Windows can be left open during the night in order to have the benefit of night time ventilation to remove the excessive heat and maintain indoor temperature. Night time ventilation should be managed for the security reasons (Figure 3-1.3). During summer days, the need for opening windows is connected to the outside temperature. If outdoor temperature rises to more than the indoor temperature, windows should be closed in order to prevent excessive heat from entering the building (this situation does not usually happen in the UK climate).

Figure 3-1.2: Role of Heavy thermal mass in the UK Climate during summer nights (cited in the concrete centre, 2009)

Figure 3-1.3: Role of Heavy thermal mass in the UK Climate during summer days (cited in the concrete centre, 2009)

Winter: During the heating season, the solar heat will be stored in floor, ceiling and inside wall during the day (Figure 3-1.4) and the heat is released later during the night (Figure 3-1.5). If the building is sufficiently insulated, the indoor temperature is maintained at comfort levels during the night, with no or low heating demand. Curtains should be drawn to minimise heat loss. In addition, during the morning, the building needs a considerable amount of energy to heat up during the winter. As a result of the stored heat release during the night before, the building needs less energy to heat up.

Figure 3-1.4: Role of Heavy thermal mass in the UK Climate during winter nights (cited in the concrete centre, 2009)

Figure 3-1.5: Role of Heavy thermal mass in the UK Climate during winter days (cited in the concrete centre, 2009)

d) Ventilation and indoor temperature

This part concentrates on the definition, benefits, mechanism and different strategies for the use of natural ventilation. Ventilation has two major roles: providing thermal comfort during summer (cooling effect) and air quality. The impact of natural ventilation on thermal comfort is discussed in this part and its impact on air quality is reviewed later in the following chapter. The requirements of having natural ventilation are discussed in this section.

d1) Definition and roles of natural ventilation:

The definition of natural ventilation is 'the process of supplying and removing air through an indoor space by natural means' (Aynsley et al, 1977).

d2) Mechanism of natural ventilation

Natural ventilation is mainly driven by two mechanisms i.e. wind pressure (wind effect) and the stack effect (BB101, 2006):

- Wind pressure mechanism: in this mechanism, wind causes pressure around the outside of the building. Variations in pressure are highly dependent on the building form and the wind speed and direction. Typically, a positive pressure is experienced on the façade facing the wind and a negative pressure on other façades.
- Stack effect mechanism: Two separate openings in the wall at different heights create pressure difference, when the inside is warmer than outside. This pressure difference causes air to flow in from the lower opening and out of the higher one. When the temperature inside decreases to match the outside temperature, the stack effect reduces. As a counter measure, the open area of the facade should be increased. It should be noted that it is not necessary to have physical 'stack' and 'chimney' to achieve stack effect.

d3) Reasons of natural ventilation

Schools should be designed to be naturally ventilated as it is energy efficient, except the areas where contamination (e.g. changing rooms, etc) or high heat gain might occur (e.g. kitchen), that may require mechanical ventilation [(CIBSE Guide B2, 2005) and (BB87, 2003)]. In addition, recent studies show that in naturally ventilated buildings, occupants adapt themselves to the indoor climate, accepting a wider range of indoor temperatures as comfortable (Roulet, 2005).

The simplest natural ventilation strategy is the window-opening strategy. The benefits of natural ventilation through windows are that it is free of charge and eliminates the running/maintenance and capital costs for cooling and provides fresh air. It also eliminates the noise that would be produced by the plant (BB101, 2006). Other ventilation strategies proposed in BB101 for schools are as follows:

- Single-sided ventilation with high and low-level openings
- Cross ventilation with or with out height difference on two sides
- Stack ventilation
- Multiple classrooms with stack ventilation served by a corridor or atrium
- Split duct roof-mounted ventilation

d4) Specific natural ventilation rates for different purposes

Ventilation rates required for air quality are different from those required for cooling purposes. For example, the minimum ventilation rate for air quality purpose is 3 l/s per person with the capability of 8 l/s per person, while this amount should be greater than 8 l/s per person for cooling purpose in school classrooms (BB101, 2006). As a rule of thumb, it is generally agreed that natural ventilation systems can meet total heat loads averaged over the day, of around 30-40 W/m^2 (i.e. solar plus internal gain). However, the natural ventilation cooling potential depends on prevailing climate and also the occupants' expectations of thermal comfort (CIBSE AM10, 2005).

d5) Natural ventilation and thermal comfort

Summer temperatures play a role on the practicality of natural ventilation to provide cooling effect and maintaining indoor temperature. Its practicality is limited by prevailing climate and the occupants' expectations of thermal comfort. The natural ventilation cooling effect is due to the removal of heat from the building and consequently the human body. The procedures for removing heat from the buildings and human body are explained as follows:

- **Natural ventilation and removal of heat from buildings**: The procedure of removal of heat from buildings depends on the buildings' climate. The strategy which is used to remove heat in hot climate is different to the strategy which is used in moderate climate.

In hot climates, buildings are built with lightweight construction materials with large openings. These openings allow the buildings to have a high level of ventilation rate. In these buildings, the indoor temperature becomes higher than outdoor temperature. The high level of ventilation removes excessive heat from buildings and allows the indoor temperature to decrease and adjust to the outside temperature and provide a comfortable temperature. Also, good solar shading has a role in controlling indoor temperature (Allard et al, 1998).

In moderate climates, such as the UK, excessive heat can be removed from a building by night time cooling. In this strategy, passive cooling solution (nigh time ventilation) is used to reduce the building's structure temperature. For this reason, an exposed structure (thermal mass) should have a direct contact with the solar gain entering the space through an opening to absorb the excessive heat, and also direct contact with night-time ventilation to remove the excessive heat, to provide a comfortable temperature. Night time ventilation can be used in the UK as night time temperatures are often below daytime comfort temperatures (CIBSE, 2005).

- **Natural ventilation and removal of heat from human body:** In summer, thermal comfort for an individual, in a naturally ventilated building, is achieved by removal of heat from the body by air movement. The air movement causes convective heat and mass exchange of the human body with the surrounding air. Higher velocities result in higher skin evaporations and consequently a person experiences the cooling sensation.

In the situation that the building indoor temperature reaches the outdoor temperature which is still high and uncomfortable, the thermal comfort zone can shift to a higher region as a result of natural ventilation, if there is an adequate air movement. However, this has a limitation as the maximum comfortable air movement is 0.8-1 m/s. Any higher air movement could be annoying for an individual and also disturb papers. This speed allows a space to be 2C warmer and still provide optimum comfort with the relative humidity of 60%. In the other words, thermal comfort can be provided at a higher level (Allard et al, 1998).

d6) Natural ventilation potential

Natural ventilation potential is defined as the possibility of providing thermal comfort and air quality by natural means. This depends on the potential of the building and its location, and also the strategies which are adopted. The three potentials for achieving natural ventilation are:

- Building potential for having natural ventilation
- Site potential for having natural ventilation
- Adoption of suitable strategies to provide natural ventilation

• Building potential for having natural ventilation

Each building has a different potential for using natural ventilation. Different factors that have impacts on buildings' potential for using natural ventilation are as follows:

- Form of the building envelope
- Height of the room and building envelope
- Length of the building envelope
- Opening in building envelope

The form of the building envelope: The building envelopes have different impacts on air movement around the building and natural ventilation according to its shape, such as square, linear, U shape, L shape & T shape.

Air movement around buildings may increase the energy consumption within the structure during winter and decrease it in the summer (Boutet, 1988).

Height of room & building envelope: The peak summer temperature can be reduced by increasing the ceiling height. By increasing the ceiling height from 2.5m to 3.5m in a medium thermal mass office, the peak summer temperature can be reduced by 1.5C if glazed areas are kept constant (EnREI programme, 1995). In addition, stack effect (through stairwells and other shafts) can be increased by increasing the height of a multi-story building when the wind flow is weak.

Length of the room and building envelope: For 'single side ventilation', the depth of the room should be between 2 to 2.5 times of the height for an effective ventilation. For cross-ventilation, the depth should be between 2.5 to 5 times the height of the room [(CIBSE AM10, 2005) and (BB101, 2006)].

Opening in building envelope: The orientation, size and style of the windows have significant impacts on the ventilation rate in a building. For instance, ventilation rate can be increased by placing a window on the building edge and perpendicular to the summer winds (impact of window orientation). The opening size should be determined according to the minimum required area for the worse-case summer ventilation scenarios. For single-sided ventilation, the opening area required is approximately 5% of the floor area and for cross ventilation, the opening area required is approximately 2% of the floor area - 1% on each side of the space (impact of window size). In addition, different window types have different ventilation characteristics, acoustic properties and weather protection levels. For example, sash windows are often used in schools because they provide high and low level openings, thereby giving occupants a considerable amount of control. However, only 50% of their area is available for ventilation (CIBSE Guide B2, 2005). Side hung casement windows give a greater open area, but care must be taken to ensure that they do not present a safety hazard when fully open (BB101, 2006). In upper stories, the openings of windows are often restricted to minimise the risk of children falling out of windows (impact of window style).

- **Site potential for having natural ventilation**

Each site according to its characteristics has different potential for providing natural ventilation for the building. It is possible to divide the sites according to their potentials into 3 different groups:

- **High potential sites:** High potential sites refer to the sites that have potentials to increase the natural ventilation by making amendments to the site. Air movements can be redirected in order to provide higher natural ventilation, by designing a suitable landscape around the building. Parallel plants can deflect wind or funnel air into the narrow way created between them, and generate a higher wind velocity. For example, the wind velocity can be increased by up to 25% by decreasing the spaces between trees that redirect the air flow (Allard et al, 1998).
- **Low potential sites:** Low potential site refers to sites that decrease the natural ventilation potential for the building built on according to the site characteristics (Allard et al, 1998 and CIBSE AM10, 2005). In the following, two examples of such sites are discussed:

High terrain sites: Types of terrains that surround a building, have a significant impact on the local wind speed and also the building's potential to have natural ventilation. The local wind speed is reduced if the terrains are congested in comparison to the metrological wind speed, and consequently the building's potential for using natural ventilation is reduced.

Dense sites: A very dense urban area can a have significant impact on local wind speed and consequently have a negative impact on the potential of the building for using natural ventilation. To overcome this loss of ventilation potential, the spaces that need more ventilation should be placed in the highest floor where wind flow is stronger and are not sheltered or obstructed by other buildings.

- **Zero potential sites:** These kind of site due to their characteristic (the barriers exists on these sites), they do not allow the building to benefit from natural ventilation and therefore called zero potential. The barriers include noise, air pollution, safety, shading and drought prevention. Noise and air pollutions are the most important barriers as they can have a significant negative health impact on occupants.

Noise as a barrier: Although natural ventilation systems do not generate noise themselves, but transfer external noise into the buildings (BB101, 2006). For this reason, the estimation of noise level in urban regions (Wilson et al, 2005) and the indoor ambient noise which are produced by the occupants (BB101, 2006) are necessary if the potential for natural ventilation is to be assessed. In European cities, 10 to 20 percent of urban residences experience a noise level of more than 65dB(A) according to Wackernagel et al. (1999 cited Santamouris, 2005, p.15). Unacceptable noise levels affect 10 to 50 percent of urban inhabitants according to Dorbis assessment carried out by European Environment Agency (ibid). In addition, 130 million people are exposed to unacceptable noise levels (Santamouris, 2005) in OECD countries (twenty countries that originally signed the convention of the Organisation for Economic Co-operation and Development on 14th December 1960. For this reason, noise is a barrier for using natural ventilation in many countries. At present, the strategy for acoustic performance of schools agreed by BB93 and Building Regulation, demand a careful focus on the interaction between acoustic performance and ventilation strategy in school buildings. This is because the experience has shown that good natural ventilation strategies have not performed well in practice, as some have a conflict with acoustic comfort since they transmit unwanted sounds (BB101, 2006).

The noise sources are road vehicles, rail & air traffic. These are often counted as barriers for utilising natural ventilation since windows are required to be kept closed to maintain the background noise at the recommended levels and provide acoustic comfort. It is generally accepted that the impact of external noise is attenuated between 8 dB to 14 dB according to the size and extent (degree) of an opening by closing it. Therefore, in a school classroom, the external noise level should not be greater than 49 dB so that the accepted level of 35 dB for background noise can be achieved when windows are closed. [Note: BB101 accepts 54dB as the maximum acceptable external noise (Parkin, 2005)]. Unfortunately, 90% of rural residents and sub-urban school sites in the UK (the sites set back 30m from the main road) experience a high level of background noise as their external noise levels exceed 49dB(A) as shown by research funded by the DfES.

Air pollution as a barrier: Another barrier for utilising natural ventilation is air pollution. The ratio of indoor-outdoor concentration depends on the function of airflow from one side to the other side of facade and also the outdoor concentration (Chiaus et al, 2005). A study shows that outdoor concentration has an impact on indoor concentration even when windows are closed. This impact varies according to the air tightness of buildings. Therefore, utilisation of the natural ventilation in a polluted area significantly causes the outdoor concentration to transfer indoor. Thus, indoor quality becomes more polluted as the indoor environment is another source of pollution itself. Indoor air pollution is a reason for a range of health effects, from discomfort to chronic illnesses. As a result, by sacrificing the use of ventilation in polluted sites, it is possible to reduce indoor pollution and its impact on the occupants.

Other barriers: Other barriers that reduce buildings' potential for using natural ventilation are safety, shading and drought, etc. The impact of these barriers can be reduced by the application of appropriate architectural solutions. Noise and pollutant site issues are out of architectural responsibilities and are mostly dependant on urban design solutions.

- **Safety:** The opening in the building's envelope should be protected against unauthorised intrusions. The unauthorised intrusion can be people, animals (e.g. mice, cats, dogs, birds, etc) and insects (e.g. bugs, mosquitoes, etc) which can enter from naturally ventilated openings in buildings. To overcome this problem, the size of the openings can be reduced, bars can be added and/or insect screens added to the window frame. Although these techniques can protect buildings' envelope from unauthorised intrusions, they also limit and reduce the intensity of natural ventilation and have negative impacts on daylight and visual contact to the outside. Careful design may overcome this problem (Maldonado, 1998).

One of the solutions is to have a window with two separate openings, one allocated to daylight and outside viewing and the other to natural ventilation. The latter should be insulated with a shutter that protects the inside from unauthorised access.

- **Shading:** Blocking direct solar gain to reduce the risk of overheating either by external (overhang, fins, roller shades, etc) or internal shading (curtains, shade, etc) can have a negative impact on air flow. Natural ventilation and shading are coexisting phenomena that require architectural solutions. Lack of architectural concern regarding the interrelation between shading and natural ventilation can result in the shading becoming a barrier for natural ventilation. One of the solutions to overcome this problem is the use of vertical fins or horizontal slab shading, which are fixed shading devices. Although these kinds of shading protect the inside from direct solar gain, they create a larger pressure difference on the building envelope increasing the barrier to natural ventilation. As a result, lack of sufficient design consideration could cause the shading to become a barrier for having natural ventilation (Maldonado, 1998).

- **Draught:** The air exchange rate between the inside and outside of a building depends on the wind speed and temperature difference. Natural ventilation should be provided in a building even in poor conditions (i.e. low wind speeds and small temperature differences) however, the window opening should be large enough to satisfy the building requirements in poor conditions. A careful design should be applied to prevent draughts when the wind speed and temperature difference are high, because the occupants cannot respond to rapid fluctuations of outside conditions and consequently this could cause large air exchange rates. In addition, automatic controls (where used) cannot respond to fast changing outdoor conditions. As a general solution to overcoming this issue, windows with multiple openings could be used that allow the occupant to open them as per their preference i.e. window openings could be used separately. Hence it can be seen that the lack of sufficient design consideration could result in drought and becomes a barrier to having natural ventilation (Maldonado, 1998).

- **Occupants' lack of knowledge:** Openings can be designed in such a way that are suitable for cross ventilation (by increasing the intensity of air exchange rate as a result of increasing the opening area) or single side ventilation (by increasing the stack effect by opening a portion in the lower zone and another in the upper zone). For example, Figure 3-1.6 illustrates a window with different types of openings. The opening A and C create single side ventilation and openings B provide cross ventilation. Therefore, the occupants of such buildings should have primary knowledge of which parts of the windows should be opened or kept closed to maximise the benefit of natural ventilation. Unfortunately, this is not always the case and this leads to the building losing its natural ventilation potential (Maldonado, 1998).

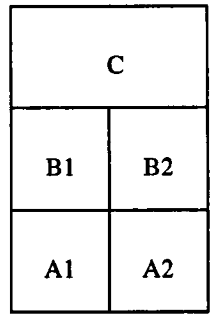


Figure 3-1.6: Diagram of a window with multiple openings that allow
the building to have both cross and single side ventilation (Maldonado, 1998)

- **Rain:** Rain is also is one of the barriers for using natural ventilation as it may enter a building. To prevent the rain from entering a building, openings should be controlled manually (by occupants) or automatically (Maldonado, 1998).

d7) Adoption of suitable strategies to provide natural ventilation

As discussed in this section, there are different strategies for achieving natural ventilation. These strategies can be implemented to provide the opportunity of using natural ventilation for a building which is located in a Zero potential site (e.g. noisy site).

For example, Breathing Buildings Company proposes a natural ventilation system with a 25dB attenuation level which provides the opportunity for natural ventilation in Barnfield South Academy. This building is located under the Luton flight path, immediately adjacent to the M1 motorway, where the chance for having natural ventilation without precaution is limited (Breathing Buildings, 2011).

d8) Summary of the impact of natural ventilation on indoor temperature

It can be concluded that the utilisation of natural ventilation is beneficial and cost effective. It is also more acceptable to the occupants. Possibility of having natural ventilation depends on buildings, sites potential and also the strategy which is applied for having natural ventilation. Therefore, a building's potential to use natural ventilation is not sufficient on its own unless the site has this potential. Selecting a ventilation strategy that is compatible with the building and site is important in order to have the full benefits of natural ventilation. For this reason and in order to naturally ventilate a building, the emphasis should be given to achieve multi-dimensional approach for the building, site and also natural ventilation strategy.

3.2. Analysis: Impact of high level aircraft noise on summer overheating

Overview

The aim of this part of the research is to assess the impact of aircraft noise on summer overheating and compare occupants' dissatisfaction from overheating and the occurrence of overheating in noisy schools with quiet ones. For this reason, the study is carried out both **objectively** and **subjectively**.

3.2.1. Objective study:

The objective study is carried out based on the objective data that are collected. The objective data are indoor temperature, building data which are explained around 'ventilation potential, solar gain and thermal mass' and climate data which are explained around 'outdoor temperature and solar irradiance data'.

The indoor temperature of 70 classrooms from 18 free running primary schools were recorded every half an hour by placing two 'I Buttons' with the accuracy of 0.5 ° C in each classroom. The indoor temperature was recorded for both occupied and unoccupied durations. In UK Primary Schools, children attend school from Monday to Friday between 0900 to 1530 hours. The occupied indoor temperature mentioned in this text refers to the recorded classrooms' temperatures over these durations. In order to assess the impact of aircraft noise on indoor temperature, a study is carried out in the following stages:

3.2.1.1: Compare classrooms indoor temperature on each day with different overheating criteria which are either based on adaptive or fixed models (the result is called classroom-day indoor temperature).

3.2.1.2: Categorise classrooms based on building factors, and duration of study based on climate conditions.

3.2.1.3: Compare those classroom-days indoor temperatures (assessed based on fixed and adaptive model in 3.2.1.1) which have similar building factors and climate conditions, but located in different regions (i.e. noisy and quiet).

3.2.1.1: Compare indoor temperature with different overheating criteria:

In this part of the study, the indoor occupied temperatures for each classroom on each day for the duration of occupied hours, are compared with the fixed and adaptive overheating models to determine the classrooms' risk to experience overheating. The overheating models are mentioned earlier in this chapter. This comparison is carried out for each day. This is because the climate conditions are different for each classroom on each day, therefore each classroom on each day creates a unique scenario. Samples of these data can be found in Appendix.8.

So the following data are provided for each classroom on each day of the study which is defined as 'Classroom-Day' in this research. Each classroom therefore has many Classroom-Days data according to their duration of study.

The results of the study of indoor temperature based on adaptive mode are as follow:

- Percentage of dissatisfaction from overheating for each day (mean and maximum are calculated and coded as Mean.PDH and Max.PDH).
- Maximum allowable deviation from adaptive thermal comfort for each day (coded as PGR.CatII and PGR.CatIII).

  See Appendix 8.2 and Appendix 8.3.

The results of the study of indoor temperature based on fixed model are as follow:

- The percentages of occasions that indoor temperatures exceed 25°C for each day (these data are coded as PGR. 25°C).
- The percentages of occasions that indoor temperatures exceed 28°C for each day (these data are coded as PGR. 28°C).

  See Appendix 8.4.

3.2.1.2. Categorising schools (and consequently their classrooms) based on building factors, and duration of study based on climate condition:

According to CIBSE TM37 (2006), overheating can be controlled by building factors against climate conditions. For this reason, to study the impact of high levels of aircraft noise on indoor temperature, comparisons are carried out between the indoor temperatures (which that are already assessed based on different overheating criteria) in classrooms with similar properties (i.e. thermal mass, solar gain potential) and climate conditions (i.e. on days which have similar solar irradiance and outside temperature) [but located in noisy areas with those classrooms located in quiet areas].

In order to have similar building properties (i.e. thermal mass, solar gain potential) with the same climate conditions (i.e. on days which have similar solar irradiance and outside temperature), the categorisation should be carried out as follow:

- **Firstly**: Classrooms should be categorised based on building factors which are schools' ventilation potential, classrooms' thermal mass level and risk of receiving solar gain.
- **Secondly**: Duration of study should be categorised based on daily solar irradiance and cooling degree hours.

a) Categorising schools (and consequently their classrooms) based on building factors:

As it was mentioned earlier in the literature review, according to CIBSE TM37 (2006), the principles of overheating control are: the control of solar gain, internal gain, thermal mass, ventilation and design factors.

In this section:

- Firstly the schools are categorised based on their locations which may have impacts on their ventilation potential. The term of ventilation potential is used as there are some barriers such as noise to use natural ventilation in naturally ventilated buildings.
- Secondly, the schools are categorised based on their thermal mass level. The schools under study are from a broad construction time range (i.e. Victorian to modern) with different build specifications.
- Thirdly, classrooms are categorised based on their risk of receiving solar gain.
- Fourthly, internal gains inside classroom are studied.

a1) Categorising schools (and consequently their classrooms) based on background noise level:

According to the comprehensive study carried out in the literature review, it is suggested that the high level of background noise in regions within a close distance to airports may be a predominant obstacle for having natural ventilation. The validity of this is studied in this chapter.

There are 5 different airports in and around London. Heathrow Airport is the largest airport with the highest volume of traffic among them (Figure 3-2.1).

Figure 3-2.1: Airports location around London

The schools chosen for this study are simply categorised as noisy or quiet schools. Noisy schools are defined as those lying in the Heathrow noise map of above 57dBA and Quiet schools are defined as those lying outside the noise map. The benchmark of 57dBA is under constant review (Peters et al, 2011). Aircraft noise contours are shown in Figure 3-2.4. The lowest level contour provided on noise maps for Heathrow is 57 dBA and regarded as the limit to the noise impact of the airport because the percentage of people who found aircraft noise to be unacceptable, increases from 15% at 57 dBA to around 57% at 69 dB based on the Aircraft Noise Index Study (ANIS) in 1984 (ibid). The classrooms of noisy schools are identified as 'noisy classrooms' and the classrooms of quiet schools are identified as 'quiet classrooms'.

The hypothesis of this study is that the schools which are at a further distance from Heathrow Airport (located on the noise contour below 57 dBA) do have the potential for having natural ventilation, such as the ones located in Haringey and Islington, while the schools that are located in Hounslow borough which are located in the vicinity of Heathrow airport (located on the noise contour above 57 dBA) do not have such potential.

It should be noted that in this study the schools were chosen in such a way so as to be at a considerable distance from main roads and construction sites. For this reason, the ones located within a close distance to Heathrow Airport (above 57 dBA) only suffer from aircraft noise and those located at a far distance to Heathrow Airport (below 57 dBA) do not suffer from any kinds of environmental noises.

Figure 3-2.2: Heathrow airport location in relation to Hounslow, Haringey & Islington Boroughs

Figure 3-2.3 illustrates the noise contours around Heathrow Airport. As can be seen, the level of aircraft noise is high around the airport.

Figure 3-2.3: Noise contours map on Hounslow borough

Figure 3-2.4 shows the locations of schools in Hounslow Borough when overlapped with the Noise Contour map. As can be seen, not all the schools located in this borough suffer from a high level of aircraft noise.

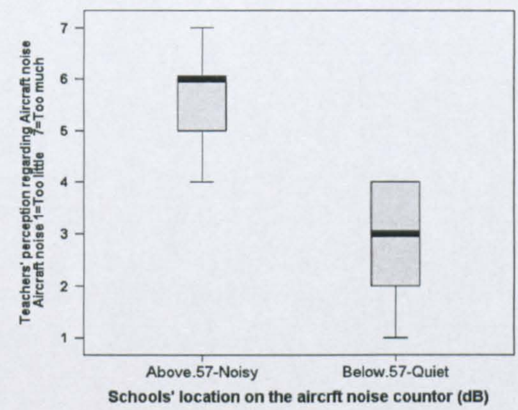
Figure 3-2.4: Noise contours map & schools' locations

In addition, the noise level of all schools in this study are summarised in Table 3-2.1.

Schools	Cranford	Grove Rd	STM&M	Orchard	Wellington	Andrew Ewing	Rosary	Heston	Hounslow	Feltham	Pools	Ambler	Norwood	Lady	Hungerford	Colerain	St Gildas	Green Church
Aircraft noise level LAeq	66	63	63	63	60	60	57	57	57	<57								
Schools' region	Noisy									Quiet								

Table 3-2.1: Aircraft noise level in each school (using data derived from Figure 3-2.4)

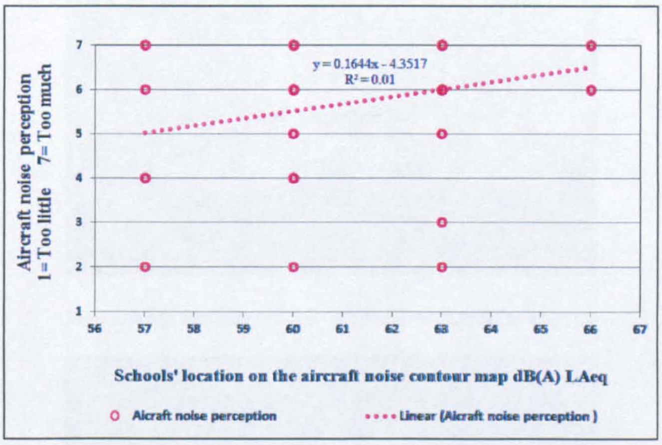
In the questionnaires, the teachers were asked to rate the aircraft noise which is heard inside classrooms from one to seven. Graph 3-2.1shows the average of teachers' perceptions regarding aircraft noise based on the schools locations on the aircraft noise contour (above 57: Noisy, below 57: Quiet).



Graph 3-2.1: Teachers' perceptions re aircraft noise vs. schools' locations on the noise counter

Graph 3-2.2 shows the average of teachers' perceptions regarding aircraft noise inside the classrooms versus the schools' locations on the noise counter map (above and below 57dBA noise contour map). As can be seen, teachers of the schools located on the noise counter of above 57 dBA rated a higher level of aircraft noise inside the classrooms and vice versa.

In order to have a better understanding of how the aircraft noise is heard inside classrooms and its relationship with schools' locations on the noise counter map, the teachers' perceptions on aircraft noise are compared with the schools' locations on the noise counter map of above 57 dBA through regression analysis (Appendix 10.3) . The result of this comparison shows a significant relationship between them (n=59, p<0.05 and r=0.316) which is shown in the following graph (Graph 3-2.1). As can be seen from this graph, teachers' perception on aircraft noise is higher in schools' located on the higher aircraft noise counters and vice versa.



Graph 3-2.2: The relation between schools' location on aircraft noise contour map with aircraft noise perceptions

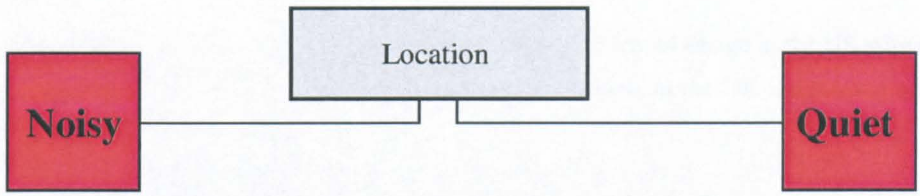
Figure 3-2.5: Close distance of Heathrow Airport to a school

Figure 3-2.6: Medium distance of Heathrow Airport to a school

Figure 3-2.7: Medium distance of Heathrow Airport to a school

Figure 3-2.5, Figure 3-2.6 and Figure 3-2.7 show the variable distances between the flight path and schools, which is the reason that the occupants in these schools suffer from variable levels of aircraft noise.

According to the above explanation, schools are divided into two groups of Noisy schools and Quiet schools according to their locations on the noise contour map (Graph 3-2.3) .



Graph 3-2.3: Schools' breakdown according to their locations

a2) Categorising schools (and consequently their classrooms) based on their thermal mass level:

According to the comprehensive study regarding the history of school design in the UK which was carried out in Chapter Two, it can be concluded that the schools in the UK are divided into the following types:

1- Victorian schools
2- Open air schools
3- Post war schools
4- Post oil crisis school
5- PCP and BSF school

In this part of study, classrooms are categorised based on their thermal mass level which are heavy, medium and low. The properties of a low thermal mass building is in such a way that it heats up and cools down quickly unlike a heavy thermal mass building, which stores heath during day time and releases over night, hence less thermal fluctuation. A medium thermal mass is in between. Each classroom has 6 surfaces which are external wall (s), internal wall(s), ceiling and floor. In order to categorise classrooms based on their thermal mass, all surfaces should be studied. On each surface firstly, construction material and secondly, percentage of each material should be considered. All classrooms are mainly covered with carpet therefore the study of the floors can be discounted. In the following pages, it is explained how the schools are categorised in a specific thermal mass category (i.e. low, medium and heavy).

- **Heavy thermal mass school:**

The Victorian schools were built before 1920. The following figures (3-2.8 and 3-2.9) show the internal and external wall of one of the Victorian schools under study (Hungerford primary school). As can be seen, internal and external surfaces are constructed with exposed brick works.

Figure 3-2.8: Internal wall – exposed brick work (heavy thermal mass)

Figure 3-2.9: External wall – exposed brick work (heavy thermal mass)

Generally in these schools, internal & external walls are solid built either with bricks or blocks which are internally and externally exposed, both load bearing. Ceilings are built of timber frame covered with plaster boards which are classed as low thermal mass materials.

In these schools, 4 out or 5 surfaces (floors are discounted) contain heavy thermal mass material (nearly 80%). For this reason, it is possible to categorise Victorian schools as heavy thermal mass. Table 3-2.2 shows the summary of thermal mass levels for different surfaces in Victorian schools.

Victorian		
Schools	Thermal mass surfaces	Result
Ambler	**Heavy** external wall (s) **Heavy** internal wall (s) **Low** ceiling	**Heavy** Thermal mass
Coleraine	**Heavy** external wall (s) **Heavy** internal wall (s) **Low** ceiling	**Heavy** Thermal mass
Feltham	**Heavy** external wall (s) **Heavy** internal wall (s) **Low** ceiling	**Heavy** Thermal mass
Hunger ford	**Heavy** external wall (s) **Heavy** internal wall (s) **Low** ceiling	**Heavy** Thermal mass
Heavy thermal mass schools		

Table 3-2.2: Thermal mass level in each Victorian school

- **Low thermal mass schools**

Open air schools were built in early 1920s following concerns over the spread of tuberculosis and Post war schools were built as a result of baby booms and shortage of school. In this duration, instead of solid walls, buildings were built with cavity walls without insulation.

- **Open air schools**

As a solution to overcome tuberculosis, these schools were built with large areas of glass windows installed on two sides to allow cross ventilation. In other words, these classrooms have two glass external walls and two solid internal walls. The main characteristic of these schools is that they have a row of classrooms with windows on both sides. Due to the environmental improvements made to this types of schools at a later stage, the classrooms were covered with a glass corridor on one side (Figure 3-2.10).

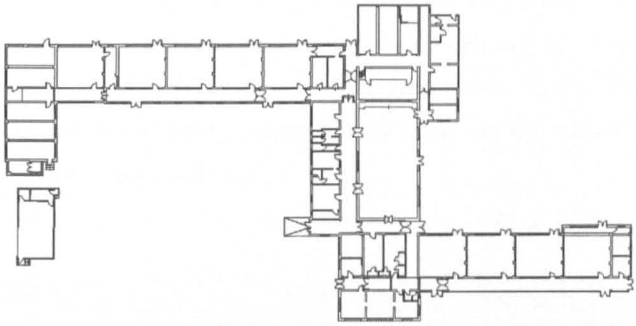


Figure 3-2.10: Cranford Junior School (Open air school)

Figure 3-2.11 shows the corridor side view (right image) and play ground (adjacent to the corridor, left image) in an open air school.

Figure 3-2.11: Corridor and play ground view in an open air school

Figure 3-2.12 (left) shows the outside view from a classroom and Figure 3-2.12 (right) shows the view from classroom to the corridor in an open air school.

Figure 3-2.12: Internal wall (left) / External wall (right) made of glass - low thermal mass

Due to a large portion of glass in the external and internal wall adjacent to the corridor, these walls are classed as low thermal mass.

At these schools, the dividing walls are brickwork covered with plaster board which reduces the capability of storing heat, hence makes these walls to be classed as medium thermal mass. Ceilings are constructed of light-weight pitched roofs (low thermal mass). As a result, 3 out of 5 surfaces (nearly 60%) are low and the rest are medium thermal mass. For this reason, these schools can be categorised as low thermal mass buildings.

- **Post war schools**

Post war schools can be discussed around two groups of schools. Group one are light-weight schools and group two are those built with prefabricated materials.

Group 1: Light weight school

These schools are mainly one story buildings built with light frames (steel/timber) and their internal spaces are divided with plaster board which is low thermal mass. Ceilings are also constructed with light material.

Figure 3-2.13, 14 and 15 show the external walls, ceiling and internal walls of such schools. As can be seen from Figure 3-2.13, the external is a curtain wall which is categorised as a low thermal mass material. As can be seen from Figure 3-2.14, ceilings are of a corrugated type ceiling which is again a low thermal mass material. The internal walls are made of plaster board which is also categorised as a low thermal mass material (Figure 3-2.15).

Figure 3-2.13: External wall – Curtain wall (Low thermal mass)

Figure 3-2.14: Ceiling – Corrugated ceiling covered with suspended plaster-board ceiling (low thermal mass)

Figure 3-2.15: Internal wall – plaster board (low thermal mass)

Figure 3-2.16 shows another type of post war light-weight school. This school has been constructed with portal frames. Ceilings are covered with corrugated metal sheets and therefore considered as low thermal mass surfaces. Externals are cavity walls without insulation which are considered as medium thermal mass surfaces (Figure 3-2.16). Internal walls are constructed with plaster board which are considered as low thermal mass.

Figure 3-2.16:

Ceiling – Portal frame (low thermal mass)

Figure 3-2.17:

External wall – Cavity wall without insulation (low thermal mass)

As a result, in these schools, nearly 4 out of 5 surfaces (nearly 80%) and in some schools 5 out of 5 surfaces (nearly 100%) are of low thermal mass materials. For this reason, they can be categorised as light weight schools which are low thermal mass.

Group2: Prefabricated schools

Pre fabricated schools are also an outcome of post war and shortage of schools. Prefabricated classrooms which are famous as mobile classrooms are constructed with low thermal mass materials. These schools have timber frames covered with timber sheets which have a low thermal capability. Figure 3-2.18 shows samples of these classrooms.

Figure 3-2.18: Prefabricated classrooms (low thermal mass)

In these schools, 5 out of 5 surfaces (nearly 100%) have a low thermal mass material. For this reason, they can be categorised as low thermal mass schools.

In summary, Post War schools that are grouped into 'light weight' and 'prefabricated' schools are considered as low thermal mass schools.

The following table (Table 3-2.3) shows the summary of the level of thermal mass in different surfaces in open air and post war schools.

Open air			Post war			
Schools	Thermal mass surfaces	Result	Schools		Thermal mass surfaces	Result
Cranford	Low-Medium external wall (s) Low-Medium internal wall(s) Low ceiling	Low Thermal mass	Light weight	Hounslow	Low-Medium external wall (s) Low internal wall (s) Low ceiling	Low Thermal mass
Heston	Low-Medium external wall (s) Low-Medium internal wall(s) Low ceiling	Low Thermal mass	Light weight	Norwood Green	Low-Meduim external wall (s) Low internal wall (s) Low ceiling	Low Thermal mass
Wellington	Medium external wall (s) Low-Medium internal wall(s) Low ceiling	Low Thermal mass	Light weight	Rosary	Low-Meduim external wall (s) Low internal wall (s) Low ceiling	Low Thermal mass
			Prefabricated	Heston mobile	Low external wall (s) Low internal wall (s) Low ceiling	Low Thermal mass
			Prefabricated	Orchard mobile	Low external wall (s) Low internal wall (s) Low ceiling	Low Thermal mass
Low thermal mass schools						

Table 3-2.3: Thermal mass level in Open air and Post war primary schools

- **Medium thermal mass school**

Energy efficient schools (Post oil crisis schools) were constructed after oil crisis in 1970s. In this duration, there was a great concern regarding insulation and meeting suitable level of U value. Insulation was applied to cavity walls which were usually without insulation. Lofts and roofs were covered with suitable amount of insulation. Internal walls were constructed as load bearing walls with exposed brick which can be considered as a heavy thermal mass material. The internal walls were usually covered with either plaster or notice boards which are considered as medium thermal mass material.

Figure 3-2.19 shows an internal surface constructed with brick and covered with notice boards. Brick usually has heavy thermal properties, however in these schools, this capability reduces due to the high percentage of walls' area being covered with notice boards. This leads to them being classed as medium thermal mass classrooms.

Figure 3-2.19: Internal wall in Pools Park Primary school (an energy efficient school)

Figure 3-2.20 shows an internal view of a Victorian school. As can be seen from this figure, although a part of the surface is covered with student works, a large area of the wall is out of the reach of students and teachers (due to high ceilings) and therefore brick surfaces remain exposed. This is why they are considered as heavy thermal mass.

Figure 3-2.20: Internal wall in Ambler Primary school (a Victorian school)

Although post oil crisis schools have a lower level of thermal mass in comparison with Victorian schools to control the high level of indoor temperature (as a result of solar gain during cooling seasons), external walls and ceilings have a higher resistant (lower U value) to control high indoor temperature (as a result of high outside temperature).

- **The difference between external walls in Post Oil Crisis and Post War schools**

External walls in Post Oil crisis schools have a higher resistance (due to insulation in cavity wall) than external walls in Post War schools, therefore provide better environmental conditions. In Post Oil Crisis schools, the level of heat transfer from outside to inside is lower due to the lower U value.

Figure 3-2.21 & 22 show the plan and view of Hounslow Town primary school as a Post War school. Figure 3-2.23 & 24 show the plan / overview of Andrew Ewing as a Post Oil Crisis school. As it can be seen in both schools, most of the classrooms' surfaces are allocated to external rather than classrooms' internal walls. Hounslow Town heat up very quickly not only due to the low level of thermal mass (that do not have capability to store excessive solar gain) but also due to heat transferring very quickly to the inside (due to the lack of insulation in cavity wall) in comparison with Andrew Ewing.

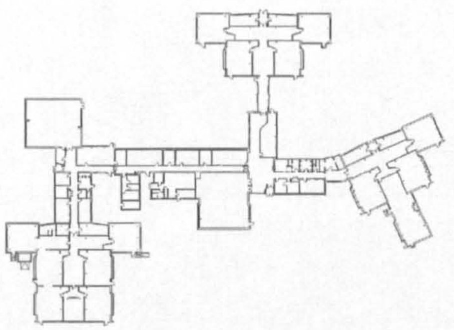


Figure 3-2.21: Plan of Hounslow Town primary school (left)

Figure 3-2.22: Overview of Hounslow Town primary school (right)

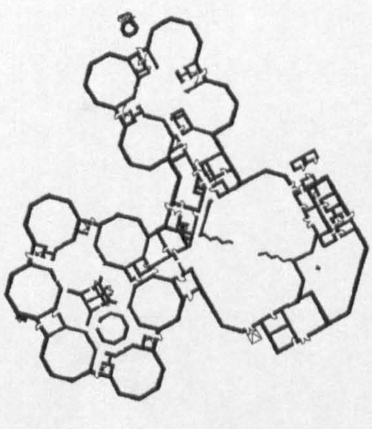


Figure 3-2.23: Ground floor plan of Andrew Ewing primary school (left)

Figure 3-2.24: Overview of Andrew Ewing primary school (right)

- The difference between ceilings in Post Oil Crisis, Victorian and Post War schools

Ceiling in Post Oil Crisis schools have a higher resistance than ceilings in the Victorians and Post War schools, therefore provide better environmental conditions by stopping heat transfer from outside to inside. The reasons are explained as follows:

Ceiling in Victorian schools were constructed with timber frame covered with plaster boards. They were constructed with light-weight materials in Post War and with insulated concrete slabs in Post Oil Crisis. None of these ceilings have the ability to store heat generated by direct solar gain (through windows). Among these ceilings, Post Oil Crisis ceilings have the highest resistance (lowest U value) and therefore have a higher ability to stop heat to transfer to the inside space. This is the case for classrooms which are located on the top floor.

The following table (Table 3-2.4) shows the summary of the level of thermal mass in Post Oil Crisis schools.

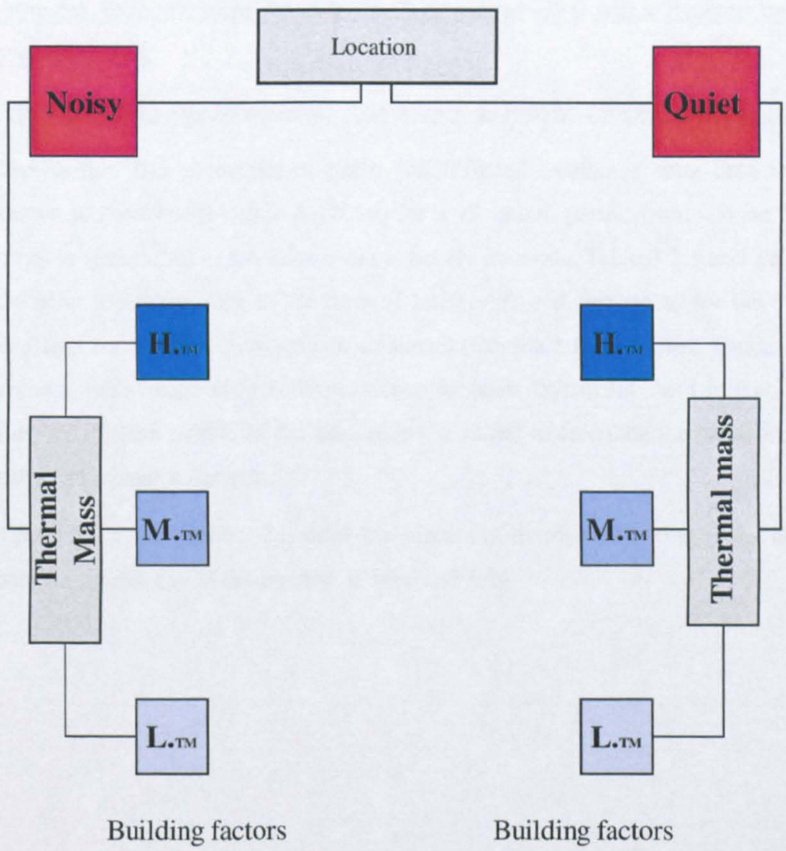
Energy crisis school		
Schools	**Thermal mass surfaces**	**Result**
Andrew Ewing	Medium external wall (s) Medium internal wall (s) Medium ceiling	Medium Thermal mass
Green Church	Medium external wall (s) Medium internal wall (s) Medium ceiling	Medium Thermal mass
Grove Road	Medium external wall (s) Medium internal wall (s) Medium ceiling	Medium Thermal mass
Our Lady	Medium external wall (s) Medium internal wall (s) Medium ceiling	Medium Thermal mass
Pools Park	Medium external wall (s) Medium internal wall (s) Medium ceiling	Medium Thermal mass
St Gildas	Medium external wall (s) Medium internal wall (s) Medium ceiling	Medium Thermal mass
St M & M	Medium external wall (s) Medium internal wall (s) Medium ceiling	Medium Thermal mass
Medium thermal mass schools		

Table 3-2.4: Thermal mass level in energy efficient schools under study

In the following flowchart (Graph 3-2.4), noisy and quiet classrooms are categorised based on their thermal mass level.

It is not possible to study all the categories, as heavy and low thermal mass schools (built over two periods of 'Victorian' and 'Post-world war-II' respectively) have not evenly been constructed (in noisy & quiet regions) in London boroughs. For example no heavy thermal mass schools have been constructed in a noisy area such as Hounslow or there is only one low thermal mass school in quiet areas. Therefore, the impact of high level of aircraft noise in schools with medium thermal mass are studied as there are a considerable number of them evenly constructed in noisy and quiet regions. Therefore up to this stage, there are 2 available series of classrooms as follows:

1- Noisy, medium thermal mass
2- Quiet, medium thermal mass



Graph 3-2.4: Schools' break down according to their location and level of thermal mass

a3) Categorise classrooms based on maximum risk of receiving solar gain:

As mentioned earlier, one of the overheating control principles is to control solar gain. The amount of solar gain that each classroom receives is different on each day as the climate conditions (solar irradiation, sky type etc.) vary depending on the day.

On a clear day, classrooms could receive maximum solar gain. In order to calculate the maximum risk of receiving solar gain for each classroom during the duration of the study (June & July), the 'CIBSE design 97.5 percentile for a clear day in June and July' is used (Appendix 3).

The maximum risk of receiving solar gain by each classroom is calculated by multiplying four factors which are the window area, Perimeter area, average daily solar irradiance for a peak day in June and July on vertical surfaces & shading coefficient. The impact of overshadowing is considered in the effect of solar irradiance.

- **Window area:** is measured in individual classrooms with a simple measuring tape.
- **Perimeter zone:** is measured in each single classroom from schools' construction drawings. Perimeter zone refers to the floor area which is within 6 meters on the plan from a window wall.
- **Average daily solar irradiance:** is calculated as follows for each orientation.

  The design 97.5 percentile of beam and diffused irradiance solar data for London are shown in the CIBSE Guide A (2006) for a 12 month period from sunrise (3:30 am solar time) to sunset (20:30 pm solar time) at hourly intervals. Table 3-2.5 and Table 3-2.6 show the solar irradiance data in the form of beam, diffused and global for the months of June and July for London from sunrise to sunset (extracted from CIBSE Guide A). In the last column, the average daily solar irradiance for peak days in June and July are calculated for each orientation as one of the parameters required to calculate the classroom's maximum risk of receiving solar gain.

  Tables 3-2.5 and Table 3-2.6 show the amount of hourly and average solar daily irradiance data for a peak day in the months of June and July.

June																				
Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average W/m² June
		Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																		
N	Beam	40	100	132	85	0	0	0	0	0	0	0	0	0	0	82	133	100	40	
	Diffuse	25	55	76	85	111	117	125	134	139	140	135	127	121	114	85	77	58	25	
	Globe	**65**	**155**	**208**	**170**	**111**	**117**	**125**	**134**	**139**	**140**	**135**	**127**	**121**	**114**	**167**	**210**	**158**	**65**	**137**
NE	Beam	64	185	342	417	397	285	134	0	0	0	0	0	0	0	0	0	0	0	
	Diffuse	32	72	124	157	158	150	134	158	139	140	135	127	113	94	69	42	21	9	
	Globe	**96**	**257**	**466**	**574**	**555**	**435**	**268**	**158**	**139**	**140**	**135**	**127**	**113**	**94**	**69**	**42**	**21**	**9**	**205**
E	Beam	50	162	352	504	579	544	445	290	100	0	0	0	0	0	0	0	0	0	
	Diffuse	27	66	126	175	189	189	180	163	140	149	135	127	113	94	69	42	20	8	
	Globe	**77**	**228**	**478**	**679**	**768**	**733**	**625**	**453**	**240**	**149**	**135**	**127**	**113**	**94**	**69**	**42**	**20**	**8**	**280**
SE	Beam	7	44	155	296	422	484	496	447	345	204	36	0	0	0	0	0	0	0	
	Diffuse	21	50	82	133	163	180	187	183	173	157	123	134	113	94	69	42	20	8	
	Globe	**28**	**94**	**237**	**429**	**585**	**664**	**683**	**630**	**518**	**361**	**159**	**134**	**113**	**94**	**69**	**42**	**20**	**8**	**270**
S	Beam	0	0	0	0	18	141	256	342	387	389	335	247	133	17	0	0	0	0	
	Diffuse	8	18	41	77	83	125	154	170	179	180	172	158	130	87	77	42	20	8	
	Globe	**8**	**18**	**41**	**77**	**101**	**266**	**410**	**512**	**566**	**569**	**507**	**405**	**263**	**104**	**77**	**42**	**20**	**8**	**222**
SW	Beam	0	0	0	0	0	0	0	37	203	346	438	479	457	395	284	157	44	7	
	Diffuse	8	18	41	69	91	110	132	122	156	175	185	193	188	169	133	83	52	21	
	Globe	**8**	**18**	**41**	**69**	**91**	**110**	**132**	**159**	**359**	**521**	**623**	**672**	**645**	**564**	**417**	**240**	**96**	**28**	**266**
W	Beam	0	0	0	0	0	0	0	0	0	101	284	431	513	542	483	355	163	51	
	Diffuse	8	18	41	69	91	110	125	134	148	140	165	185	197	196	175	128	69	27	
	Globe	**8**	**18**	**41**	**69**	**91**	**110**	**125**	**134**	**148**	**241**	**449**	**616**	**710**	**738**	**658**	**483**	**232**	**78**	**275**
NW	Beam	0	0	0	0	0	0	0	0	0	0	0	130	269	371	399	345	186	65	
	Diffuse	9	19	41	69	91	110	125	134	139	140	159	138	156	164	157	126	75	32	
	Globe	**9**	**19**	**41**	**69**	**91**	**110**	**125**	**134**	**139**	**140**	**159**	**268**	**425**	**535**	**556**	**471**	**261**	**97**	**203**

Table 3-2.5: Hourly and average daily solar irradiance data for a peak day in June from sunrise to sunset

(Derived from CIBSE, 2006 - Appendix 3)

July																				
Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average W/m² July
		Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																		
N	Beam	35	88	122	75	0	0	0	0	0	0	0	0	0	0	74	121	87	35	
	Diffuse	20	47	64	73	103	110	121	133	140	141	132	123	113	102	78	62	43	18	
	Globe	**55**	**135**	**186**	**148**	**103**	**110**	**121**	**133**	**140**	**141**	**132**	**123**	**113**	**102**	**152**	**183**	**130**	**53**	**126**
NE	Beam	57	165	320	379	353	260	119	0	0	0	0	0	0	0	0	0	0	0	
	Diffuse	25	61	103	132	146	143	132	156	140	141	132	123	107	85	64	35	15	6	
	Globe	**82**	**226**	**423**	**511**	**499**	**403**	**251**	**156**	**140**	**141**	**132**	**123**	**107**	**85**	**64**	**35**	**15**	**6**	**189**
E	Beam	45	145	331	461	519	502	409	265	90	0	0	0	0	0	0	0	0	0	
	Diffuse	22	57	106	147	174	179	176	166	144	150	132	123	107	85	64	35	14	5	
	Globe	**67**	**202**	**437**	**608**	**693**	**681**	**585**	**431**	**234**	**150**	**132**	**123**	**107**	**85**	**64**	**35**	**14**	**5**	**259**
SE	Beam	7	40	148	273	381	450	459	412	315	190	37	0	0	0	0	0	0	0	
	Diffuse	16	43	69	113	151	171	183	186	179	162	124	131	107	85	64	35	14	5	
	Globe	**23**	**83**	**217**	**386**	**532**	**621**	**642**	**598**	**494**	**352**	**161**	**131**	**107**	**85**	**64**	**35**	**14**	**5**	**253**
S	Beam	0	0	0	0	20	135	240	318	355	361	317	236	132	20	0	0	0	0	
	Diffuse	6	16	35	67	81	121	152	173	185	186	172	156	124	80	71	35	14	5	
	Globe	**6**	**16**	**35**	**67**	**101**	**256**	**392**	**491**	**540**	**547**	**489**	**392**	**256**	**100**	**71**	**35**	**14**	**5**	**212**
SW	Beam	0	0	0	0	0	0	0	37	187	320	411	451	440	385	272	147	40	7	
	Diffuse	6	16	35	60	85	104	129	124	161	180	185	188	176	150	121	67	39	15	
	Globe	**6**	**16**	**35**	**60**	**85**	**104**	**129**	**161**	**348**	**500**	**596**	**639**	**616**	**535**	**393**	**214**	**79**	**22**	**252**
W	Beam	0	0	0	0	0	0	0	0	0	92	264	402	491	524	459	329	144	45	
	Diffuse	6	16	35	60	85	104	121	133	149	144	165	181	184	173	157	102	52	20	
	Globe	**6**	**16**	**35**	**60**	**85**	**104**	**121**	**133**	**149**	**236**	**429**	**583**	**675**	**697**	**616**	**431**	**196**	**65**	**258**
NW	Beam	0	0	0	0	0	0	0	0	0	0	0	117	254	357	377	318	164	57	
	Diffuse	6	17	35	60	85	104	121	133	140	141	155	135	147	145	141	100	56	23	
	Globe	**6**	**17**	**35**	**60**	**85**	**104**	**121**	**133**	**140**	**141**	**155**	**252**	**401**	**502**	**518**	**418**	**220**	**80**	**188**

Table 3-2.6: Hourly and average daily solar irradiance data for a peak day in July from sunrise to sunset

(Derived from CIBSE, 2006- Appendix 3)

Table 3-2.7 summarises the results of the above tables and shows the average daily solar irradiance (W/m^2) for a peak day in the months of June and July which are received at each orientation from sunrise to sunset.

Orientation	Average W/m^2 June	Average W/m^2 July	Average W/m^2 June and July
N	137	126	132
NE	205	189	197
E	280	259	270
SE	270	253	262
S	222	212	217
SW	266	252	259
W	275	258	267
NW	203	188	196

Table 3-2.7: Average solar daily irradiance for a peak day in the months of Jun and July in each direction

- **Shading:** The amount of shading are studied under two categories of building shading devices and overshadowing.

The amount of solar gain that penetrates into the classroom can be reduced by building shading devices and overshadowing by other buildings or trees.

i. Building shading devices:

The building shading devices are divided in to temporary or permanent shading.

a) Permanent shading:

- Solar film reduces the amount of solar radiation that penetrates into a classroom depending on its specification. One of the schools used for this study (Feltham Junior School) is equipped with solar film.
- Overhang blocks the solar penetration depending on its position and surface area. Some classrooms under study (Grove Road Primary School) are equipped with overhangs. The fraction of solar gain which is blocked according to the dimensions of the window and the overhang in each direction are shown in Appendix.5.

b) Temporary shading:

The impact of temporary shading is determined by the type of the blinds used in classrooms and also the duration that the blinds are shut. This information has been collated through questionnaires. The impact of temporary shading is very small and negligible for the purpose of this study.

ii. Overshadow

The formula [Qsl = (1/Ap) ∑ (Ag Qs geff)] proposed by CIBSE TM37 under the name of 'Design for Improved Solar Shading Control' does not consider the impact of overshadowing effect and only considers solar shading. In the case that a building (a classroom in this study) is overshadowed by other buildings or trees, the solar irradiance can be masked completely (by other buildings or part of the main building) or partially by trees which are constructed or planted near the building respectively. British Standard (BS no. 8206-Lighting for Building) presents a method of drawing the probability of sunshine diagram in order to calculate how the buildings and trees are masking solar irradiance.

a) Overshadowing by building: If solar irradiance is masked by other buildings or part of the main building itself, the amount of solar irradiance over the overshadowed period is considered zero.

b) Overshadowing by tree: Trees transfer different amount of solar irradiance according to their density.

Table 3-2.8 shows the types of the trees creating shading on the classrooms referred to in this study. The types of trees in this study are recognised with the help of a specialist. The shading coefficients of some of the trees are not available in the reference (Table 3-2.1). Therefore, using the Table 3-2.1, the specialist helped the author to make educated estimates for coefficients of the trees for which no data are available.

The following table shows the images, names and shading coefficients of the tress that are available in this study. As can be seen, the percentages of transmission for all the trees in this study are around 15%.

School name	Tree image	Tree's name 1.Botanical name 2. Common name	Percentage of transmission during summer
Hounslow		1.Elaeagnus angustifolia 2. Russian Olive	13
Wellington		1.Fagus sylvatica 2.European Beech	12
Heston		1. Quercus palustris 2. Pine oak	15
Norwood		1. Betula pendula 2. European Birch	15

Norwood		1. Crataegus laevigate 2. English Hawthron	14
Hungerford		1. Tilia cordata 2. Littleleaf Linden	17
St Gilda's		1. Populud tremuloides 2. Quaking Aspen	20
Green-church		1. Acer platanoides 2. Norway Maple	14

Table 3-2.8: The types of the trees creating shading on the classrooms referred to in this study, with their name, shading coefficient and images

In this study, some of the classroom windows are blocked with varying types of trees. These trees on an average block 85% of the irradiance. Therefore, a coefficient of 0.15 is considered to reflect the irradiance reaching the windows through the obscuring trees. For this reason, the solar irradiance over the times that the building is overshadowed by trees is multiplied by 0.15.

The following 3 scenarios show the method of calculating the maximum risk of receiving solar gain for a classroom which faces the south direction taking into consideration the impact of overshadowing on solar irradiance.

- Scenario 1: Figure 3-2.25 shows the plan, elevation, section and sunlight probability of a classroom which faces the south and is not overshadowed by any trees or buildings.

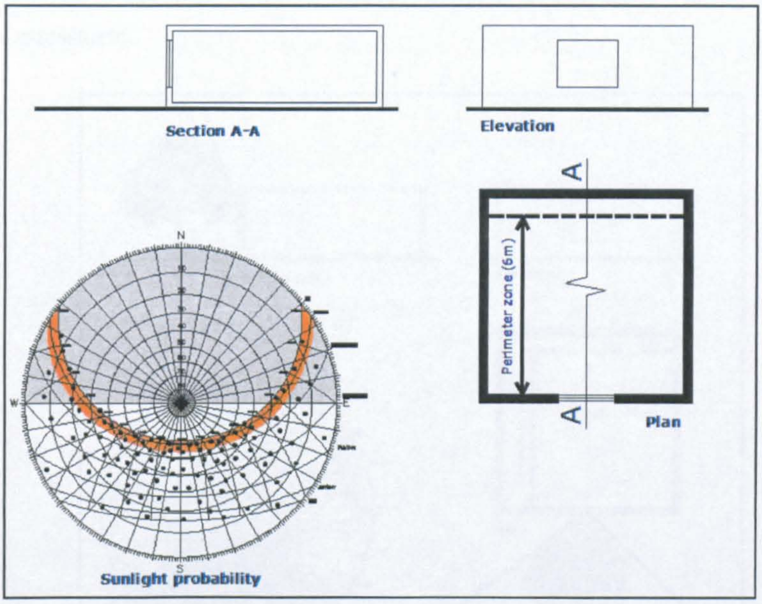


Figure 3-2.25: Plan, elevation and section of a classroom which faces the south and is not overshadowed by any tree or building.

Table 3-2.9 shows the hourly and daily average of solar irradiance from the south direction in the months of June and July, for a classroom that has a window facing the south direction. As can be seen, this classroom is not overshadowed by any buildings or trees, so the daily average solar irradiance for the months of June and July is 217 W/m² (average of 222 & 212).

June																				
Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) June
		Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																		
S	Beam	0	0	0	0	18	141	256	342	387	389	335	247	133	17	0	0	0	0	
	Diffuse	8	18	41	77	83	125	154	170	179	180	172	158	130	87	77	42	20	8	
	Globe	8	18	41	77	101	266	410	512	566	569	507	405	263	104	77	42	20	8	222
July																				
Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July
		Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																		
S	Beam	0	0	0	0	20	135	240	318	355	361	317	236	132	20	0	0	0	0	
	Diffuse	6	16	35	67	81	121	152	173	185	186	172	156	124	80	71	35	14	5	
	Globe	6	16	35	67	101	256	392	491	540	547	489	392	256	100	71	35	14	5	212
Solar irradiance on South direction when ther is not any obstruction = [(222+212)/2]=217 (W/m²)																				

Table 3-2.9: Hourly and daily average of solar irradiance from south direction in the months of June and July for south direction

• Scenario 2: Figure 3-2.26 shows the plan, elevation, section and sunlight probability of a classroom which faces the south and is overshadowed by a tree. The original shapes of trees vary based on the type of the tree. However, they are considered as being cubic for ease in sunlight probability assessment.

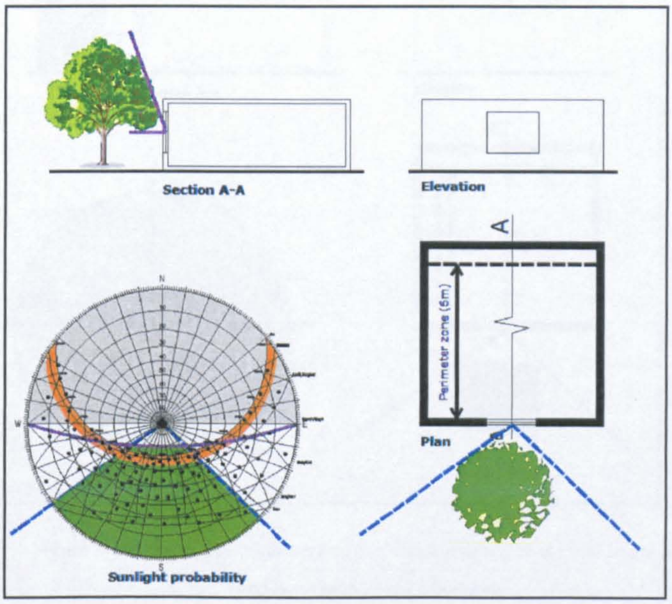


Figure 3-2.26: Plan, elevation and section of a classroom which faces the south and is overshadowed by a tree

Table 3-2.10 shows the hourly and daily average of solar irradiance from the south direction in the months of June and July for a classroom that has a window facing the south direction, taking into consideration the impact of overshadowing by a tree. As can be seen, the classroom is overshadowed by a tree in the south direction between 10:30 am to 14:30 pm solar times. For this reason, the beam solar irradiance for this duration (10:30-14:30) should be multiplied by 0.15 (shading coefficient). Therefore, the daily average solar irradiance for the months of June and July is 139.5 W/m² (average of 142 & 137).

June																				
Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) June
		Mean hourly irradiance (/ W.m−2) for stated solar time from sunrise to sunset																		
S	Beam	0	0	0	0	18	141	256	51.3	58.05	58.35	50.25	37.05	133	17	0	0	0	0	
	Diffuse	8	18	41	77	83	125	154	170	179	180	172	158	130	87	77	42	20	8	
	Globe	8	18	41	77	101	266	410	221	237	238	222	195	263	104	77	42	20	8	142
July																				
Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July
		Mean hourly irradiance (/ W.m−2) for stated solar time from sunrise to sunset																		
S	Beam	0	0	0	0	20	135	240	47.7	53.25	54.15	47.55	35.4	132	20	0	0	0	0	
	Diffuse	6	16	35	67	81	121	152	173	185	186	172	156	124	80	71	35	14	5	
	Globe	6	16	35	67	101	256	392	221	238	240	220	191	256	100	71	35	14	5	137
Solar irradiance on South direction when ther is not any obstruction = [(142+137)/2] = 139.5 (W/m²)																				

Table 3-2.10: Hourly and daily average of solar irradiance from the south direction in the months of June and July for the south direction considering the impact of overshadowing by a tree

• Scenario 3: Figure 3-2.27 shows the plan, elevation and section of a classroom which faces the south and is overshadowed by a building.

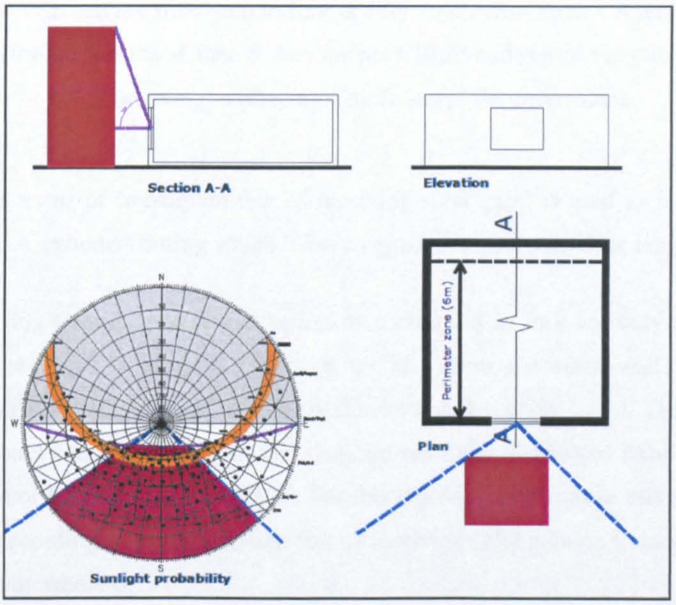


Figure 3-2.27: plan, elevation, section of a classroom which is faced to the south and is overshadowed a building

Table 3-2.11 shows the hourly and daily average solar irradiance from the south direction in the months of June and July for a classroom that has a window facing the south, taking into consideration the impact of overshadowing by a building. As seen, the classroom is overshadowed by a building from the south direction between 10:30 am to 14:30 pm solar times. For this reason, the beam solar irradiance for this duration (10:30-14:30) should be multiplied by zero. Therefore, the daily average solar irradiance for these months is 125.5 W/m² (average of 127 & 124).

June																				
Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) June
		Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																		
S	Beam	0	0	0	0	18	141	256	0	0	0	0	0	133	17	0	0	0	0	
	Diffuse	8	18	41	77	83	125	154	170	179	180	172	158	130	87	77	42	20	8	
	Globe	8	18	41	77	101	266	410	170	179	180	172	158	263	104	77	42	20	8	127
July																				
Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July
		Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																		
S	Beam	0	0	0	0	20	135	240	0	0	0	0	0	132	20	0	0	0	0	
	Diffuse	6	16	35	67	81	121	152	173	185	186	172	156	124	80	71	35	14	5	
	Globe	6	16	35	67	101	256	392	173	185	186	172	156	256	100	71	35	14	5	124
Solar irradiance on South direction when ther is not any obstruction = [(127+124)/2]= 125.5 (W/m²)																				

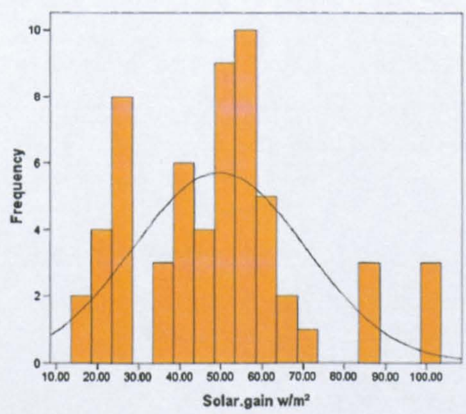
Table 3-2.11: Hourly and daily average of solar irradiance from south direction in the months of June and July for the south direction considering the impact of overshadowing by a building

- **Solar gain maximum potential:** The maximum amount of solar gain that could be received on a clear day in the months of Jun and July are calculated as follow:

Maximum risk of receiving solar gain in June & July = [Window Area x Average daily solar irradiance for the months of June & July (as per CIBSE and considering the impact of overshadowing) x Shading Coefficient] / Perimeter Zone

In this study, the terms of 'maximum risk of receiving solar gain' is used as it is calculated for cooling seasons (i.e. summer) during which it has a negative impact on indoor temperature.

The risk of receiving solar gain of 60 classrooms on a clear day in June and July are calculated for the perimeter zone which is within 6 meters on the plan from a window wall. The results vary between '16 W/m²' and '103 W/ m²' for the perimeter zones (Graph 3-2.5). The distributions of these data are tested and it is found out that they are normally distributed (Appendix 10.4). The mean and median of these data are 50 W/ m². For this reason, classrooms in this study are divided into two groups according to their maximum risk of receiving solar gain on a clear day in June and July based on the threshold of 50.



Graph 3-2.5: Risk of receiving solar gain in 60 number classrooms

Perimeter zones of classrooms are selected to calculate solar gain for the following three reasons:

1- Perimeter zone is the area that receives direct solar load which has the most impact on the indoor temperature.

2- The amount of solar gain (load) is calculated based on perimeter zone to categorise classrooms rather than the impact of solar gain on indoor temperature. (If the latter was the case, the classroom areas would have been considered).

3- The minimum area required for primary school children is around 2 m^2 per head. The number of children in a classroom varies from 20 to 30, therefore on average, the required classroom area is around 55 m^2 in these energy efficient schools.

In this study, the measured classroom areas are not significantly different from this figure according to T test values carried out on 'the classrooms areas' and '55 m^2' ($n=59$, $P<0.05$) (Appendix 10.5).

The schools' history background, ventilation potential, thermal mass and maximum risk of receiving solar in each classrooms are gathered in schools' characteristic part (Appendix 9).

In the following flowchart (Graph 3-2.6), the classrooms which have been categorised based on their location and thermal mass level, are broken down according to their maximum risk of receiving solar gain (above or below 50 W/m²).

Therefore up to this stage, there are 4 available series of classrooms as follows:

1. Noisy, medium thermal mass classroom with solar gain above 50 W/m²
2. Noisy, medium thermal mass classroom with solar gain below 50 W/m²
3. Quiet, medium thermal mass classroom with solar gain above 50 W/m²
4. Quiet, medium thermal mass classroom with solar gain below 50 W/m²

Graph 3-2.6:

Classrooms' break down based on their location, thermal mass level and maximum risk of receiving solar gain

a4) Internal gain evaluation for each classroom

The impact of internal gain in the classrooms of this study are assumed to be constant, as the number of students, teachers, the types and number of equipments in the primary schools' classrooms and also their area are almost equal. The classrooms' areas are not significantly different from the required standard classrooms area confirmed by the T test result that is carried out between 'classrooms' area' and '55 m^2'.

b) Categorising the duration of the study based on the climate factors:

As explained earlier in this chapter, climate factors such as daily temperature and irradiance have significant impacts on indoor temperature.

b1) Categorising the duration of the study based on 'Actual daily solar irradiance':

Table 3-2.11 shows the 'actual daily solar irradiances' (obtained from Met Office) on horizontal surfaces for the weekdays of the duration of the study, in the years of 2005, 2007 and 2008. In this study, the actual daily solar irradiance in June and July varied from 838 W/m² to 8251 W/m². The distributions of these data are tested and it is found out that they are normally distributed (Appendix 10.6). The mean and median of these data are 4960 wh/m². For this reason, days are divided in two groups according to their corresponding daily irradiance level on horizontal surfaces in order to study the impact of actual daily solar irradiance on indoor temperature.

Group 1: includes the days with a solar irradiance of above 4960 wh/m² which are identified as 'High Irradiance' and coded as 'H'.

Group 2: includes the days with a solar irradiance of below 4960 wh/m2 which are identified as 'Low Irradiance' and coded as 'L'.

The following table (Table 3-2.12) shows the actual daily solar irradiance on the horizontal surfaces for each day.

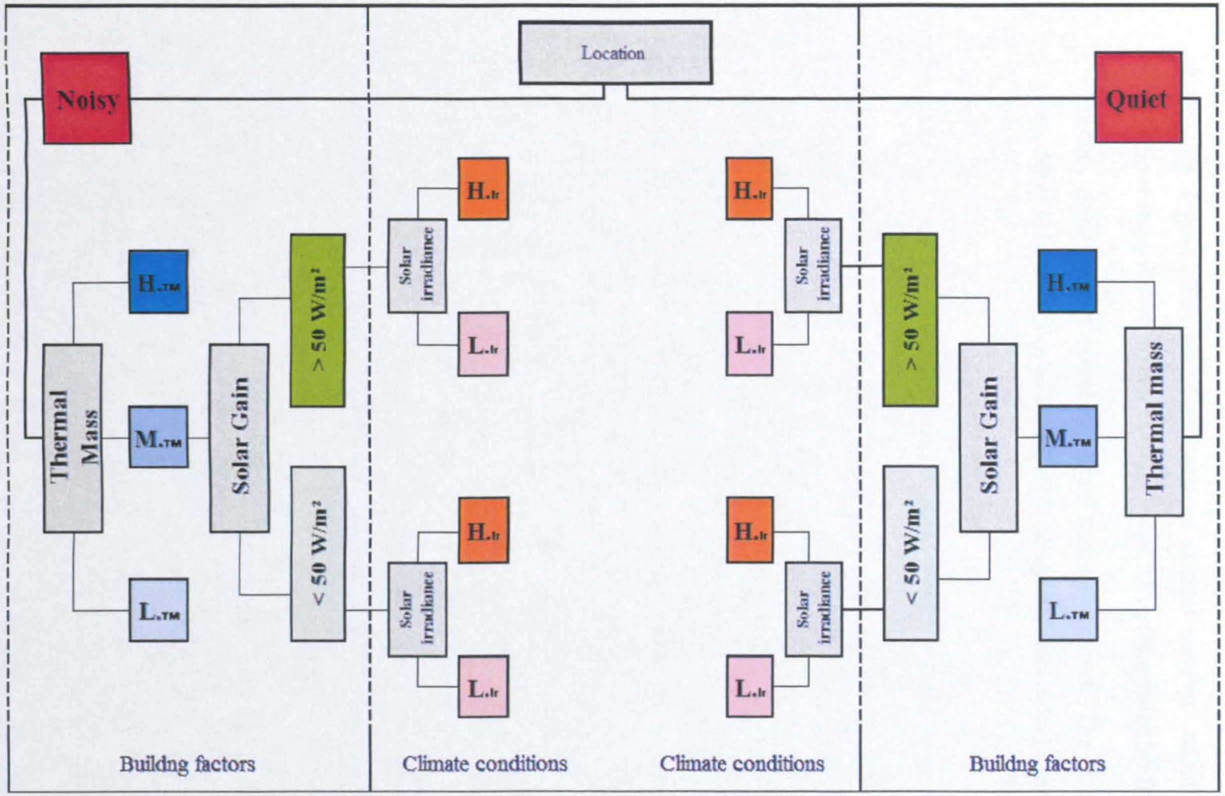
2005	Date	Irradiance on Horizontal surfaces W/m²	Coding	2007	Date	Irradiance on Horizontal surfaces W/m²	Coding	2008	Date	Irradiance on Horizontal surfaces W/m²	Coding
Wed	15/06/2005	3698	L	Mon	11/06/2007	3053	L	Mon	09/06/2008	7475	H
Thu	16/06/2005	2176	L	Tue	12/06/2007	5194	H	Tue	10/06/2008	6567	H
Fri	17/06/2005	5203	H	Wed	13/06/2007	6091	H	Wed	11/06/2008	4989	H
Mon	20/06/2005	4950	L	Thu	14/06/2007	3437	L	Thu	12/06/2008	4174	L
Tue	21/06/2005	7512	H	Fri	15/06/2007	5127	H	Fri	13/06/2008	6100	H
Wed	22/06/2005	7845	H	Mon	18/06/2007	3736	L	Mon	16/06/2008	6721	H
Thu	23/06/2005	6922	H	Tue	19/06/2007	6244	H	Tue	17/06/2008	6459	H
Fri	24/06/2005	5394	H	Wed	20/06/2007	6665	H	Wed	18/06/2008	3106	L
Mon	27/06/2005	7788	H	Thu	21/06/2007	5769	H	Thu	19/06/2008	7218	H
Tue	28/06/2005	6462	H	Fri	22/06/2007	4166	L	Fri	20/06/2008	4306	L
Wed	29/06/2005	4921	L	Mon	25/06/2007	3783	L	Mon	23/06/2008	7604	H
Thu	30/06/2005	2108	L	Tue	26/06/2007	5108	H	Tue	24/06/2008	6589	H
Fri	01/07/2005	4119	L	Wed	27/06/2007	4194	L	Wed	25/06/2008	6430	H
Mon	04/07/2005	4901	L	Thu	28/06/2007	4917	L	Thu	26/06/2008	6758	H
Tue	05/07/2005	3302	L	Fri	29/06/2007	5693	H	Fri	27/06/2008	3954	L
Wed	06/07/2005	4031	L	Mon	02/07/2007	3997	L	Mon	30/06/2008	7364	H
Thu	07/07/2005	3198	L	Tue	03/07/2007	4805	L	Tue	01/07/2008	8251	H
Fri	08/07/2005	2949	L	Wed	04/07/2007	4879	L	Wed	02/07/2008	3094	L
Mon	11/07/2005	6680	H	Thu	05/07/2007	3794	L	Thu	03/07/2008	4719	L
Tue	12/07/2005	7530	H	Fri	06/07/2007	4181	L	Fri	04/07/2008	7024	H
Wed	13/07/2005	6390	H	Mon	09/07/2007	5729	H	Mon	07/07/2008	3527	L
Thu	14/07/2005	7093	H	Tue	10/07/2007	4109	L	Tue	08/07/2008	5692	H
Fri	15/07/2005	5712	H	Wed	11/07/2007	3874	L	Wed	09/07/2008	1604	L
Mon	18/07/2005	5883	H	Thu	12/07/2007	3220	L	Thu	10/07/2008	5134	H
Tue	19/07/2005	5066	H	Fri	13/07/2007	3899	L	Fri	11/07/2008	4899	L
Wed	20/07/2005	7157	H	Mon	16/07/2007	4728	L	Mon	14/07/2008	5968	H
Thu	21/07/2005	5512	H	Tue	17/07/2007	5678	H	Tue	15/07/2008	5145	H
Fri	22/07/2005	3174	L	Wed	18/07/2007	6088	H	Wed	16/07/2008	4705	L
Mon	25/07/2005	2060	L	Thu	19/07/2007	4313	L	Thu	17/07/2008	2102	L
Tue	26/07/2005	3681	L	Fri	20/07/2007	3537	L	Fri	18/07/2008	2141	L
Wed	27/07/2005	838	L	Mon	23/07/2007	1564	L	Mon	21/07/2008	6629	H

Table 3-2.12: Actual daily solar irradiance in years 2005, 2007 & 2008

The following flowchart (Graph 3-2.7) shows the classrooms breakdown based on building factors (i.e. ventilation potential, thermal mass and solar gain) followed by the study-duration breakdown based on one of the climate conditions (i.e. actual daily solar irradiance).

This results in the following 8 groups:

1. Noisy, medium thermal mass classroom with solar gain above 50 W/m^2 for the days with high solar irradiance.
2. Noisy, medium thermal mass classroom with solar gain above 50 W/m^2 for the days with low solar irradiance.
3. Noisy, medium thermal mass classroom with solar gain below 50 W/m^2 for the days with high solar irradiance.
4. Noisy, medium thermal mass classroom with solar gain below 50 W/m^2 for the days with low solar irradiance.
5. Quiet, medium thermal mass classroom with solar gain above 50 W/m^2 for the days with high solar irradiance.
6. Quiet, medium thermal mass classroom with solar gain above 50 W/m^2 for the days with low solar irradiance.
7. Quiet, medium thermal mass classroom with solar gain below 50 W/m^2 for the days with high solar irradiance.
8. Quiet, medium thermal mass classroom with solar gain below 50 W/m^2 for the days with low solar irradiance.

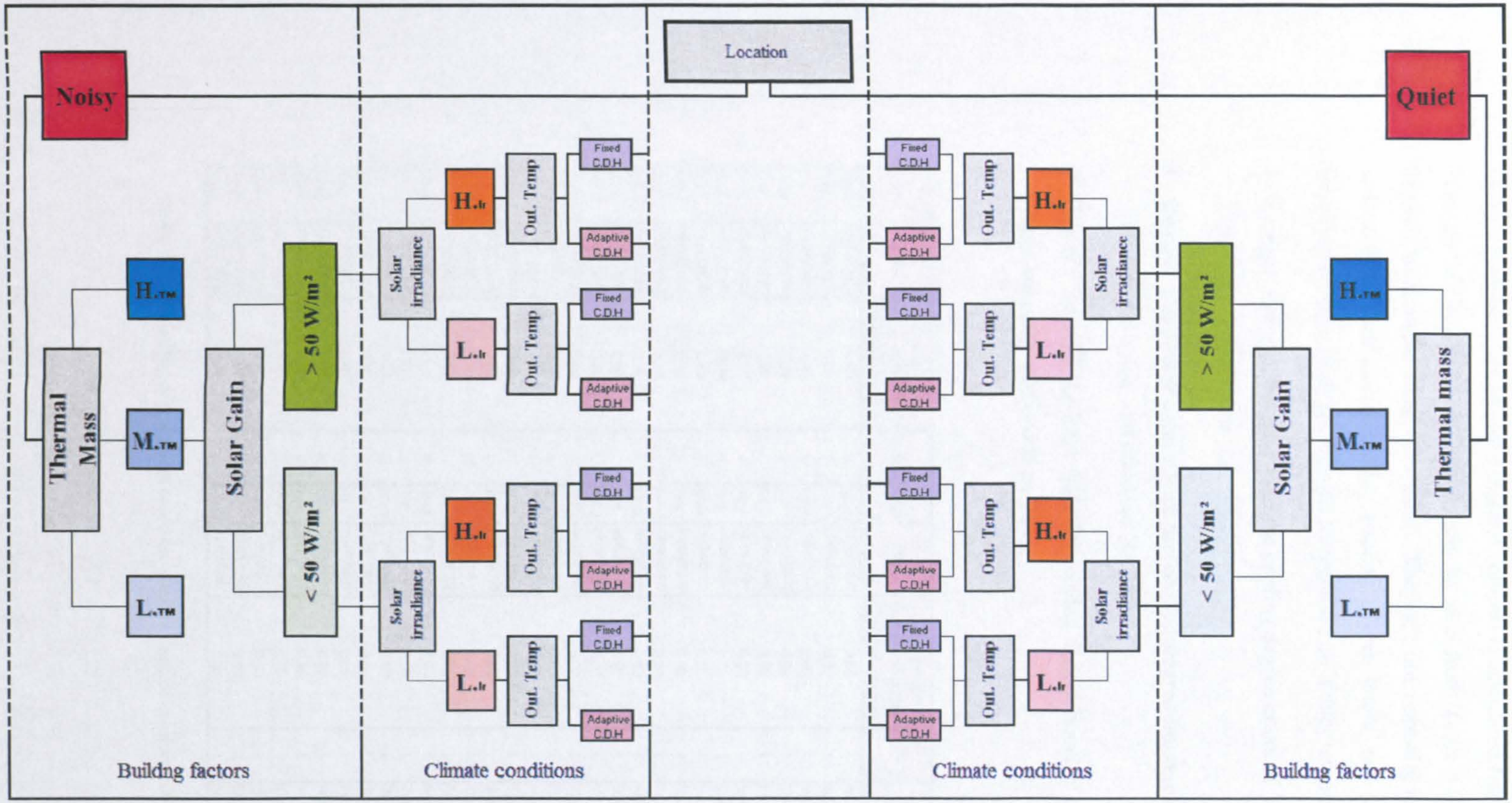


Graph 3-2.7:
Categorising classrooms based on their location, thermal mass level and maximum risk of receiving solar gain, and categorising the duration of study based on daily solar irradiance

b2) Categorising the duration of the study based on 'outdoor temperature':

To study the impact of outside temperature on indoor temperature, duration of study should be categorised according to cooling degree hours. Two types of cooling degree hours are calculated at this stage:

- Cooling degree hours based on adaptive thermal comfort. Adaptive thermal comfort is calculated from this formula: ($T_c=0.33T_{rm}+18.8$) as suggested by BS EN 15251.
- Cooling degree hours based on fixed thermal comfort. The fixed thermal comfort is considered to be 25°C due to the fact that occupants start to feel warm at this temperature.



Graph 3-2.8: Categorising classrooms based on their location, thermal mass level and maximum risk of receiving solar gain and categorising duration of study based on daily solar irradiance and cooling degree hours (adaptive and fixed)

- **Categorising the duration of the study based on 'adaptive cooling degree hours':**

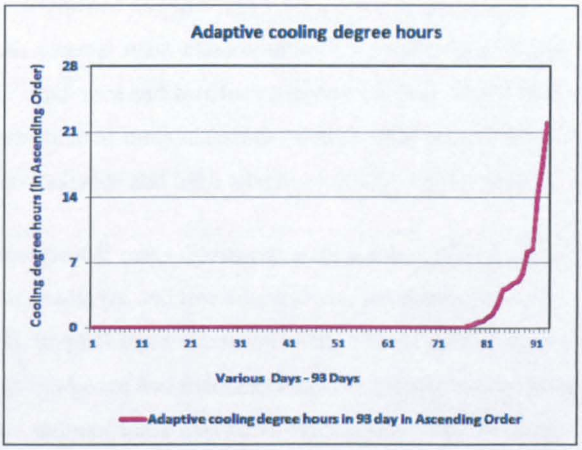
The adaptive cooling degree hour is a cooling degree hour which is calculated based on adaptive thermal comfort. The adaptive thermal comfort is calculated from this formula (Tc=0.33Trm+18.8) as suggested by BS EN 15251. As can be seen from Table 3-2.13, the range of adaptive cooling degree hours varies from 0 to 21.96. They are not normally distributed (Appendix 10.7). Days, according to their corresponding cooling degree hours, are categorised to the following three groups in order to study the outside temperature on indoor temperature.

- Group1: includes the days with the cooling degree hours of '0 to 7' which are identified as 'low out.temp' and coded as 'L'.
- Group2: includes the days with the cooling degree hours of '7 to 14' which are identified as 'medium out.temp' and coded as 'M'.
- Group3: includes the days with the cooling degree hours of above '14' which are identified as 'high out.temp' and coded as 'H'.

2005	Date	Cooling degree hours base on (BS) Thermal comfort	Coding	2007	Date	Cooling degree hours base on (BS) Thermal comfort	Coding	2008	Date	Cooling degree hours base on (BS) Thermal comfort	Coding
Wed	15/06/2005	0.00	L	Mon	11/06/2007	0.00	L	Mon	09/06/2008	4.14	L
Thu	16/06/2005	0.00	L	Tue	12/06/2007	0.00	L	Tue	10/06/2008	0.00	L
Fri	17/06/2005	4.78	L	Wed	13/06/2007	0.00	L	Wed	11/06/2008	0.00	L
Mon	20/06/2005	5.03	L	Thu	14/06/2007	0.00	L	Thu	12/06/2008	0.00	L
Tue	21/06/2005	0.00	L	Fri	15/06/2007	0.00	L	Fri	13/06/2008	0.00	L
Wed	22/06/2005	5.86	L	Mon	18/06/2007	0.00	L	Mon	16/06/2008	0.00	L
Thu	23/06/2005	17.38	H	Tue	19/06/2007	1.48	L	Tue	17/06/2008	0.00	L
Fri	24/06/2005	0.00	L	Wed	20/06/2007	0.00	L	Wed	18/06/2008	0.00	L
Mon	27/06/2005	0.69	L	Thu	21/06/2007	0.00	L	Thu	19/06/2008	0.00	L
Tue	28/06/2005	1.10	L	Fri	22/06/2007	0.00	L	Fri	20/06/2008	0.00	L
Wed	29/06/2005	0.38	L	Mon	25/06/2007	0.00	L	Mon	23/06/2008	0.00	L
Thu	30/06/2005	0.00	L	Tue	26/06/2007	0.00	L	Tue	24/06/2008	0.00	L
Fri	01/07/2005	0.00	L	Wed	27/06/2007	0.00	L	Wed	25/06/2008	0.00	L
Mon	04/07/2005	0.00	L	Thu	28/06/2007	0.00	L	Thu	26/06/2008	0.00	L
Tue	05/07/2005	0.00	L	Fri	29/06/2007	0.00	L	Fri	27/06/2008	0.00	L
Wed	06/07/2005	0.00	L	Mon	02/07/2007	0.00	L	Mon	30/06/2008	0.00	L
Thu	07/07/2005	0.00	L	Tue	03/07/2007	0.00	L	Tue	01/07/2008	8.12	M
Fri	08/07/2005	0.00	L	Wed	04/07/2007	0.00	L	Wed	02/07/2008	0.00	L
Mon	11/07/2005	8.51	M	Thu	05/07/2007	0.00	L	Thu	03/07/2008	0.00	L
Tue	12/07/2005	2.54	L	Fri	06/07/2007	0.00	L	Fri	04/07/2008	0.00	L
Wed	13/07/2005	14.01	H	Mon	09/07/2007	0.00	L	Mon	07/07/2008	0.00	L
Thu	14/07/2005	21.96	H	Tue	10/07/2007	0.00	L	Tue	08/07/2008	0.00	L
Fri	15/07/2005	4.29	L	Wed	11/07/2007	0.00	L	Wed	09/07/2008	0.00	L
Mon	18/07/2005	0.28	L	Thu	12/07/2007	0.00	L	Thu	10/07/2008	0.00	L
Tue	19/07/2005	0.00	L	Fri	13/07/2007	0.00	L	Fri	11/07/2008	0.00	L
Wed	20/07/2005	0.00	L	Mon	16/07/2007	0.00	L	Mon	14/07/2008	0.00	L
Thu	21/07/2005	0.00	L	Tue	17/07/2007	0.00	L	Tue	15/07/2008	0.78	L
Fri	22/07/2005	0.00	L	Wed	18/07/2007	0.00	L	Wed	16/07/2008	0.00	L
Mon	25/07/2005	0.00	L	Thu	19/07/2007	0.00	L	Thu	17/07/2008	0.00	L
Tue	26/07/2005	0.00	L	Fri	20/07/2007	0.00	L	Fri	18/07/2008	0.00	L
Wed	27/07/2005	0.00	L	Mon	23/07/2007	0.00	L	Mon	21/07/2008	0.00	L

Table 3-2.13: Cooling degree hours based on adaptive thermal comfort in years 2005, 2007 & 2008

In this part of study, 7 is chosen as a benchmark to divide the cooling degree hours in two 3 groups. It should be noted that later in this chapter (Detailed procedure in Method A), an analysis is carried out based on each individual cooling degree hours (as opposed to considering 7 as benchmark) in order to have more accurate results. Graph 3-2.9 shows ascending distribution of cooling degree hours for different days. The cooling degree hours in Group 1 have a higher frequency than the ones in Groups 2 and 3. In addition, the differences between the cooling degree hours of Group 1 are lower than the differences between the cooling degree hours in Groups 2 and 3.



Graph 3-2.9. Distribution of Adaptive cooling degree hours

The following flowchart (Graph 3-2.10) shows the classrooms breakdown based on building factors (i.e. ventilation potential, thermal mass and solar gain) followed by the study-duration breakdown based on the climate conditions (i.e. solar irradiance and adaptive cooling degree hours). This results in the following 24 groups:

1. Noisy, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with high solar irradiance and **low** adaptive cooling degree hours.
2. Noisy, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with high solar irradiance and **medium** adaptive cooling degree hours.
3. Noisy, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with high solar irradiance and **high** adaptive cooling degree hours.
4. Noisy, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with low solar irradiance and **low** adaptive cooling degree hours.
5. Noisy, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with low solar irradiance and **medium** adaptive cooling degree hours.
6. Noisy, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with low solar irradiance and **high** adaptive cooling degree hours.

7. Noisy, medium thermal mass classroom with a solar gain of below 50 W/m² for the days with high solar irradiance and **low** adaptive cooling degree hours.
8. Noisy, medium thermal mass classroom with a solar gain of below 50 W/m² for the days with high solar irradiance and **medium** adaptive cooling degree hours.
9. Noisy, medium thermal mass classroom with a solar gain of below 50 W/m² for the days with high solar irradiance and **high** adaptive cooling degree hours.

10. Noisy, medium thermal mass classroom with a solar gain of below 50 W/m² for the days with low solar irradiance and **low** adaptive cooling degree hours.
11. Noisy, medium thermal mass classroom with a solar gain of below 50 W/m² for the days with low solar irradiance and **medium** adaptive cooling degree hours.
12. Noisy, medium thermal mass classroom with a solar gain of below 50 W/m² for the days with low solar irradiance and **high** adaptive cooling degree hours.

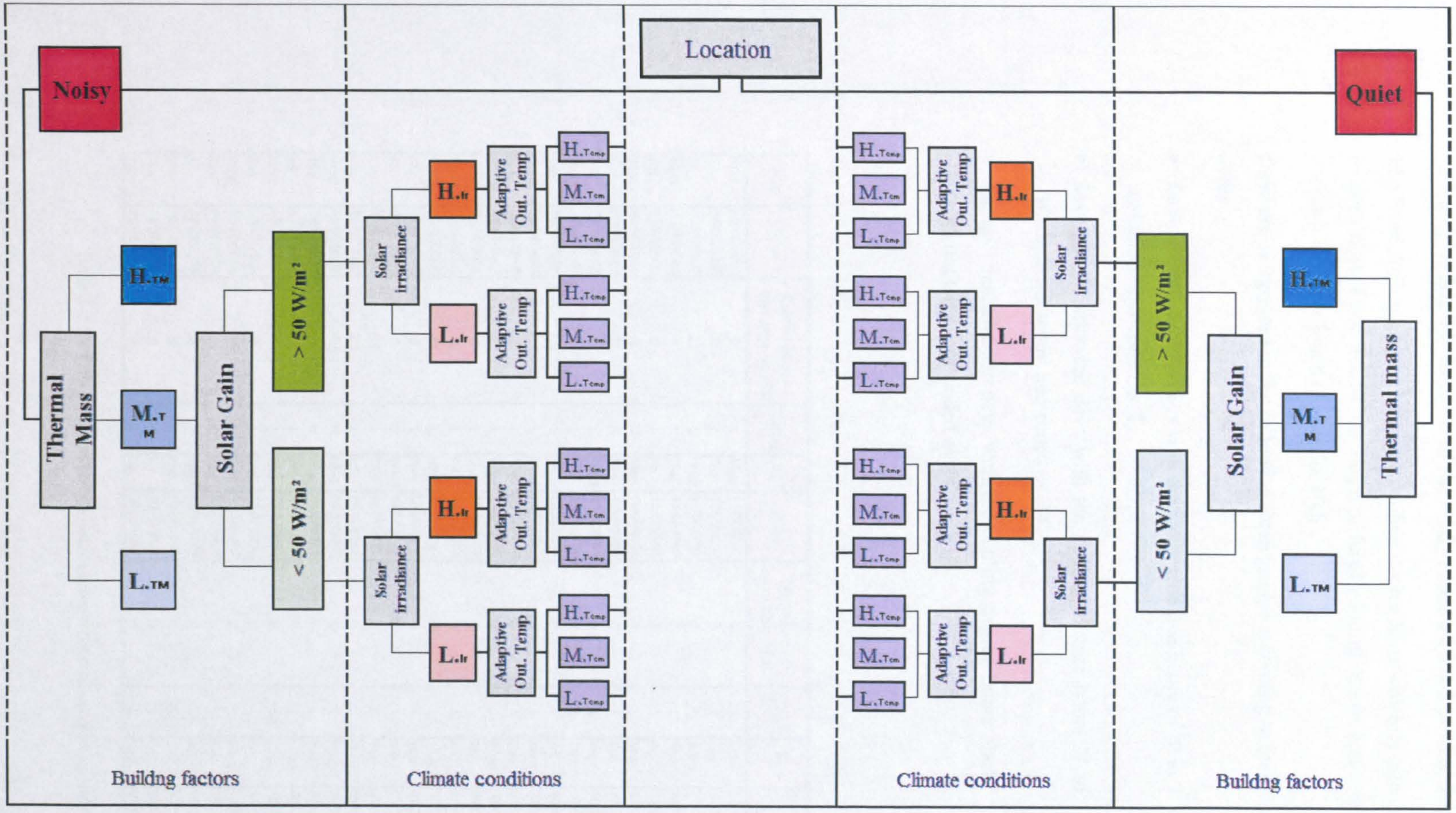
13. Quiet, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with high solar irradiance and **low** adaptive cooling degree hours.
14. Quiet, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with high solar irradiance and **medium** adaptive cooling degree hours.
15. Quiet, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with high solar irradiance and **high** adaptive cooling degree hours.

16. Quiet, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with low solar irradiance and **low** adaptive cooling degree hours.
17. Quiet, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with low solar irradiance and **medium** adaptive cooling degree hours.
18. Quiet, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with low solar irradiance and **high** adaptive cooling degree hours.

19. Quiet, medium thermal mass classroom with a solar gain of below 50 W/m² for the days with high solar irradiance and **low** adaptive cooling degree hours.
20. Quiet, medium thermal mass classroom with a solar gain of below 50 W/m² for the days with high solar irradiance and **medium** adaptive cooling degree hours.
21. Quiet, medium thermal mass classroom with a solar gain of below 50 W/m² for the days with high solar irradiance and **high** adaptive cooling degree hours.

22. Quiet, medium thermal mass classroom with a solar gain of below 50 W/m² for the days with low solar irradiance and **low** adaptive cooling degree hours.
23. Quiet, medium thermal mass classroom with a solar gain of below 50 W/m² for the days with low solar irradiance and **medium** adaptive cooling degree hours.

24. Quiet, medium thermal mass classroom with a solar gain of below 50 W/m^2 for the days with low solar irradiance and **high** adaptive cooling degree hours.



Graph 3-2.10: Categorising classrooms based on their location, thermal mass level and maximum risk of receiving solar gain and categorising their duration of study based on daily solar irradiance and cooling degree hours (adaptive and fixed)

- **Categorising the duration of the study based on fixed cooling degree hours:**

The fixed cooling degree hour is a cooling degree hour which is calculated based on 25°C. As can be seen from Table 3-2.14, the range of fixed cooling degree hours varies from 0 to 24. They are not normally distributed (Appendix 10.8).

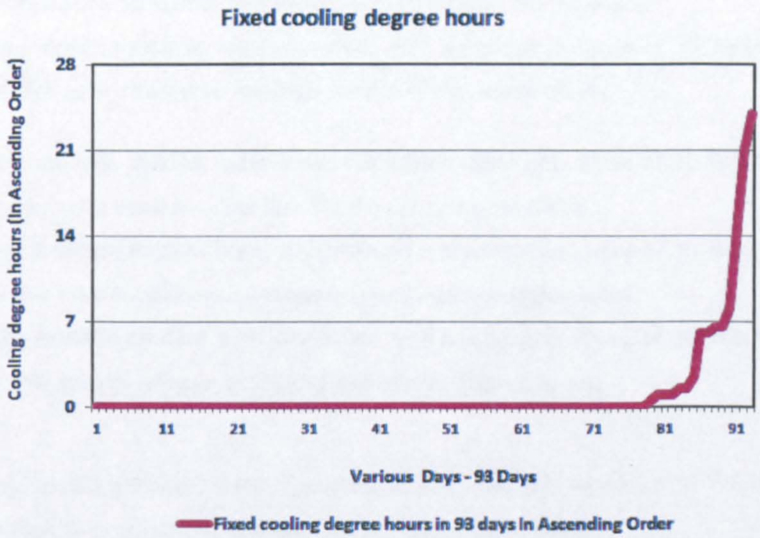
Days are categorised to the following three groups according to their corresponding cooling degree hours:

- Group1: includes the days with the cooling degree hours of '0 to 7' which are identified as 'low out.temp' and coded as 'L'.
- Group2: includes the days with the cooling degree hours '7 to 14' which are identified as 'medium out.temp' and coded as 'M'.
- Group3: includes the days with the cooling degree hours above '14' which are identified as 'high out.temp' and coded as 'H'.

2005	Date	Cooling degree hours base on 25°C	Coding	2007	Date	Cooling degree hours base on 25°C	Coding	2008	Date	Cooling degree hours base on 25°C	Coding
Wed	15/06/2005	0	L	Mon	11/06/2007	0	L	Mon	09/06/2008	1	L
Thu	16/06/2005	0	L	Tue	12/06/2007	0	L	Tue	10/06/2008	0	L
Fri	17/06/2005	1.5	L	Wed	13/06/2007	0	L	Wed	11/06/2008	0	L
Mon	20/06/2005	6	L	Thu	14/06/2007	0	L	Thu	12/06/2008	0	L
Tue	21/06/2005	0	L	Fri	15/06/2007	0	L	Fri	13/06/2008	0	L
Wed	22/06/2005	8	M	Mon	18/06/2007	0	L	Mon	16/06/2008	0	L
Thu	23/06/2005	21	H	Tue	19/06/2007	0	L	Tue	17/06/2008	0	L
Fri	24/06/2005	0	L	Wed	20/06/2007	0	L	Wed	18/06/2008	0	L
Mon	27/06/2005	1	L	Thu	21/06/2007	0	L	Thu	19/06/2008	0	L
Tue	28/06/2005	1.5	L	Fri	22/06/2007	0	L	Fri	20/06/2008	0	L
Wed	29/06/2005	0.5	L	Mon	25/06/2007	0	L	Mon	23/06/2008	0	L
Thu	30/06/2005	0	L	Tue	26/06/2007	0	L	Tue	24/06/2008	0	L
Fri	01/07/2005	0	L	Wed	27/06/2007	0	L	Wed	25/06/2008	0	L
Mon	04/07/2005	0	L	Thu	28/06/2007	0	L	Thu	26/06/2008	0	L
Tue	05/07/2005	0	L	Fri	29/06/2007	0	L	Fri	27/06/2008	0	L
Wed	06/07/2005	0	L	Mon	02/07/2007	0	L	Mon	30/06/2008	0	L
Thu	07/07/2005	0	L	Tue	03/07/2007	0	L	Tue	01/07/2008	6	L
Fri	08/07/2005	0	L	Wed	04/07/2007	0	L	Wed	02/07/2008	0	L
Mon	11/07/2005	6.5	L	Thu	05/07/2007	0	L	Thu	03/07/2008	0	L
Tue	12/07/2005	2.5	L	Fri	06/07/2007	0	L	Fri	04/07/2008	0	L
Wed	13/07/2005	14.5	H	Mon	09/07/2007	0	L	Mon	07/07/2008	0	L
Thu	14/07/2005	24	H	Tue	10/07/2007	0	L	Tue	08/07/2008	0	L
Fri	15/07/2005	6.5	L	Wed	11/07/2007	0	L	Wed	09/07/2008	0	L
Mon	18/07/2005	1	L	Thu	12/07/2007	0	L	Thu	10/07/2008	0	L
Tue	19/07/2005	0	L	Fri	13/07/2007	0	L	Fri	11/07/2008	0	L
Wed	20/07/2005	0	L	Mon	16/07/2007	0	L	Mon	14/07/2008	0	L
Thu	21/07/2005	0	L	Tue	17/07/2007	0	L	Tue	15/07/2008	0	L
Fri	22/07/2005	0	L	Wed	18/07/2007	0	L	Wed	16/07/2008	0	L
Mon	25/07/2005	0	L	Thu	19/07/2007	0	L	Thu	17/07/2008	0	L
Tue	26/07/2005	0	L	Fri	20/07/2007	0	L	Fri	18/07/2008	0	L
Wed	27/07/2005	0	L	Mon	23/07/2007	0	L	Mon	21/07/2008	0	L

Table 3-2.14: Cooling degree hours based on fixed thermal comfort in years 2005, 2007 & 2008

In this part of study, 7 is chosen as a benchmark to divide the cooling degree hours in two 3 groups. In should be noted that later on in this chapter (Detailed procedure in Method B), an analysis is carried out based on each individual cooling degree hours (as opposed to considering 7 as benchmark) in order to have more accurate results. Graph 3-2.11 shows ascending distribution of cooling degree hours for different days. The cooling degree hours in Group 1 have a higher frequency than the ones in Groups 2 and 3. In addition, the differences between the cooling degree hours of group 1 are lower than the differences between the cooling degree hours in Groups 2 and 3.



Graph 3-2.11. Distribution of Fixed cooling degree hours

Graph 3-2.12 shows the classrooms' breakdown based on building factors (i.e. ventilation potential, thermal mass and solar gain) followed by the study-duration breakdown based on the climate conditions (i.e. solar irradiance and fixed cooling degree hours). This results in the following 24 groups:

1. Noisy, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with high solar irradiance and **low** fixed cooling degree hours.
2. Noisy, medium thermal mass classroom with a solar gain of above 50 W/m² for the days with high solar irradiance and **medium** fixed cooling degree hours.
3. Noisy, medium thermal mass classroom with a solar gain above of 50 W/m² for the days with high solar irradiance and **high** fixed cooling degree hours.

4. Noisy, medium thermal mass classroom with a solar gain above of 50 W/m² for the days with low solar irradiance and **low** fixed cooling degree hours.
5. Noisy, medium thermal mass classroom with a solar gain above of 50 W/m² for the days with low solar irradiance and **medium** fixed cooling degree hours.
6. Noisy, medium thermal mass classroom with a solar gain above of 50 W/m² for the days with low solar irradiance and **high** fixed cooling degree hours.

7. Noisy, medium thermal mass classroom with a solar gain below of 50 W/m² for the days with high solar irradiance and **low** fixed cooling degree hours.
8. Noisy, medium thermal mass classroom with a solar gain below of 50 W/m² for the days with high solar irradiance and **medium** fixed cooling degree hours.
9. Noisy, medium thermal mass classroom with a solar gain below 50 W/m² for the days with high solar irradiance and **high** fixed cooling degree hours.

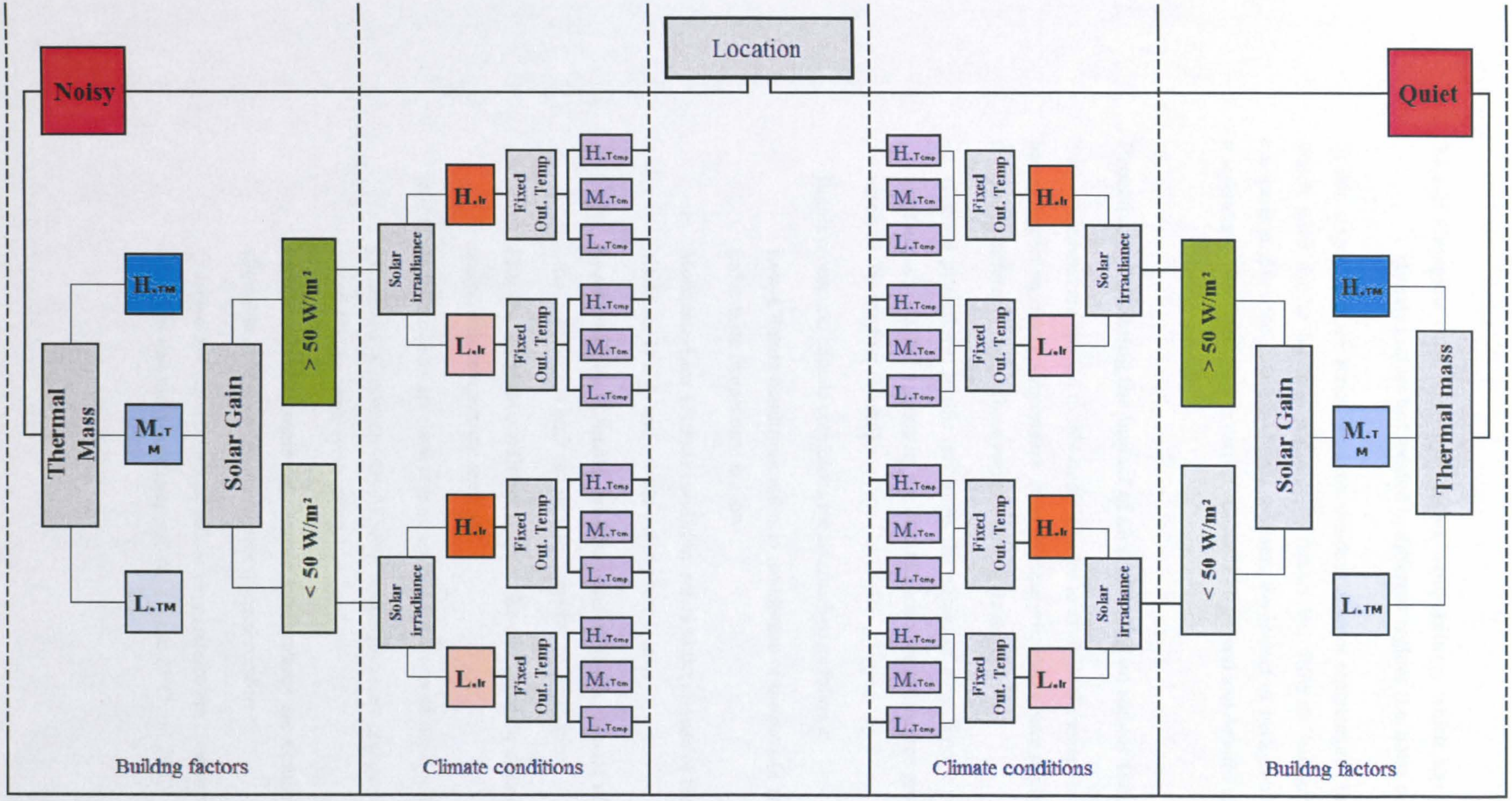
10. Noisy, medium thermal mass classroom with a solar gain below of 50 W/m² for the days with low solar irradiance and **low** fixed cooling degree hours.
11. Noisy, Medium thermal mass classroom with a solar gain below of 50 W/m² for the days with low solar irradiance and **medium** fixed cooling degree hours.
12. Noisy, medium thermal mass classroom with a solar gain below of 50 W/m² for the days with low solar irradiance and **high** fixed cooling degree hours.

13. Quiet, medium thermal mass classroom with a solar gain above of 50 W/m² for the days with high solar irradiance and **low** fixed cooling degree hours.
14. Quiet, medium thermal mass classroom with a solar gain above of 50 W/m² for the days with high solar irradiance and **medium** fixed cooling degree hours.
15. Quiet, medium thermal mass classroom with a solar gain above of 50 W/m² for the days with high solar irradiance and **high** fixed cooling degree hours.

16. Quiet, medium thermal mass classroom with a solar gain above of 50 W/m^2 for the days with low solar irradiance and **low** fixed cooling degree hours.
17. Quiet, medium thermal mass classroom with a solar gain above of 50 W/m^2 for the days with low solar irradiance and **medium** fixed cooling degree hours.
18. Quiet, medium thermal mass classroom with a solar gain above of 50 W/m^2 for the days with low solar irradiance and **high** fixed cooling degree hours.

19. Quiet, medium thermal mass classroom with a solar gain below of 50 W/m^2 for the days with high solar irradiance and **low** fixed cooling degree hours.
20. Quiet, Medium thermal mass classroom with a solar gain below of 50 W/m^2 for the days with high solar irradiance and **medium** fixed cooling degree hours.
21. Quiet, Medium thermal mass classroom with a solar gain below of 50 W/m^2 for the days with high solar irradiance and **high** fixed cooling degree hours.

22. Quiet, medium thermal mass classroom with a solar gain below of 50 W/m^2 for the days with low solar irradiance and **low** fixed cooling degree hours.
23. Quiet, medium thermal mass classroom with a solar gain below of 50 W/m^2 for the days with low solar irradiance and **medium** fixed cooling degree hours.
24. Quiet, medium thermal mass classroom with a solar gain below of 50 W/m^2 for the days with low solar irradiance and **high** fixed cooling degree hours.



Graph 3-2.12: Categorising classrooms based on their location, thermal mass level and maximum risk of receiving solar gain, and categorising duration of study based on daily solar irradiance and fixed cooling degree hours

3.2.1.3: Compare classroom-days' indoor temperatures which have similar building and climate factors but located in different regions (i.e. noisy and quiet)

In this stage, there are series of classroom-days' indoor temperatures that are placed in groups which have similar building and climate factors but different background noise levels. This comparison gives the author a chance to assess the impact of background noise level on indoor temperature. This assessment is carried out based on general and detailed studies.

Procedure of assessing the impact of aircraft noise on indoor temperature

Two procedures are applied to this study in order to evaluate the extent to which the aircraft noise has an impact on indoor temperature. Both of these procedures have the same principles but study the data in different ranges. These two procedures are as follows:

- **General procedure:** In this procedure, the impact of aircraft noise on indoor temperature is assessed as a whole by grouping the data in such a way that three groups of 8 scenarios to be assessed (twenty four in total).

  In this procedure, climate conditions are summarised as follows:

  - **Low-Climate condition:** refers to the climate of the days in which the solar irradiance and outside temperature are low.
  - **Moderate-Low Climate condition:** refers to the climate of the days in which the solar irradiance is high and outside temperature is low.
  - **Moderate-High Climate condition:** refers to the climate of the days in which the solar irradiance is high and outside temperature is medium.
  - **Extreme Climate condition:** refers to the climate of the days in which solar irradiance and outside temperature are high.

  In this procedure, there are three criteria applied to classroom-days' indoor temperatures:

  - Criterion 1: Classroom-days' indoor temperatures are compared with the percentage of dissatisfaction from overheating
  - Criterion 2: Classroom-day' indoor temperatures are compared with the maximum allowable differences from adaptive thermal comfort
  - Criterion 3: Classroom-days' indoor temperatures are compared with the percentage of occasions that the indoor temperatures exceed 25°C and 28°C.

The eight scenarios studied in each of the criteria as follows:

- Scenarios 1: Noisy and quiet classroom-days' indoor temperatures of medium thermal mass schools with risk of solar gain below 50 W/m^2 in Low climate condition.
- Scenarios 2: Noisy and quiet classroom-days' indoor temperatures of medium thermal mass schools with risk of solar gain above 50 W/m^2 in Low climate condition.
- Scenarios 3: Noisy and quiet classroom-days' indoor temperatures of medium thermal mass schools with risk of solar gain below 50 W/m^2 in Moderate - Low climate condition.
- Scenarios 4: Noisy and quiet classroom-days' indoor temperatures of medium thermal mass schools with risk of solar gain above 50 W/m^2 in Moderate - Low climate condition.
- Scenarios 5: Noisy and quiet classroom-days' indoor temperatures of medium thermal mass classrooms with risk of solar gain below 50 W/m^2 in Moderate - High climate condition.
- Scenarios 6: Noisy and quiet classroom-days' indoor temperatures of medium thermal mass classrooms with risk of solar gain above 50 W/m^2 in Moderate - High climate condition.
- Scenarios 7: Noisy and quiet classroom-days' indoor temperatures of medium thermal mass classrooms with risk of solar gain below 50 W/m^2 in Extreme Climate condition climate condition.
- Scenarios 8: Noisy and quiet classroom-days' indoor temperatures of medium thermal mass classrooms with risk of solar gain above 50 W/m^2 in Moderate - High climate condition.

Noisy and quiet classroom-days' indoor temperatures are compared with each other based on the above 8 scenarios which are assessed based on adaptive and fixed models.

- **Detailed procedure:** In this procedure, the impact of aircraft noise on indoor temperature is assessed in detail by grouping data in such as way that around 40 scenarios to be assessed for classroom-days' indoor temperatures based on adaptive model, and around 42 based on fixed model.

  In this procedure, climate conditions are summarised as follows:

  - Climate conditions with **high** solar irradiance and **fixed** cooling degree hours of 0, 1, 2, 3, 6, 7, 8, 15, 21 and 24.
  - Climate conditions with **low** solar irradiance and **fixed** cooling degree hours of 0, 1, 2, 3, 6, 7, 8, 15, 21 and 24.

- Climate conditions with **high** solar irradiance and **adaptive** cooling degree hours of 0, 1, 3, 4, 5, 6, 8, 9, 14, 17 and 22.
- Climate conditions with **low** solar irradiance and **adaptive** cooling degree hours of 0, 1, 3, 4, 5, 6, 8, 9, 14, 17 and 22.

In this procedure these criteria are studied:

- Criterion 1: Classroom-days' indoor temperatures are compared with percentage of dissatisfaction from overheating
- Criterion 2: Classroom-days' indoor temperatures are compared with the maximum allowable differences from adaptive thermal comfort
- Criterion 3: Classroom-days' indoor temperatures are compared with the percentage of occasions that indoor temperatures exceed 25°C and 28°C.

Noisy and quiet classroom-days' indoor temperatures are compared with each other based on 42 scenarios considering the climate conditions based on adaptive cooling degree hours for classroom-days which assessed based on adaptive model (Criterion 1 and Criterion 2).

Noisy and quiet classroom-days' indoor temperatures are compared with each other based on 40 scenarios considering the climate conditions based on fixed cooling degree hours for classroom-days which are assessed based on fixed model (Criterion 3).

a) General procedure

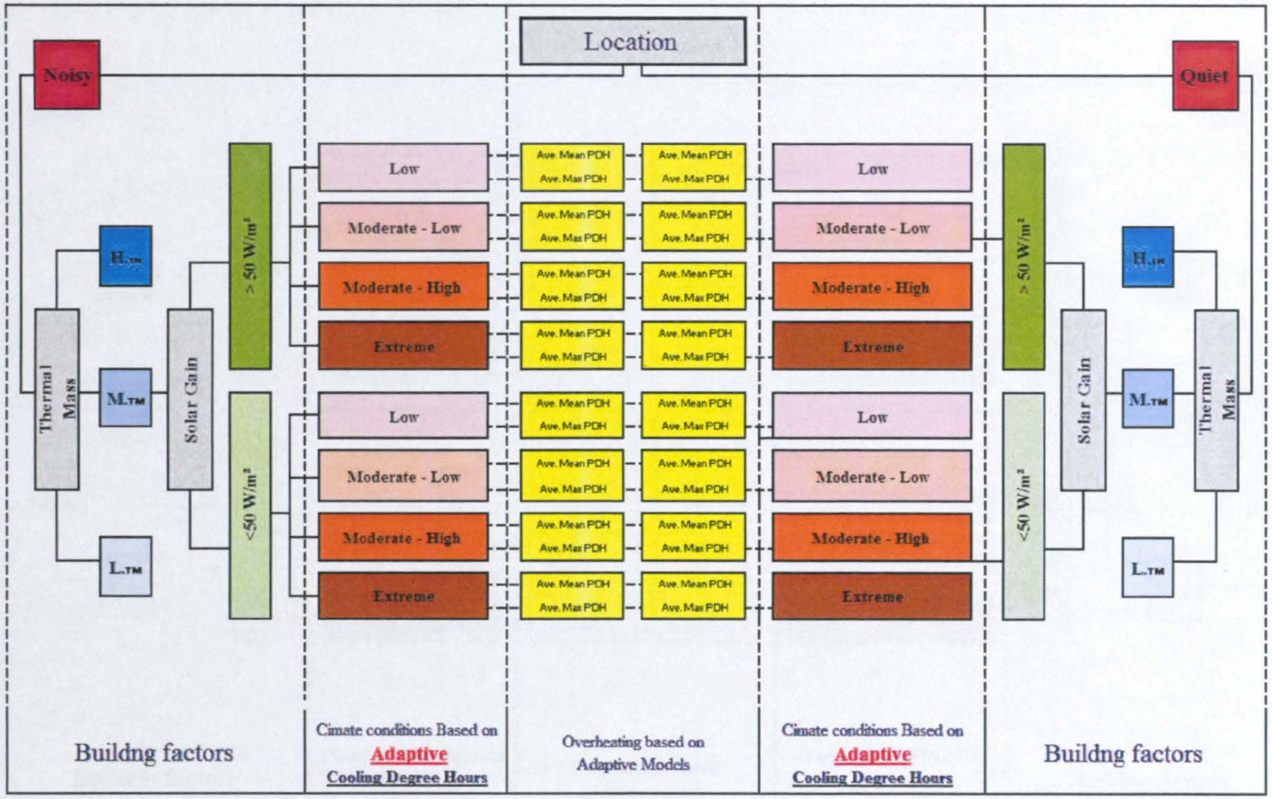
a1) Evaluating the impact of aircraft noise on indoor temperature

The impact of aircraft noise on indoor temperature is evaluated based on adaptive and fixed models. Graphs 3-2.13, 14 & 15 show that how noisy and quiet classroom-day's indoor temperatures are compared with each other.

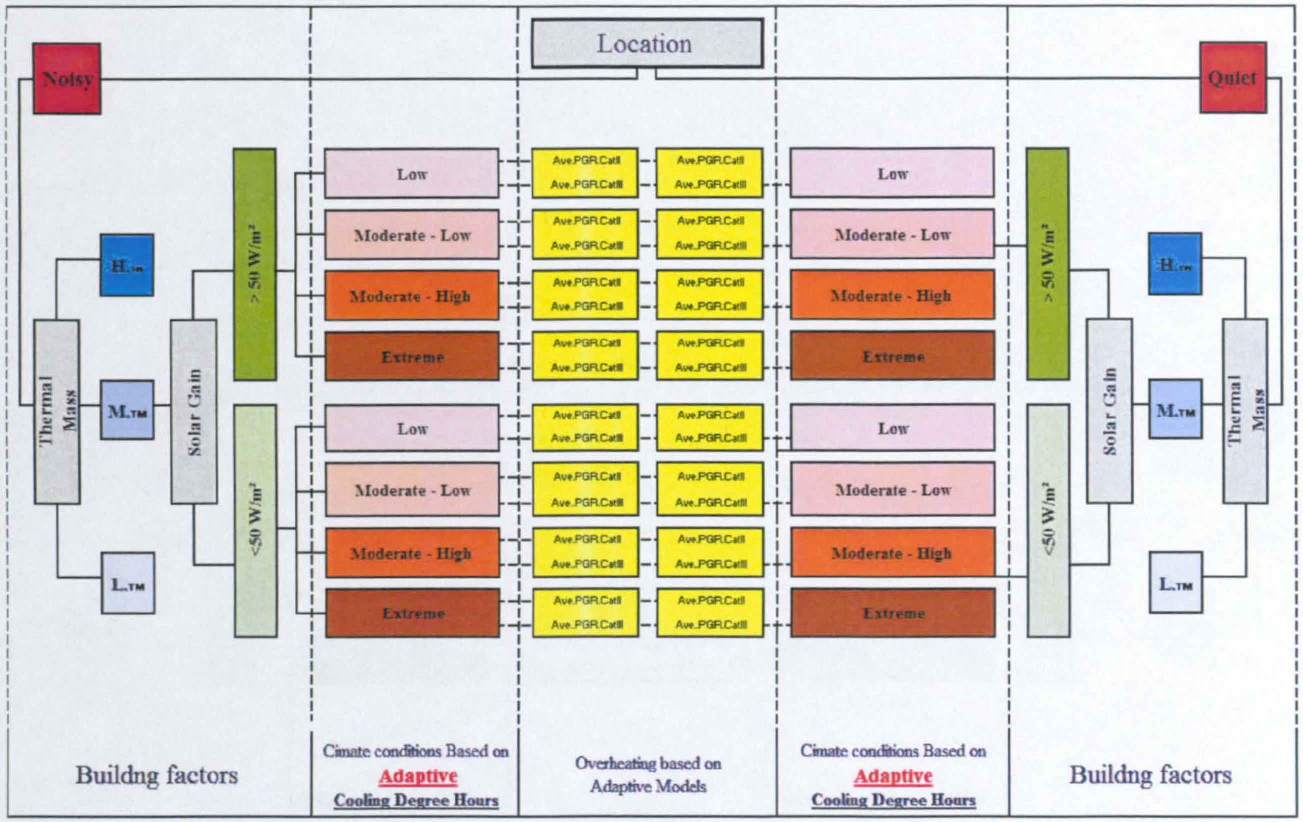
As can be seen from Graph 3-2.13, the classroom-days' indoor temperatures, which are compared with adaptive model are placed in two groups (noisy and quiet) which have similar building and climate conditions. The criterion which is used in this comparison is the percentage of dissatisfaction from overheating which is designed based on adaptive model (Criterion 1).

As can be seen from Graph 3-2.14, the classroom-days' indoor temperatures, which are compared with adaptive model are placed in two groups (noisy and quiet) which have similar building and climate conditions. The criterion which is used in this comparison is the maximum allowable differences from adaptive thermal comfort (Criterion 2).

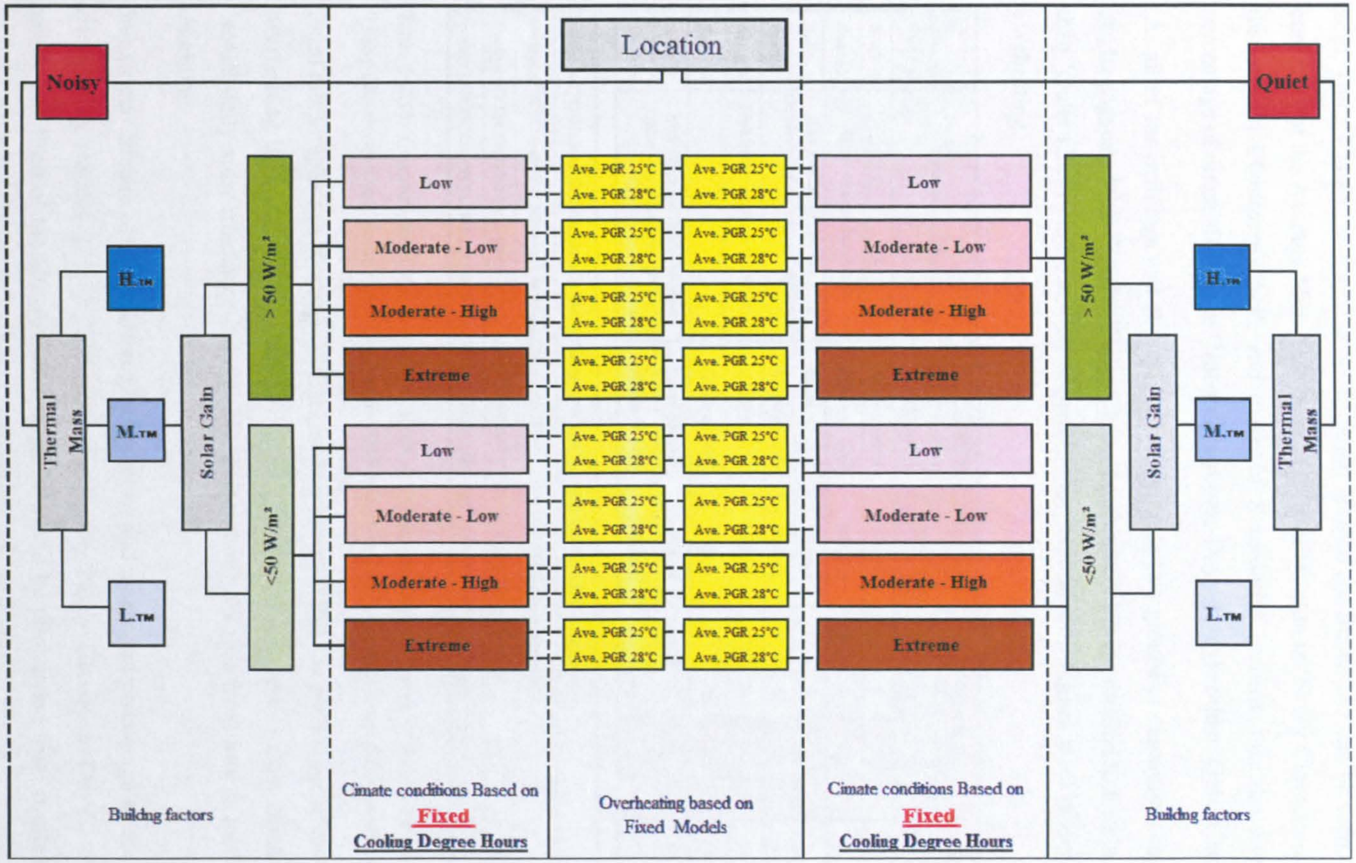
As can be seen from Graph 3-2.15, the classroom-days' indoor temperatures, which are compared with adaptive model are placed in two groups (noisy and quiet) which have similar building and climate conditions. In this comparison, the percentage of occasions that indoor temperatures exceed 25°C and 28°C in noisy and quiet classroom-days are compared with each other (Criterion 3).



Graph 3-2.13: Evaluating the impact of aircraft noise on percentage of dissatisfaction from overheating



Graph 3-2.14: Evaluating the impact of aircraft noise on the allowable differences from adaptive thermal comfort



Graph 3-2.15: Evaluating the impact of aircraft noise on the percentages of occasions that indoor temperatures exceed 25°C & 28°C

Criterion 1 - Study the impact aircraft noise on the percentage of occupants' dissatisfaction from overheating, according to Adaptive model:

Table 3-2.15 shows the comparison of the average of Mean & Maximum Percentages of dissatisfaction from overheating (according to the adaptive model) for the 'Noisy Classroom-Days' with 'Quiet Classroom-Days' under different climate conditions. As can be seen, all the scenarios confirm that the Average Mean Percentage of dissatisfaction in 'Noisy Classrooms-Days' is higher than 'Quiet Classroom-Days', and 6 out of 8 scenarios confirm that the Average Maximum percentage of dissatisfaction in 'Noisy Classrooms-Days' is higher than 'Quiet Classroom-Days' .

As all of the buildings and climate factors for these two groups of classrooms-days are similar, it can be suggested that that the 'Noisy Classrooms' have a lower potential to have natural ventilation than 'Quiet Classrooms', and consequently they experience a higher level of dissatisfaction from overheating.

Scenarios	Climate conditions	Building factors		Ave (PDH.Mean)			Ave (PDH.Maximum)		
		Risk of receiving solar gain	Thermal mass	Quiet	Noisy	Comparison	Quiet	Noisy	Comparison
Snario.1	Low Irradiance-Low Out.temp (Low climate condition)	Below 50 w/m²	Medium	4	5	Q<N	5	8	Q<N
Snario.2		Above 50 w/m²	Medium	3	5	Q<N	4	7	Q<N
Snario.3	High Irradiance-Low Out.temp (Moderate-Low climate condition)	Below 50 w/m²	Medium	5	6	Q<N	7	9	Q<N
Snario.4		Above 50 w/m²	Medium	5	6	Q<N	8	8	Q=N
Snario.5	High Irradiance-Meduim Out.temp (Moerate-High cliamte condition)	Below 50 w/m²	Medium	9	11	Q<N	18	18	Q=N
Snario.6		Above 50 w/m²	Medium	9	10	Q<N	13	15	Q<N
Snario.7	High Irradiance -High Out.temp (Extreme climate condition)	Below 50 w/m²	Medium	10	21	Q<N	13	29	Q<N
Snario.8		Above 50 w/m²	Medium	17	22	Q<N	27	37	Q<N

Average of PDH.Mean/PDH.Maximum in 'Noisy.Classroom-Days' is greater than 'Quiet.Classroom-Days'

Average of PDH.Mean/PDH.Maximum in 'Noisy.Classroom-Days' is lower than 'Quiet.Classroom-Days'

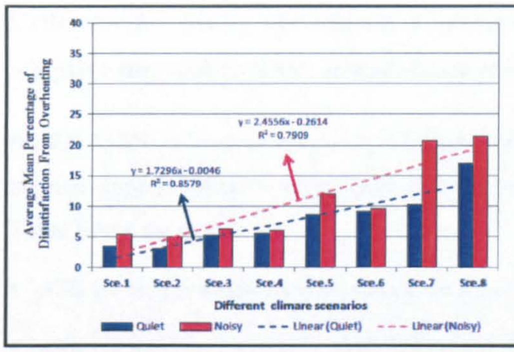
Average of PDH.Mean/PDH.Maximum in 'Noisy.Classroom-Days' is equal to 'Quiet.Classroom-Days'

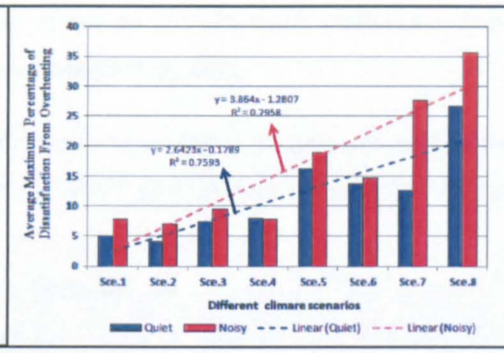
Average of PDH.Mean/PDH.Maximum in 'Noisy.Classroom-Days' and 'Quiet.Classroom-Days' are equal to zero

Table 3-2.15: Comparison of the average of Mean & Maximum percentages of dissatisfaction from overheating for 'Noisy Classroom-Days' with 'Quiet Classroom-Days' based on adaptive model under different climate conditions

From the Graphs 3-2.16 and 3-2.17, it can be concluded that the percentage of dissatisfaction from overheating in 'Noisy Classrooms' & 'Quiet Classrooms' increases as the climate condition (i.e. 'actual daily solar irradiances' & outside temperature) changes from low & moderate to extreme condition.

In extreme climate conditions, the average mean and maximum percentage of dissatisfaction from overheating reaches 22% & 37% respectively for 'Noisy Classroom-Days', which means that nearly one third of the classrooms' occupants would be dissatisfied from overheating in extreme climate conditions in noisy classroom, and this is considerable.





Graph 3-2.16: Average mean percentage of dissatisfaction from overheating for noisy and quiet classroom-days under different scenarios

Graph 3-2.17: Average max percentage of dissatisfaction from overheating for noisy and quiet classroom-days under different scenarios

By comparing the rate of indoor temperature increase based on climate conditions in noisy and quiet regions, it can be suggested that climate (outside temperature & actual daily solar irradiances) have a higher impact on 'noisy classrooms' (due to closed windows) compared to 'quiet-classrooms'. In the other words, the indoor temperature increases at a higher rate in noisy classrooms. The mean rate of increase in noisy classroom-days is 2.4 while it is 1.7 in quiet ones. The maximum rate of increase in noisy classroom-days is 3.6 while it is 2.6 in quiet ones. This difference may be due to both, the amount of heat which transfers inside through the buildings' fabric (as a consequence of high outside temperature), and solar irradiance. In these classrooms, heat may trap inside and cannot be removed due to a higher possibility of window closure, while in quiet classrooms, this heat may be removed by ventilation that discounts the rate of increase.

Generally, in a naturally ventilated building, the indoor temperature during summer increases by the amount of heat that transfers from the outside to inside through the buildings fabric. This is as a result of a high outside temperature and 'actual daily solar irradiances'. Similarly, the indoor temperature decreases by the amount of heat which is removed by ventilation.

The results of this part of study are summarised as follows:

First: it can be concluded that the percentage of occupants' dissatisfaction from overheating in 'Noisy Classroom-Days' are higher than 'Quiet Classroom-Days'.

Second: the percentage of occupants' dissatisfaction from overheating in noisy and quiet classrooms increases as the climate condition (i.e. 'actual daily solar irradiances' & outside temperature) changes from low to extreme condition.

Third: The rate of increase for the average of mean and max percentages of dissatisfaction from overheating for 'Noisy Classroom-Days' are higher than 'Quiet Classroom-Days'. This corresponds to the change of climate conditions [i.e. from 1 (low) to 4 (extreme)] due to closed windows.

Criterion 2 - Study the impact of aircraft noise on the allowable difference from adaptive thermal comfort temperature (recommended by BS):

BS EN 15251 defines a maximum allowable difference between indoor temperature and adaptive thermal comfort temperature (calculated from Tc=0.33Trm + 18.8) for new and existing buildings. These limits are as follows:

- +3K for new and renovated buildings (normal expectation).
- +4K for existing buildings (moderate expectation).

As mentioned in part 2 of this research, the percentage of occasions that indoor temperature goes above the adaptive thermal comfort by at least 3 & 4 K are calculated for each classroom on each day. As it is not clear as to which classroom has been renovated, each classroom is assessed against both the new and existing criteria.

The following table (Table 3-2.16) shows the comparison of the percentages of occasions that the indoor temperatures exceed the adaptive thermal comfort by at least 3 & 4 K for the 'Noisy Classroom-Days' with 'Quiet Classroom-Days' under different climate conditions.

Scenarios	Climate conditions	Building factors		Ave (PGR.Cat2)			Ave (PGR.Cat3)		
		Risk of receiving solar gain	Thermal mass	Quiet	Noisy	Comparison	Quiet	Noisy	Comparison
Snario.1	Low Irradiance-Low Out.temp **(Low climate condition)**	Below 50 w/m²	Medium	0	0	N=Q (Not.app)	0	0	N=Q (Not.app)
Snario.2		Above 50 w/m²	Medium	0	0	N=Q (Not.app)	0	0	N=Q (Not.app)
Snario.3	High Irradiance-Low Out.temp **(Moderate-Low climate condition)**	Below 50 w/m²	Medium	0	0	N=Q (Not.app)	0	0	N=Q (Not.app)
Snario.4		Above 50 w/m²	Medium	0	0	N=Q (Not.app)	0	0	N=Q (Not.app)
Snario.5	High Irradiance-Meduim Out.temp **(Moerate-High cliamte condition)**	Below 50 w/m²	Medium	2	4	Q<N	0	1	Q<N
Snario.6		Above 50 w/m²	Medium	0	0	N=Q (Not.app)	0	0	N=Q (Not.app)
Snario.7	High Irradiance -High Out.temp **(Extreme climate condition)**	Below 50 w/m²	Medium	0	31	Q<N	0	1	Q<N
Snario.8		Above 50 w/m²	Medium	20	38	Q<N	6	14	Q<N

Legend	Colour
Average of PGR.Cat2/PGR.Cat3 in 'Noisy.Classroom-Days' is greater than 'Quiet.Classroom-Days'	(orange)
Average of PGR.Cat2/PGR.Cat3 in 'Noisy.Classroom-Days' is lower than 'Quiet.Classroom-Days'	(blue)
Average of PGR.Cat2/PGR.Cat3 in 'Noisy.Classroom-Days' is equal to 'Quiet.Classroom-Days'	(green)
Average of PGR.Cat2/PGR.Cat3 in 'Noisy.Classroom-Days' and 'Quiet.Classroom-Days' are equal to zero	(purple)

Table 3-2.16: Comparison of the percentage of occasions that indoor temperatures exceed adaptive thermal comfort by at least 3 & 4K in 'Noisy Classroom-Days' with 'Quiet Classroom-Days'

The above table (Table 3-2.16) shows that the classroom-days' indoor temperatures do not exceed 3K (Cat2) & 4K (Cat3) above adaptive thermal comfort in 5 out of 8 scenarios. Therefore, a comparison between them is not possible. This could be associated with the low & moderate climate conditions that did not cause classroom-days' indoor temperature to exceed 3 and 4K above the adaptive thermal comfort.

- In scenario no.5 the percentages of occasions where the classroom-days' indoor temperatures exceed the adaptive thermal comfort by 3 & 4K in noisy regions are higher than those in quiet regions by 2% & 1%, respectively. This condition is for *'moderate-high climate condition'* for the classrooms with *'the maximum risk of receiving solar gain of below 50W/m²'.*
- In scenario no.7 the percentage of occasions where the classroom-days' indoor temperatures exceed the adaptive thermal comfort by 3K in noisy regions is higher than those in quiet regions by 31%. This condition is for *'extreme climate condition'* for classrooms with *'the maximum risk of receiving solar gain of below 50W/m²'.*
- In scenario no.8 the percentages of occasions that classroom-days' indoor temperature exceed the adaptive thermal comfort by 3 & 4K in noisy regions are higher than those in quiet regions by 52% & 43% respectively. This condition is for *'extreme climate condition'* for classrooms with *'the maximum risk of receiving solar gain of above 50W/m²'.*

The results of this part of the study are summarised as follows:

First: It can be concluded that the classroom-days' indoor temperatures hardly exceed 3 & 4K above adaptive thermal comfort under low & moderate climate conditions, while they significantly exceed this level under extreme climate condition.

Second: The percentage of the occasions that indoor temperatures exceed the adaptive thermal comfort by 3&4K for the 'Noisy Classroom-Days' is higher than those for quiet ones under the extreme climate condition.

Criterion 3 - Study the impact of aircraft noise on the percentage of occupants' dissatisfaction from overheating according to Fixed model:

At the first stage of this analysis, it was mentioned that the adaptive model is a more appropriate tool to evaluate the occupants' dissatisfaction from overheating when compared to the fixed model. According to the fixed model, people feel dissatisfied, as they feel warm if the indoor temperature goes above 25°C, and hot if goes above 28°C.

The following table (Table 3-2.17) shows the comparison of the percentages of occasions that indoor temperatures exceed 25°C & 28°C in noisy and quiet classroom-days, and consequently occupants feel dissatisfied.

Scenarios	Climate conditions	Building factors		Ave (PGR.25°C)			Ave (PGR.28°C)		
		Risk of receiving solar gain	Thermal mass	Quiet	Noisy	Comparison	Quiet	Noisy	Comparison
Snario.1	Low Irradiance-Low Out.temp (Low climate condition)	Below 50 w/m²	Medium	3	11	Q<N	0	0	N=Q (Not.app)
Snario.2		Above 50 w/m²	Medium	2	4	Q<N	0	0	N=Q (Not.app)
Snario.3	High Irradiance-Low Out.temp (Moderate-Low climate condition)	Below 50 w/m²	Medium	10	16	Q<N	0	0	N=Q (Not.app)
Snario.4		Above 50 w/m²	Medium	19	10	Q>N	1	1	N=Q
Snario.5	High Irradiance-Meduim Out.temp (Moerate-High cliamte condition)	Below 50 w/m²	Medium	96	100	Q<N	0	42	Q<N
Snario.6		Above 50 w/m²	Medium	86	89	Q<N	6	4	Q>N
Snario.7	High Irradiance -High Out.temp (Extreme climate condition)	Below 50 w/m²	Medium	63	100	Q<N	0	38	Q<N
Snario.8		Above 50 w/m²	Medium	91	100	Q<N	25	45	Q<N

Average of PGR.25°C/PGR.28°C in 'Noisy.Classroom-Days' is greater than 'Quiet.Classroom-Days'	(orange)
Average of PGR.25°C/PGR.28°C in 'Noisy.Classroom-Days' is lower than 'Quiet.Classroom-Days'	(blue)
Average of PGR.25°C/PGR.28°C in 'Noisy.Classroom-Days' is equal to 'Quiet.Classroom-Days'	(green)
Average of PGR.25°C/PGR.28°C in 'Noisy.Classroom-Days' and 'Quiet.Classroom-Days' are equal to zero	(lilac)

Table 3-2.17: Comparison of the percentages of occasions that indoor temperatures exceed 25°C & 28°C in noisy and quiet classroom-days

As can be seen, in 7 out of 8 scenarios, the percentages of the occasions when classroom-days' indoor temperatures exceed 25°C in noisy regions, is higher than those in quiet regions. In addition, in 3 out of 8 scenarios, the percentages of the occasions where classroom-day's indoor temperatures exceed 28°C in noisy regions is higher than quiet regions with the exception of one scenario (scenario4).

In 3 out of 8 scenarios, the classroom-days' indoor temperature do not exceed 28°C, which could be the result of low & moderate climate conditions that did not cause classroom-days' indoor temperatures to exceed 28°C. Therefore it is not possible to compare these scenarios.

The results of this part of study are summarised as follows:

First: In general, nearly under all climate conditions the occupants of noisy classrooms feel warmer compared to those in quiet ones.

Second: In general under only extreme climate conditions, the occupants of noisy classrooms feel overheated more than those in quiet classrooms.

a2) Results of the objective survey based on general procedure:

The summary of this studies are as follows:

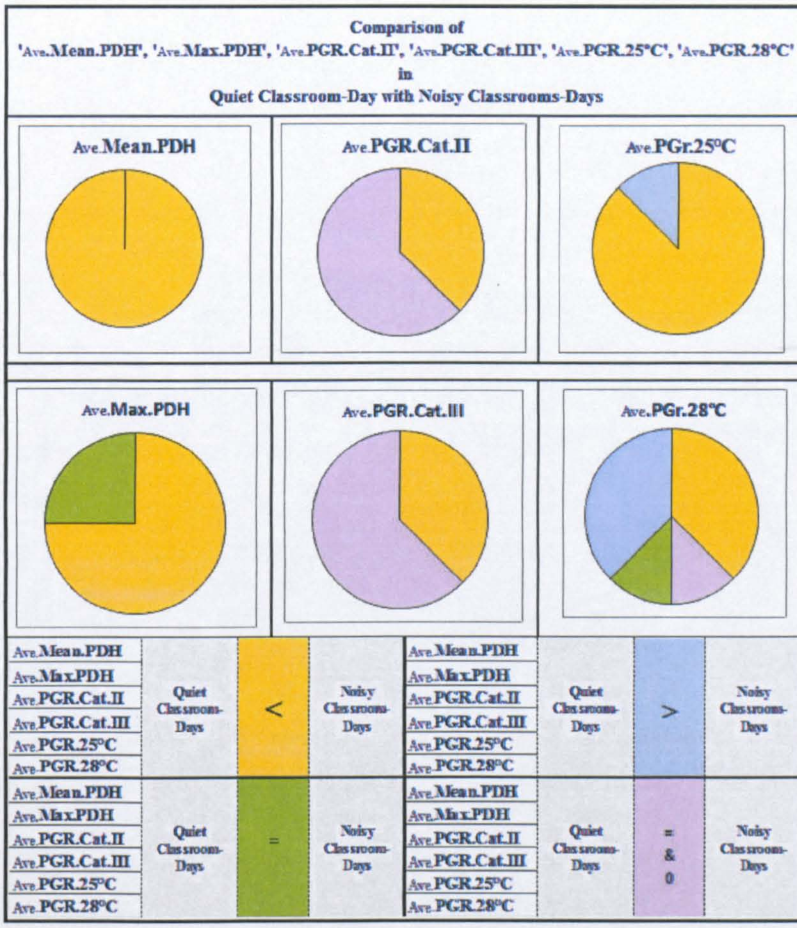
- Based on criterion one, the percentage of occupants' dissatisfaction from overheating is generally higher in *'Noisy Classroom-Days'* in comparison to those in quiet regions under all climate conditions with an exception of 2 cases in which the Average Maximum percentage of occupants' dissatisfaction from overheating is equal in quiet and noise Classroom-Days.

- Based on criterion two, the maximum allowable differences from adaptive thermal comfort are higher in *'Noisy Classroom-Days'* in comparison to those in quiet regions under 'extreme climate condition' (i.e. high 'actual daily solar irradiance' and high outside temperature), with the exception of 10 cases in which the percentage of occupied hours that exceed the maximum allowable difference from the adaptive thermal comfort is 0, in both *'Noisy Classroom-Days'* and *'Quiet Classroom-Days'*. This is related to the climate condition.

- Based on criterion three, the percentage of occasions that the indoor temperatures exceed 25°C and 28°C are higher in *Noisy Classroom-Days'* than those in quiet regions under all climate conditions with the exception of 2 cases in which these occasions are higher in *'Quiet Classroom-Days'* and 3 cases in which these occasions are 0 in *'Noisy Classrooms-Days'* and *'Quiet Classroom-Days'*. This is due to the 'Low and Moderate-Low climate conditions'.

The above summaries are illustrated in Graph 3-2.18 in the next page.

The following pie-charts (Graph 3-2.18) are the summary of the above study which shows the comparisons of the Ave.Mean.PDH, Ave.Max.PDH, Ave.PGR.Cat.II, Ave.PGR.CatIII, Ave.PGR.25°C and Ave.PGr.28°C in quiet classroom-days with noisy classroom-days. As can be seen, in each pie-charts, a considerable portions is taken by the situations where Ave.Mean.PDH, Ave.Max.PDH, Ave.PGR.Cat.II, Ave.PGR.CatIII, Ave.PGR.25°C and Ave.PGr.28°C is higher in 'Noisy Classroom-Days' than those of 'Quiet Classroom-Days'.



Graph 3-2.18: Pie charts comparing Ave.Mean.PDH, Ave.Max.PDH, Ave.PGR.Cat.II, Ave.PGR.CatIII, Ave.PGR.25°C and Ave.PGr.28°C in Quiet Classroom-Days with Noisy Classroom-Days

As the buildings and climate factors in the classrooms of each specific scenario are the same, it can be suggested that aircraft noise level has an impact on indoor temperature and it may also be possible to suggest that the occupants of noisy classrooms tend to close windows to attenuate the background noise level to an acceptable level. Due to the fact that there are some exceptions, it is not yet possible to generalise this findings to confirm aircraft noise has an impact on indoor temperature. In order to generalise this finding, a study should be carried out in more detail and T test should be run on Ave.Mean.PDH, Ave.Max.PDH, Ave.PGR.CatII, Ave.PGR.CatIII, Ave.PGR.25°C and Ave.PGR28°C of 'Noisy Classroom-Days' and 'Quiet Classroom-Days'. The results would confirm whether the indoor temperature on 'Noisy Classroom-Days' is significantly higher than the 'Quiet Classroom-Days'. For this reason, the study is carried out in more detail (Detailed Procedure).

b) Detailed Procedure

In detailed procedure, two approaches are suggested in order to investigate the impact of aircraft noise on indoor temperature more accurately:

The impact of aircraft noise on indoor temperature is evaluated based on the adaptive model (first approach) and fixed model (second approach). These methods are carried out based on two-series of data which are as follows:

First series of data:

- Mean percentage of dissatisfaction from overheating
- Maximum percentage of dissatisfaction from overheating
- Percentage of occasions that indoor temperatures exceed the adaptive thermal comfort by 3K (CatII)
- Percentage of occasions that indoor temperatures exceed the adaptive thermal comfort by 4K (CatIII)

Second series of data:

- Percentage of occasions that indoor temperatures exceed the fixed thermal threshold of 25°C (occupant start to feel warm).
- Percentage of occasions that indoor temperatures exceed the fixed thermal threshold of 28°C (occupant start to feel warm).

The two methods are as follows:

b1) Method 1

In this method, the classroom-days which are assessed based on adaptive overheating model are divided into 11 groups (instead of three), based on their corresponding adaptive cooling degree hours. Adaptive cooling degree hour, is a 'cooling degree hours' which is calculated based on 'adaptive thermal comfort'. The range of adaptive cooling degree hours varies from 0 to 22. The range of adaptive cooling degree hours for the days of this study are 0,1,3,4,5,6,8,9,14,17 and 22. As these data are not normally distributed, it is suggested that the classroom-days are divided into the following groups for comparison in order to have more accurate results:

- Group 1: Includes the classroom-days' corresponding to the adaptive cooling degree hours of '0'.
- Group 2: Includes the classroom-days' corresponding to the adaptive cooling degree hours of '1'.
- Group 3: Includes the classroom-days' corresponding to the adaptive cooling degree hours of '3'.
- Group 4: Includes the classroom-days' corresponding to the adaptive cooling degree hours of '4'.
- Group 5: Includes the classroom-days' corresponding to the adaptive cooling degree hours of '5'.
- Group 6: Includes the classroom-days' corresponding to the adaptive cooling degree hours of '6'.
- Group 7: Includes the classroom-days' corresponding to the adaptive cooling degree hours of '8'.
- Group 8: Includes the classroom-days' corresponding to the adaptive cooling degree hours of '9'.
- Group 9: Includes the classroom-days' corresponding to the adaptive cooling degree hours of '14'.
- Group 10: Includes the classroom-days' corresponding to the adaptive cooling degree hours of '17'.
- Group 11: Includes the classroom-days' corresponding to the adaptive cooling degree hours of '22'.

As it was explained earlier, the classrooms days not only are categorised based on cooling degree hours but also based on actual daily solar irradiance, the maximum risk of receiving solar gain and their thermal mass level.

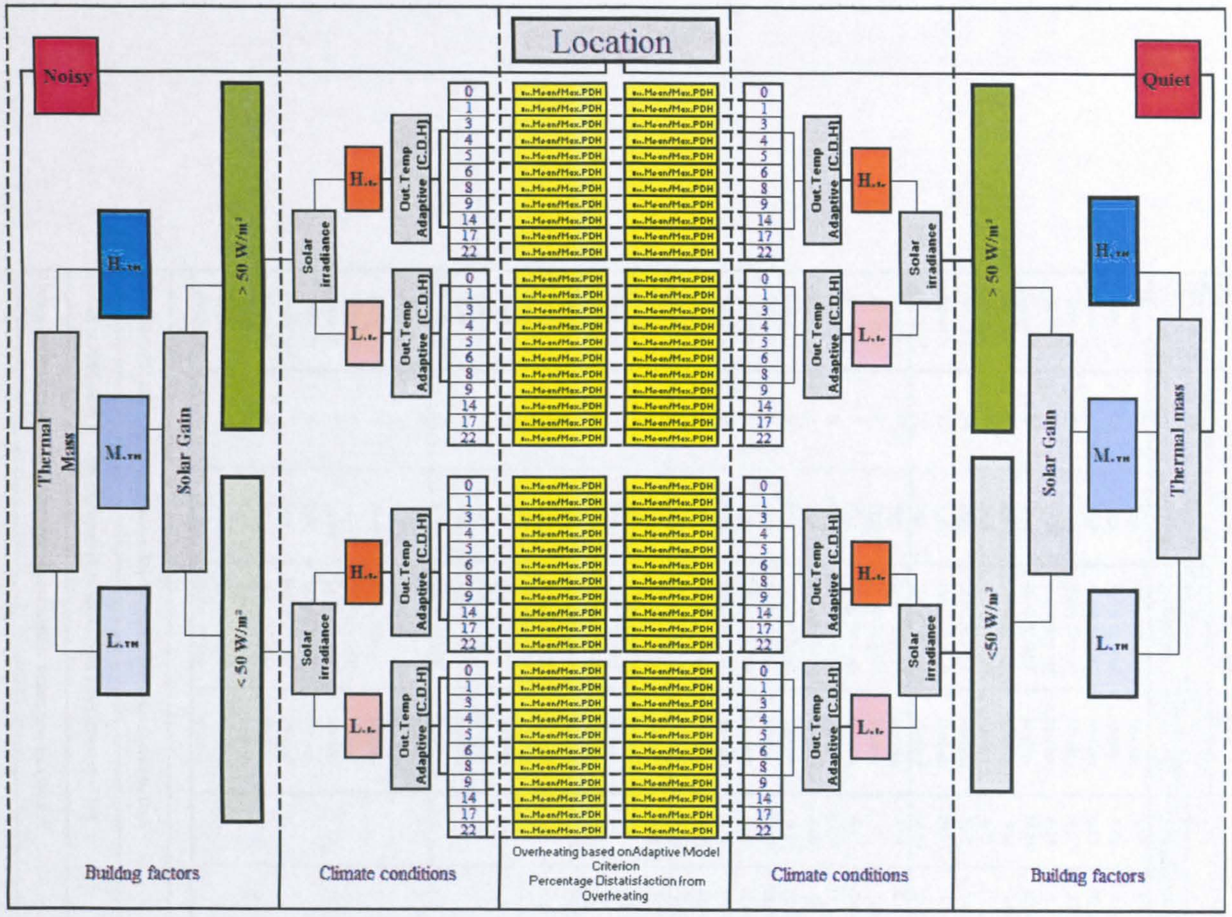
Graph 3-2.19 shows the comparison of the averages of 'maximum percentages of dissatisfaction from overheating' for 'Noisy Classrooms-Days' with 'Quiet Classrooms-Days' that have similar thermal mass, risk of receiving solar gain, solar irradiance and adaptive cooling degree hours.

Graph 3-2.20 shows the comparison of the averages of 'percentage of occasions that indoor temperatures exceed adaptive thermal comfort by 3K (CatII)' for 'Noisy Classrooms-Days' with 'Quiet Classrooms-Days' that have similar thermal mass, risk of receiving solar gain, solar irradiance and adaptive cooling degree hours.

Tables 3-2.18, 3-2.20, 3-2.22 and 3-2.24 show the following data based on adaptive cooling degree hours, actual daily irradiance, maximum risk of receiving solar gain and thermal mass level for Noisy and Quiet Classroom-Days.

Average of 'mean percentage of dissatisfaction from overheating'

- Average of 'maximum percentage of dissatisfaction from overheating'
- Average of 'percentage of occasions that indoor temperatures exceed the adaptive thermal comfort by 3K (CatII)'
- Average of 'percentage of occasions that indoor temperatures exceed the adaptive thermal comfort by 4K (CatIII)'



Graph 3-2.19: Comparison of the averages of 'maximum percentage of dissatisfaction from overheating' for

'Noisy Classroom-days' with 'Quiet Classroom-Days' which have similar thermal mass, risk of receiving solar gain, solar irradiance and adaptive cooling degree hours

- Criterion 1.1: Impact of aircraft noise on Mean percentage of dissatisfaction from overheating

The averages of 'mean percentages of dissatisfaction from overheating' in noisy and quiet classroom-days are compared with each other based on cooling degree hours, actual daily solar irradiance, maximum risk of receiving solar gain and thermal mass level in Table 3-2.18.

Scenarios	Climate Conditions		Building factors		Ave (PDH.MEAN)		
	Cooling degree hours	Actual daily irradince	Risk of receiving solar gain	Thermal mass	Quiet	Noisy	Comparison
Snario.1	0	High	Above 50 w/m²	Medium	5.87	5.51	Q>N
Snario.2	1	High	Above 50 w/m²	Medium	4.86	7.11	Q<N
Snario.3	3	High	Above 50 w/m²	Medium	6.33	10.56	Q<N
Snario.4	4	High	Above 50 w/m²	Medium	10.75	9.42	Q>N
Snario.5	5	High	Above 50 w/m²	Medium	6.13	3.9	Q>N
Snario.6	6	High	Above 50 w/m²	Medium	11.86	10.51	Q>N
Snario.7	8	High	Above 50 w/m²	Medium	9.8	8.81	Q>N
Snario.8	9	High	Above 50 w/m²	Medium	8.72	15.87	Q<N
Snario.9	14	High	Above 50 w/m²	Medium	12.7	18.8	Q<N
Snario.10	17	High	Above 50 w/m²	Medium	19.75	19.51	Q>N
Snario.11	22	High	Above 50 w/m²	Medium	18.64	27.83	Q<N
Snario.12	0	High	Below 50 w/m²	Medium	5.14	6.43	Q<N
Snario.13	1	High	Below 50 w/m²	Medium	6	7.19	Q<N
Snario.14	3	High	Below 50 w/m²	Medium	4.47	7.68	Q<N
Snario.15	4	High	Below 50 w/m²	Medium	12.52	11.31	Q>N
Snario.16	5	High	Below 50 w/m²	Medium	4.69	9.3	Q<N
Snario.17	6	High	Below 50 w/m²	Medium	9.3	19.54	Q<N
Snario.18	8	High	Below 50 w/m²	Medium	11.67	11.09	Q>N
Snario.19	9	High	Below 50 w/m²	Medium	4.04	11.94	Q<N
Snario.20	14	High	Below 50 w/m²	Medium	5.53	18.57	Q<N
Snario.21	17	High	Below 50 w/m²	Medium	14.68	22.84	Q<N
Snario.22	22	High	Below 50 w/m²	Medium	10.41	20.12	Q<N
Snario.23	0	Low	Above 50 w/m²	Medium	3.19	4.56	Q<N
Snario.24	1	Low	Above 50 w/m²	Medium	-	-	-
Snario.25	3	Low	Above 50 w/m²	Medium	-	-	-
Snario.26	4	Low	Above 50 w/m²	Medium	-	-	-
Snario.27	5	Low	Above 50 w/m²	Medium	12.28	19.83	Q<N
Snario.28	6	Low	Above 50 w/m²	Medium	-	-	-
Snario.29	8	Low	Above 50 w/m²	Medium	-	-	-
Snario.30	9	Low	Above 50 w/m²	Medium	-	-	-
Snario.31	14	Low	Above 50 w/m²	Medium	-	-	-
Snario.32	17	Low	Above 50 w/m²	Medium	-	-	-
Snario.33	22	Low	Above 50 w/m²	Medium	-	-	-
Snario.34	0	Low	Below 50 w/m²	Medium	3.85	5.34	Q<N
Snario.35	1	Low	Below 50 w/m²	Medium	-	-	-
Snario.36	3	Low	Below 50 w/m²	Medium	-	-	-
Snario.37	4	Low	Below 50 w/m²	Medium	-	-	-
Snario.38	5	Low	Below 50 w/m²	Medium	7.72	13.26	Q<N
Snario.39	6	Low	Below 50 w/m²	Medium	-	-	-
Snario.40	8	Low	Below 50 w/m²	Medium	-	-	-
Snario.41	9	Low	Below 50 w/m²	Medium	-	-	-
Snario.42	14	Low	Below 50 w/m²	Medium	-	-	-
Snario.43	17	Low	Below 50 w/m²	Medium	-	-	-
Snario.44	22	Low	Below 50 w/m²	Medium	-	-	-

Average of PDH.Mean in 'Noisy.Classroom-Days' is greater than 'Quiet.Classroom-Days'	
Average of PDH.Mean in 'Noisy.Classroom-Days' is lower than 'Quiet.Classroom-Days'	
Average of PDH.Mean in 'Noisy.Classroom-Days' is equal to 'Quiet.Classroom-Days'	
Average of PDH.Mean in 'Noisy.Classroom-Days' and 'Quiet.Classroom-Days' are equal to zero	
No data	-

Table 3-2.18: Averages of 'mean percentage of dissatisfaction from overheating' for noisy and quiet classroom-days based on cooling degree hours, actual daily solar irradiance, risk of receiving solar gain and thermal mass level.

A T test is carried out between the averages of 'mean percentages of dissatisfaction from overheating' for noisy classroom-days and quiet classroom-days. As can be seen from Table 3-2.19, they are significantly different (P <0.05) with an average difference of 3.68%. These differences vary from 1.92% to 5.45 %. Therefore, it is suggested that aircraft noise is a predictor for the mean percentage of dissatisfaction from overheating and consequently indoor temperature. In this table, the 'standard deviation' of all data is 4.37. 'Standard error mean' is calculated by dividing 'standard deviation' to the square root of the number of data. T value is calculated by the differences between the mean data in each group divided by 'standard error'. Degree of freedom (df) is calculated by subtracting 1 from the number of data. P value is derived from a table which is calculated based on 'T value' and 'Degree of freedom'.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	N.PDH.MEAN	12.5704	26	6.44980	1.26491
	Q.PDH.MEAN	8.8808	26	4.48219	.87903

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	N.PDH.MEAN - Q.PDH.MEAN	3.68962	4.37236	.85749	1.92358	5.45565	4.303	25	.000

Table 3-2.19: Comparison of the averages of 'mean percentage of dissatisfaction from overheating' for 'Noisy classroom-days' with 'Quiet Classroom-Days' using Paired Samples Test

- **Criterion 1.2: Impact of aircraft noise on Maximum percentage of dissatisfaction from overheating**

The averages of 'maximum percentages of dissatisfaction from overheating' in noisy and quiet classroom-days are compared with each other based on cooling degree hours, actual daily solar irradiance, maximum risk of receiving solar gain and thermal mass level in Table 3-2.20.

Scenarios	Climate Conditions		Building factors		Ave (PDH.MAX)		
	Cooling degree hours	Actual daily irradince	Risk of receiving solar gain	Thermal mass	Quiet	Noisy	Comparison
Snario.1	0	High	Above 50 w/m²	Medium	7.75	7.93	Q<N
Snario.2	1	High	Above 50 w/m²	Medium	7.65	10.85	Q<N
Snario.3	3	High	Above 50 w/m²	Medium	11.71	25.75	Q<N
Snario.4	4	High	Above 50 w/m²	Medium	14.82	14.9	Q<N
Snario.5	5	High	Above 50 w/m²	Medium	13.26	7.97	Q>N
Snario.6	6	High	Above 50 w/m²	Medium	20	21.17	Q<N
Snario.7	8	High	Above 50 w/m²	Medium	14.28	13.69	Q>N
Snario.8	9	High	Above 50 w/m²	Medium	12.72	24.44	Q<N
Snario.9	14	High	Above 50 w/m²	Medium	20.67	34.42	Q<N
Snario.10	17	High	Above 50 w/m²	Medium	30.92	33.9	Q<N
Snario.11	22	High	Above 50 w/m²	Medium	22.52	43	Q<N
Snario.12	0	High	Below 50 w/m²	Medium	7.32	9.39	Q<N
Snario.13	1	High	Below 50 w/m²	Medium	9.27	10.8	Q<N
Snario.14	3	High	Below 50 w/m²	Medium	6.22	12.29	Q<N
Snario.15	4	High	Below 50 w/m²	Medium	18.71	17.89	Q<N
Snario.16	5	High	Below 50 w/m²	Medium	7.97	15.81	Q<N
Snario.17	6	High	Below 50 w/m²	Medium	11.64	24.91	Q<N
Snario.18	8	High	Below 50 w/m²	Medium	23.53	17.7	Q<N
Snario.19	9	High	Below 50 w/m²	Medium	6.47	17.34	Q<N
Snario.20	14	High	Below 50 w/m²	Medium	5.89	27.02	Q<N
Snario.21	17	High	Below 50 w/m²	Medium	16.63	29.63	Q<N
Snario.22	22	High	Below 50 w/m²	Medium	15.47	31.14	Q<N
Snario.23	0	Low	Above 50 w/m²	Medium	4.27	6.48	Q<N
Snario.24	1	Low	Above 50 w/m²	Medium	–	–	–
Snario.25	3	Low	Above 50 w/m²	Medium	–	–	–
Snario.26	4	Low	Above 50 w/m²	Medium	–	–	–
Snario.27	5	Low	Above 50 w/m²	Medium	19.08	25.57	Q<N
Snario.28	6	Low	Above 50 w/m²	Medium	–	–	–
Snario.29	8	Low	Above 50 w/m²	Medium	–	–	–
Snario.30	9	Low	Above 50 w/m²	Medium	–	–	–
Snario.31	14	Low	Above 50 w/m²	Medium	–	–	–
Snario.32	17	Low	Above 50 w/m²	Medium	–	–	–
Snario.33	22	Low	Above 50 w/m²	Medium	–	–	–
Snario.34	0	Low	Below 50 w/m²	Medium	5.52	7.71	Q<N
Snario.35	1	Low	Below 50 w/m²	Medium	–	–	–
Snario.36	3	Low	Below 50 w/m²	Medium	–	–	–
Snario.37	4	Low	Below 50 w/m²	Medium	–	–	–
Snario.38	5	Low	Below 50 w/m²	Medium	10.51	19.88	Q<N
Snario.39	6	Low	Below 50 w/m²	Medium	–	–	–
Snario.40	8	Low	Below 50 w/m²	Medium	–	–	–
Snario.41	9	Low	Below 50 w/m²	Medium	–	–	–
Snario.42	14	Low	Below 50 w/m²	Medium	–	–	–
Snario.43	17	Low	Below 50 w/m²	Medium	–	–	–
Snario.44	22	Low	Below 50 w/m²	Medium	–	–	–

Average of PDH.Max in 'Noisy.Classroom-Days' is greater than 'Quiet.Classroom-Days'	
Average of PDH.Max in 'Noisy.Classroom-Days' is lower than 'Quiet.Classroom-Days'	
Average of PDH.Max in 'Noisy.Classroom-Days' is equal to 'Quiet.Classroom-Days'	
Average of PDH.Max in 'Noisy.Classroom-Days' and 'Quiet.Classroom-Days' are equal to zero	
No data	–

Table 3-2.20: Averages of 'maximum percentages of dissatisfaction from overheating for noisy and quiet classroom-days based on cooling degree hours, actual daily solar irradiance, risk of receiving solar gain and thermal mass level.

A T test is carried out between the averages of 'maximum percentages of dissatisfaction from overheating' for noisy classroom-days and quiet classroom-days. As can be seen from Table 3-2.21, they are significantly different (P<0.05) with an average difference of 6.41%. These differences vary from 3.43% to 9.38 %. Therefore, it is suggested that aircraft noise is a predictor for the maximum percentage of dissatisfaction from overheating and consequently indoor temperature. In this table, the 'standard deviation' of all data is 7.36. 'Standard error mean' is calculated by dividing 'standard deviation' to the square root of number of data. T value is calculated by the differences between the mean data in each group divided by 'standard error'. Degree of freedom (df) is calculated by subtracting 1 from the number of data. P value is derived from a table which is calculated based on T value and Degree of freedom.

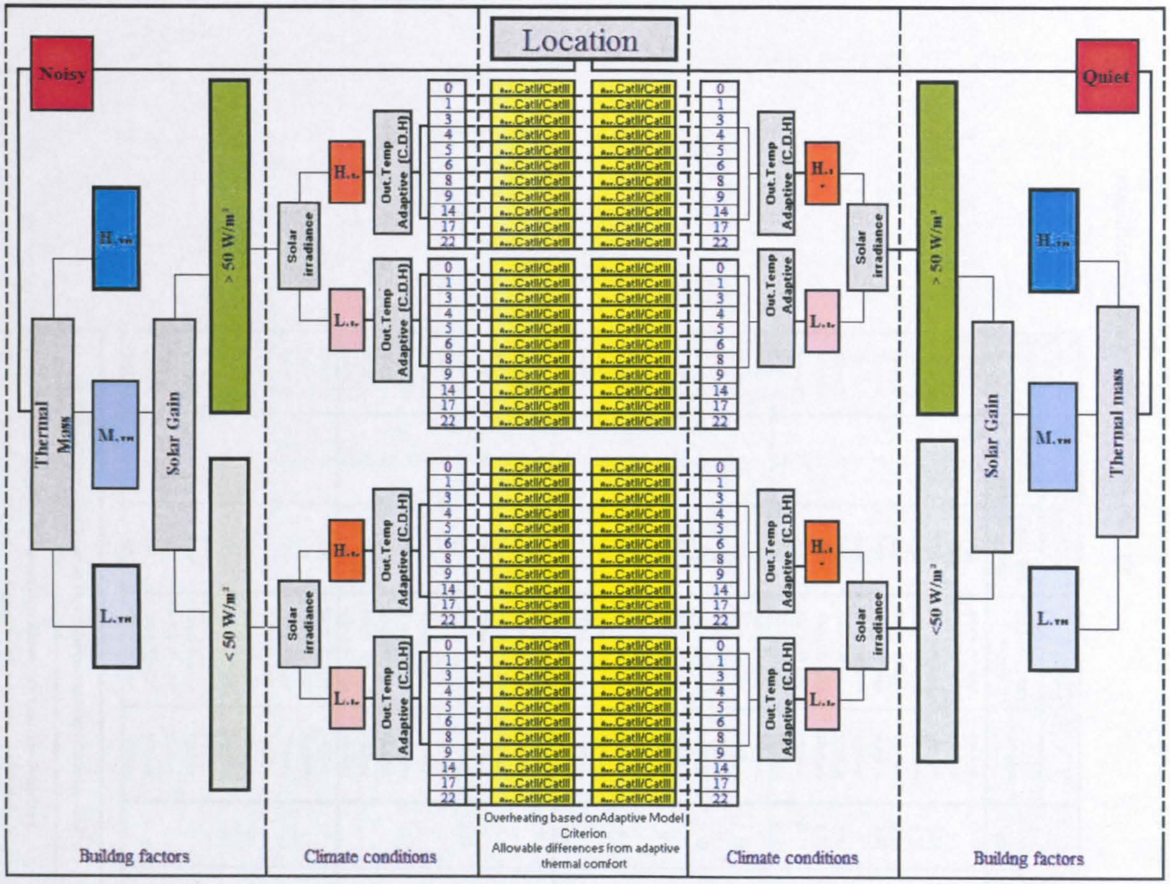
Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	N.PDH.MAX	19.6762	26	9.73170	1.90854
	Q.PDH.MAX	13.2615	26	6.72706	1.31928

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	N.PDH.MAX - Q.PDH.MAX	6.41462	7.36607	1.44460	3.43940	9.38983	4.440	25	.000

Table 3-2.21: Comparison of the averages of 'maximum percentage of dissatisfaction from overheating' for 'Noisy Classrooms-Days' with 'Quiet Classrooms-Days' using Paired Samples Test



Graph 3-2.20: Comparison of the averages of 'percentage of occasions that indoor temperatures exceed adaptive thermal comfort by 3K (CatII)' for 'Noisy Classrooms-Days' with 'Quiet Classrooms-Days' that have similar thermal mass, risk of receiving solar gain, solar irradiance and adaptive cooling degree hours

- Criterion 2.1. Impact of aircraft noise on the occasions that indoor temperatures exceed the adaptive thermal comfort by at least 3K (CatII) in noisy and quiet Classroom-Days

The averages of 'percentages of occasions that indoor temperatures exceed the adaptive thermal comfort by at least 3K (CatII)' in noisy and quiet classroom-days are compared with each other based on cooling degree hours, actual daily solar irradiance, maximum risk of receiving solar gain and thermal mass level in Table 3-2.22.

Scenarios	Climate Conditions		Building factors		Ave (PGR.CatII)		
	Cooling degree hours	Actual daily irradince	Risk of receiving solar gain	Thermal mass	Quiet	Noisy	Comparison
Snario.1	0	High	Above 50 w/m²	Medium	0.97	0.19	Q>N
Snario.2	1	High	Above 50 w/m²	Medium	0	0	Q=N
Snario.3	3	High	Above 50 w/m²	Medium	0.84	7.14	Q<N
Snario.4	4	High	Above 50 w/m²	Medium	0.59	0.59	Q>N
Snario.5	5	High	Above 50 w/m²	Medium	0.84	0	Q>N
Snario.6	6	High	Above 50 w/m²	Medium	2.94	0	Q>N
Snario.7	8	High	Above 50 w/m²	Medium	0	0	Q=N
Snario.8	9	High	Above 50 w/m²	Medium	1.26	3.57	Q<N
Snario.9	14	High	Above 50 w/m²	Medium	2.52	21.42	Q<N
Snario.10	17	High	Above 50 w/m²	Medium	28.99	21.42	Q>N
Snario.11	22	High	Above 50 w/m²	Medium	28.99	71.42	Q<N
Snario.12	0	High	Below 50 w/m²	Medium	0	0.3247	Q<N
Snario.13	1	High	Below 50 w/m²	Medium	1.19	0.14	Q>N
Snario.14	3	High	Below 50 w/m²	Medium	0	0	Q=N
Snario.15	4	High	Below 50 w/m²	Medium	9.52	3.57	Q>N
Snario.16	5	High	Below 50 w/m²	Medium	0	0	Q=N
Snario.17	6	High	Below 50 w/m²	Medium	0	9.52	Q<N
Snario.18	8	High	Below 50 w/m²	Medium	3.57	4.08	Q<N
Snario.19	9	High	Below 50 w/m²	Medium	0	0	Q>N
Snario.20	14	High	Below 50 w/m²	Medium	0	45.23	Q<N
Snario.21	17	High	Below 50 w/m²	Medium	0	45.23	Q<N
Snario.22	22	High	Below 50 w/m²	Medium	0	33.33	Q<N
Snario.23	0	Low	Above 50 w/m²	Medium	0	0	Q=N
Snario.24	1	Low	Above 50 w/m²	Medium	–	–	–
Snario.25	3	Low	Above 50 w/m²	Medium	–	–	–
Snario.26	4	Low	Above 50 w/m²	Medium	–	–	–
Snario.27	5	Low	Above 50 w/m²	Medium	3.78	25	Q<N
Snario.28	6	Low	Above 50 w/m²	Medium	–	–	–
Snario.29	8	Low	Above 50 w/m²	Medium	–	–	–
Snario.30	9	Low	Above 50 w/m²	Medium	–	–	–
Snario.31	14	Low	Above 50 w/m²	Medium	–	–	–
Snario.32	17	Low	Above 50 w/m²	Medium	–	–	–
Snario.33	22	Low	Above 50 w/m²	Medium	–	–	–
Snario.34	0	Low	Below 50 w/m²	Medium	0	0.036	Q<N
Snario.35	1	Low	Below 50 w/m²	Medium	–	–	–
Snario.36	3	Low	Below 50 w/m²	Medium	–	–	–
Snario.37	4	Low	Below 50 w/m²	Medium	–	–	–
Snario.38	5	Low	Below 50 w/m²	Medium	0	0	Q=N
Snario.39	6	Low	Below 50 w/m²	Medium	–	–	–
Snario.40	8	Low	Below 50 w/m²	Medium	–	–	–
Snario.41	9	Low	Below 50 w/m²	Medium	–	–	–
Snario.42	14	Low	Below 50 w/m²	Medium	–	–	–
Snario.43	17	Low	Below 50 w/m²	Medium	–	–	–
Snario.44	22	Low	Below 50 w/m²	Medium	–	–	–

Average of PGR.CatII in 'Noisy.Classroom-Days' is greater than 'Quiet.Classroom-Days'	
Average of PGR.Cat II in 'Noisy.Classroom-Days' is lower than 'Quiet.Classroom-Days'	
Average of PGR.Cat II in 'Noisy.Classroom-Days' is equal to 'Quiet.Classroom-Days'	
Average of PGR.Cat II in 'Noisy.Classroom-Days' and 'Quiet.Classroom-Days' are equal to zero	
No data	–

Table 3-2.22: Averages of 'percentages of occasions that indoor temperatures exceed the adaptive thermal comfort by at least 3K (CatII)' in noisy and quiet classroom-days based on cooling degree hours, solar irradiance and risk of receiving solar gain and thermal mass level.

A T test is carried out between the averages of 'percentage of occasions that indoor temperatures exceed the adaptive thermal comfort by at least 3K (CatII)' in noisy and quiet classroom-days. As can seen from Table 3-2.23, they are significantly different ($P < 0.05$) with an average difference of 7.93%. These differences vary from 1.46 % to 14.40 %. It is therefore suggested that aircraft noise is a predictor for the occasions that indoor temperatures exceed adaptive thermal comfort by at least 3K (CatII) and consequently indoor temperature. In this table, the 'standard deviation' of all data is 16.01. 'Standard error mean' is calculated by dividing 'standard deviation' to the square root of the number of data. T value is calculated by the differences between the mean data in each group divided by 'standard error'. Degree of freedom (df) is calculated by subtracting 1 from the number of data. P value is derived from a table which is calculated based on 'T value' and 'Degree of freedom'.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	N.PGR.CatII	11.2389	26	18.70399	3.66815
	Q.PGR.CatII	3.3077	26	7.83515	1.53660

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	N.PGR.CatII - Q.PGR.CatII	7.93118	16.01811	3.14141	1.46133	14.40103	2.525	25	.018

Table 3-2.23: Comparison of the averages of 'percentage of occasions that indoor temperatures exceed adaptive thermal comfort by 3K (CatII)' for 'Noisy Classrooms-Days' with 'Quiet Classrooms-Days' using Paired Sample Test

- Criterion 2.2. Impact of aircraft noise on the occasions that indoor temperatures exceed the adaptive thermal comfort by at least 4K (CatIII) in noisy and quiet Classroom-Days

The averages of 'percentages of occasions that indoor temperatures exceed the adaptive thermal comfort by at least 4K (CatIII)' in noisy and quiet classroom-days are compared with each other based on cooling degree hours, actual daily solar irradiance, maximum risk of receiving solar gain and thermal mass level in Table 3-2.24.

Scenarios	Climate Conditions		Building factors		PGR.CatIII		
	Cooling degree hours	Actual daily irradince	Risk of receiving solar gain	Thermal mass	Quiet	Noisy	Comparison
Snario.1	0	High	Above 50 w/m²	Medium	0.12	0	Q>N
Snario.2	1	High	Above 50 w/m²	Medium	0	0	Q=N
Snario.3	3	High	Above 50 w/m²	Medium	0	0	Q=N
Snario.4	4	High	Above 50 w/m²	Medium	0	0	Q=N
Snario.5	5	High	Above 50 w/m²	Medium	0.42	0	Q>N
Snario.6	6	High	Above 50 w/m²	Medium	0.84	0	Q>N
Snario.7	8	High	Above 50 w/m²	Medium	0	0	Q=N
Snario.8	9	High	Above 50 w/m²	Medium	0	0	Q=N
Snario.9	14	High	Above 50 w/m²	Medium	0.84	3.5	Q<N
Snario.10	17	High	Above 50 w/m²	Medium	7.9	3.57	Q>N
Snario.11	22	High	Above 50 w/m²	Medium	7.98	35.71	Q<N
Snario.12	0	High	Below 50 w/m²	Medium	0	0.024	Q<N
Snario.13	1	High	Below 50 w/m²	Medium	0	0	Q=N
Snario.14	3	High	Below 50 w/m²	Medium	0	0	Q=N
Snario.15	4	High	Below 50 w/m²	Medium	0	0.297	Q<N
Snario.16	5	High	Below 50 w/m²	Medium	0	0	Q=N
Snario.17	6	High	Below 50 w/m²	Medium	0.42	0	Q>N
Snario.18	8	High	Below 50 w/m²	Medium	0	1.36	Q<N
Snario.19	9	High	Below 50 w/m²	Medium	0	0	Q=N
Snario.20	14	High	Below 50 w/m²	Medium	0	0	Q=N
Snario.21	17	High	Below 50 w/m²	Medium	0	0	Q=N
Snario.22	22	High	Below 50 w/m²	Medium	0	2.3	Q<N
Snario.23	0	Low	Above 50 w/m²	Medium	0	0	Q=N
Snario.24	1	Low	Above 50 w/m²	Medium	–	–	–
Snario.25	3	Low	Above 50 w/m²	Medium	–	–	–
Snario.26	4	Low	Above 50 w/m²	Medium	–	–	–
Snario.27	5	Low	Above 50 w/m²	Medium	0.42	0	Q>N
Snario.28	6	Low	Above 50 w/m²	Medium	–	–	–
Snario.29	8	Low	Above 50 w/m²	Medium	–	–	–
Snario.30	9	Low	Above 50 w/m²	Medium	–	–	–
Snario.31	14	Low	Above 50 w/m²	Medium	–	–	–
Snario.32	17	Low	Above 50 w/m²	Medium	–	–	–
Snario.33	22	Low	Above 50 w/m²	Medium	–	–	–
Snario.34	0	Low	Below 50 w/m²	Medium	0	0	Q=N
Snario.35	1	Low	Below 50 w/m²	Medium	–	–	–
Snario.36	3	Low	Below 50 w/m²	Medium	–	–	–
Snario.37	4	Low	Below 50 w/m²	Medium	–	–	–
Snario.38	5	Low	Below 50 w/m²	Medium	0	0	Q=N
Snario.39	6	Low	Below 50 w/m²	Medium	–	–	–
Snario.40	8	Low	Below 50 w/m²	Medium	–	–	–
Snario.41	9	Low	Below 50 w/m²	Medium	–	–	–
Snario.42	14	Low	Below 50 w/m²	Medium	–	–	–
Snario.43	17	Low	Below 50 w/m²	Medium	–	–	–
Snario.44	22	Low	Below 50 w/m²	Medium	–	–	–

Average of PGR.CatIII in 'Noisy.Classroom-Days' is greater than 'Quiet.Classroom-Days'	
Average of PGR.Cat III in 'Noisy.Classroom-Days' is lower than 'Quiet.Classroom-Days'	
Average of PGR.Cat III in 'Noisy.Classroom-Days' is equal to 'Quiet.Classroom-Days'	
Average of PGR.Cat III in 'Noisy.Classroom-Days' and 'Quiet.Classroom-Days' are equal to zero	
No data	–

Table 3-2.24: Averages of 'percentages of occasions that indoor temperatures exceed the adaptive thermal comfort by at least 4K (CatIII)' in noisy and quiet classroom-days based on cooling degree hours, solar irradiance and risk of receiving solar gain and thermal mass level

A T test is carried out between the averages 'of percentages of occasions that indoor temperatures exceed adaptive thermal comfort by at least 4K (CatIII)' in noisy and quiet classroom-days. As can be seen from Table 3-2.25, they are not significantly different (P >0.05) and therefore aircraft noise is not a predictor for the percentage of occasions that indoor temperatures exceed adaptive thermal comfort by at least 4K. This is associated with low outside temperature that did not cause Classroom-Days indoor temperatures to exceed 4K above the adaptive thermal comfort. In this table, the 'standard deviation' of all data is 5.56. 'Standard error mean' is calculated by dividing 'standard deviation' to the square root of the number of data. T value is calculated by the differences between the mean data in each group divided by 'standard error'. Degree of freedom (df) is calculated by subtracting 1 from the number of data. P value is derived from a table which is calculated based on 'T value' and 'Degree of freedom'

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	N.PGR.CatIII	1.7985	26	6.99522	1.37188
	Q.PGR.CatIII	.7285	26	2.13774	.41924

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	N.PGR.CatIII - Q.PGR.CatIII	1.07004	5.56232	1.09086	-1.17663	3.31671	.981	25	.336

Table 3-2.25: Comparison of the averages of 'percentages of occasions that indoor temperatures exceed the adaptive thermal comfort by 4K (CatIII)' in 'Noisy Classrooms-Days' with ' Quiet Classrooms-Days' using Paired Sample Test

b2) Method 2

In this method, classroom-days which are assessed based on the fixed overheating model are divided into 11 groups (as opposed to three) based fixed cooling degree hours. Fixed cooling degree hours, is a 'cooling degree hours' which is calculated based on 25°C. The range of fixed cooling degree hours varies from 0 to 24. This range for the days in this study is 0, 1, 2, 3, 6, 7, 8, 15, 21 and 24. As these data are no not normally distributed, it is suggested that the classroom-days are divided into the following groups in order to have more accurate results:

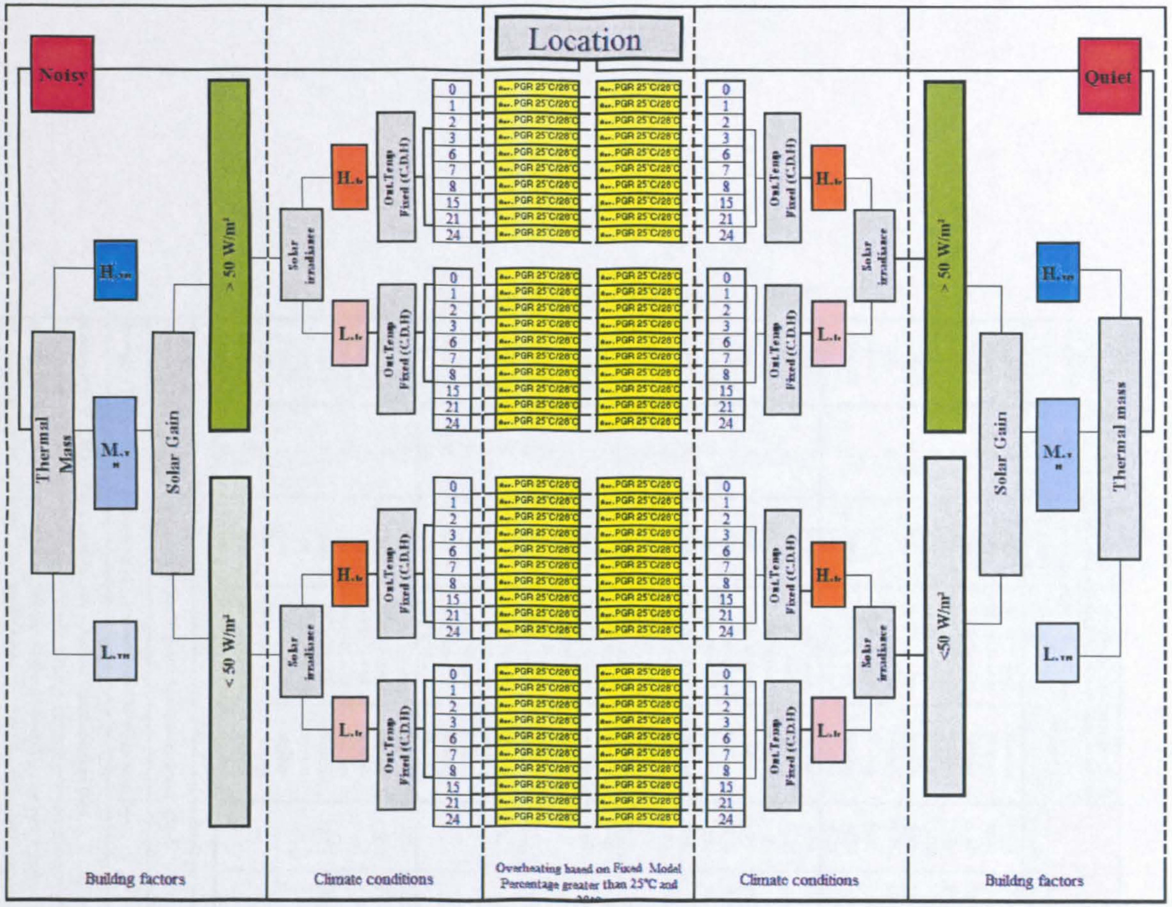
- Group 1: Includes the classroom-days' corresponding to the fixed cooling degree hour of '0'.
- Group 2: Includes the classroom-days' corresponding to the fixed cooling degree hour of '1'.
- Group 3: Includes the classroom-days' corresponding to the fixed cooling degree hour of '2'.
- Group 4: Includes the classroom-days' corresponding to the fixed cooling degree hour of '3'.
- Group 5: Includes the classroom-days' corresponding to the fixed cooling degree hours of '6'.
- Group 6: Includes the classroom-days' corresponding to the fixed cooling degree hours of '7'.
- Group 7: Includes the classroom-days' correspond to the fixed cooling degree hours of '8'.
- Group 8: Includes the classroom-days' correspond to the fixed cooling degree hours of '15'.
- Group 9: Includes the classroom-days' correspond to the fixed cooling degree hours of '21'.
- Group 10: Includes the classroom-days' correspond to the fixed cooling degree hours of '24'.

As it was explained earlier, the classrooms days not only are categorised based on cooling degree hours but also based on actual daily solar irradiance, the maximum risk of receiving solar gain and thermal mass level.

Graph 3-2.21 compares of the 'averages of percentages of occasions that indoor temperatures exceed 25°C / 28°C' in noisy and quiet Classroom-Days which have similar thermal mass, risk of receiving solar gain, solar irradiance and fixed cooling degree hours

Tables 3-2.26 and 3-2.28 show the following data based on cooling degree hours, actual daily irradiance, risk of receiving solar gain and thermal mass level for Noisy and Quiet Classrooms-Days.

- Averages of 'percentage of occasions that indoor temperatures exceed the fixed thermal threshold of 25°C'.
- Averages of 'percentage of occasions that indoor temperatures exceed the fixed thermal threshold of 28°C'.



Graph 3-2.21: Comparison of the averages of 'percentages of occasions that indoor temperatures exceed 25°C / 28°C in noisy and quiet Classroom-Days which have similar thermal mass, risk of receiving solar gain, solar irradiance and fixed cooling degree hours

- Criterion 3.1. Impact of aircraft noise on the occasions that indoor temperatures exceed 25°C:

The averages of 'percentages of occasions that indoor temperatures exceed 25°C' in noisy and quiet classroom-days are compared with each other based on cooling degree hours, actual daily solar irradiance, maximum risk of receiving solar gain and thermal mass level in Table 3-2.26.

Scenarios	Climate Conditions		Building factors		Ave (PGR.25°C)		
	Cooling degree hours	Actual daily irradince	Risk of receiving solar gain	Thermal mass	Quiet	Noisy	Comparison
Snario.1	0	High	Above 50 w/m²	Medium	16.38	9.44	Q>N
Snario.2	1	High	Above 50 w/m²	Medium	48.43	33.67	Q>N
Snario.3	2	High	Above 50 w/m²	Medium	11.975	32.143	Q<N
Snario.4	3	High	Above 50 w/m²	Medium	27.311	60.714	Q<N
Snario.5	6	High	Above 50 w/m²	Medium	53.061	40	Q>N
Snario.6	7	High	Above 50 w/m²	Medium	67.857	98.214	Q<N
Snario.7	8	High	Above 50 w/m²	Medium	85.714	89.286	Q<N
Snario.8	15	High	Above 50 w/m²	Medium	80.67	100	Q<N
Snario.9	21	High	Above 50 w/m²	Medium	97.89	100	Q<N
Snario.10	24	High	Above 50 w/m²	Medium	96.21	100	Q<N
Snario.11	0	High	Below 50 w/m²	Medium	8.54	16.49	Q<N
Snario.12	1	High	Below 50 w/m²	Medium	58.25	52.38	Q>N
Snario.13	2	High	Below 50 w/m²	Medium	0	25	Q<N
Snario.14	3	High	Below 50 w/m²	Medium	0	38.095	Q<N
Snario.15	6	High	Below 50 w/m²	Medium	51.78	47.95	Q>N
Snario.16	7	High	Below 50 w/m²	Medium	50	85.71	Q<N
Snario.17	8	High	Below 50 w/m²	Medium	96.42	100	Q<N
Snario.18	15	High	Below 50 w/m²	Medium	0	100	Q<N
Snario.19	21	High	Below 50 w/m²	Medium	100	100	Q=N
Snario.20	24	High	Below 50 w/m²	Medium	89.28	100	Q<N
Snario.21	0	Low	Above 50 w/m²	Medium	1.44	3.41	Q<N
Snario.22	1	Low	Above 50 w/m²	Medium	8.82	3.57	Q>N
Snario.23	2	Low	Above 50 w/m²	Medium	–	–	–
Snario.24	3	Low	Above 50 w/m²	Medium	–	–	–
Snario.25	6	Low	Above 50 w/m²	Medium	88.65	100	Q<N
Snario.26	7	Low	Above 50 w/m²	Medium	–	–	–
Snario.27	8	Low	Above 50 w/m²	Medium	–	–	–
Snario.28	15	Low	Above 50 w/m²	Medium	–	–	–
Snario.29	21	Low	Above 50 w/m²	Medium	–	–	–
Snario.30	24	Low	Above 50 w/m²	Medium	–	–	–
Snario.31	0	Low	Below 50 w/m²	Medium	3.01	8.98	Q<N
Snario.32	1	Low	Below 50 w/m²	Medium	0	88.09	Q<N
Snario.33	2	Low	Below 50 w/m²	Medium	–	–	–
Snario.34	3	Low	Below 50 w/m²	Medium	–	–	–
Snario.35	6	Low	Below 50 w/m²	Medium	78.57	95.23	Q<N
Snario.36	7	Low	Below 50 w/m²	Medium	–	–	–
Snario.37	8	Low	Below 50 w/m²	Medium	–	–	–
Snario.38	15	Low	Below 50 w/m²	Medium	–	–	–
Snario.39	21	Low	Below 50 w/m²	Medium	–	–	–
Snario.40	24	Low	Below 50 w/m²	Medium	–	–	–

Average of PGR.25°C in 'Noisy.Classroom-Days' is greater than 'Quiet.Classroom-Days'	
Average of PGR.25°C in 'Noisy.Classroom-Days' is lower than 'Quiet.Classroom-Days'	
Average of PGR.25°C in 'Noisy.Classroom-Days' is equal to 'Quiet.Classroom-Days'	
Average of PGR.25°C in 'Noisy.Classroom-Days' and 'Quiet.Classroom-Days' are equal to zero	
No data	–

Table 3-2.26: Averages of 'percentages of occasions that indoor temperatures exceed 25°C' for noisy and quiet classroom-days based on cooling degree hours, solar irradiance and risk of receiving solar gain and thermal mass

A T test is carried out between the averages of 'percentages of occasions that indoor temperatures exceed 25°C' for noisy and quiet classroom-days. As can be seen from Table 3-2.27, they are significantly different ($P < 0.05$) with an average difference of 15.69%. This difference varies from 4.46 % to 26.74 %. It is therefore suggested that aircraft noise is a predictor for percentage of occasions that indoor temperatures exceed 25°C and consequently indoor temperature. In this table, the 'standard deviation' of all data is 27.35. 'Standard error mean' is calculated by dividing 'standard deviation' to the square root of the number of data. T value is calculated by the differences between the mean data in each group divided by 'standard error'. Degree of freedom (df) is calculated by subtracting 1 from number of data. P value is derived from a table which is calculated based on T value and Degree of freedom.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	N.PGR.25	62.6297	26	37.33445	7.32189
	Q.PGR.25	46.9330	26	38.14812	7.48146

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	N.PGR.25 - Q.PGR.25	15.69669	27.35299	5.36436	4.64858	26.74481	2.926	25	.007

Table 3-2.27: Comparison of the averages of 'percentages of occasions that indoor temperatures exceed 25°C' in noisy and quiet classroom-days using Paired Sample Test

- **Criterion 3.2. Impact of aircraft noise on occasions that indoor temperatures exceed 28°C:**

Averages of 'percentages of occasions that indoor temperatures exceed 28°C' in noisy and quiet classroom-days are compared with each other based on cooling degree hours, actual daily solar irradiance, maximum risk of receiving solar gain and thermal mass level in Table 3-2.28.

Scenarios	Climate Conditions		Building factors		Ave (PGR.28°C)		
	Cooling degree hours	Actual daily irradince	Risk of receiving solar gain	Thermal mass	Quiet	Noisy	Comparison
Snario.1	0	High	Above 50 w/m²	Medium	1.73	0.307	Q>N
Snario.2	1	High	Above 50 w/m²	Medium	2.26	0	Q>N
Snario.3	2	High	Above 50 w/m²	Medium	0.21	0	Q>N
Snario.4	3	High	Above 50 w/m²	Medium	0.42	3.57	Q<N
Snario.5	6	High	Above 50 w/m²	Medium	0	0	Q=N
Snario.6	7	High	Above 50 w/m²	Medium	1.05	5.35	Q<N
Snario.7	8	High	Above 50 w/m²	Medium	5.88	3.57	Q>N
Snario.8	15	High	Above 50 w/m²	Medium	2.52	21.42	Q<N
Snario.9	21	High	Above 50 w/m²	Medium	41.17	42.85	Q<N
Snario.10	24	High	Above 50 w/m²	Medium	28.99	71.42	Q<N
Snario.11	0	High	Below 50 w/m²	Medium	0	0.22	Q<N
Snario.12	1	High	Below 50 w/m²	Medium	0	0.264	Q<N
Snario.13	2	High	Below 50 w/m²	Medium	0	0	Q=N
Snario.14	3	High	Below 50 w/m²	Medium	0	0	Q=N
Snario.15	6	High	Below 50 w/m²	Medium	1.78	2.72	Q<N
Snario.16	7	High	Below 50 w/m²	Medium	0	0	Q=N
Snario.17	8	High	Below 50 w/m²	Medium	0	42.85	Q<N
Snario.18	15	High	Below 50 w/m²	Medium	0	14.28	Q<N
Snario.19	21	High	Below 50 w/m²	Medium	0	66.66	Q<N
Snario.20	24	High	Below 50 w/m²	Medium	0	33.33	Q<N
Snario.21	0	Low	Above 50 w/m²	Medium	0	0	Q=N
Snario.22	1	Low	Above 50 w/m²	Medium	0	0	Q=N
Snario.23	2	Low	Above 50 w/m²	Medium	–	–	–
Snario.24	3	Low	Above 50 w/m²	Medium	–	–	–
Snario.25	6	Low	Above 50 w/m²	Medium	3.78	25	Q<N
Snario.26	7	Low	Above 50 w/m²	Medium	–	–	–
Snario.27	8	Low	Above 50 w/m²	Medium	–	–	–
Snario.28	15	Low	Above 50 w/m²	Medium	–	–	–
Snario.29	21	Low	Above 50 w/m²	Medium	–	–	–
Snario.30	24	Low	Above 50 w/m²	Medium	–	–	–
Snario.31	0	Low	Below 50 w/m²	Medium	0	0	Q=N
Snario.32	1	Low	Below 50 w/m²	Medium	0	0	Q=N
Snario.33	2	Low	Below 50 w/m²	Medium	–	–	–
Snario.34	3	Low	Below 50 w/m²	Medium	–	–	–
Snario.35	6	Low	Below 50 w/m²	Medium	0	0	Q=N
Snario.36	7	Low	Below 50 w/m²	Medium	–	–	–
Snario.37	8	Low	Below 50 w/m²	Medium	–	–	–
Snario.38	15	Low	Below 50 w/m²	Medium	–	–	–
Snario.39	21	Low	Below 50 w/m²	Medium	–	–	–
Snario.40	24	Low	Below 50 w/m²	Medium	–	–	–

Average of PGR.28°C in 'Noisy.Classroom-Days' is greater than 'Quiet.Classroom-Days'	
Average of PGR.28°C in 'Noisy.Classroom-Days' is lower than 'Quiet.Classroom-Days'	
Average of PGR.28°C in 'Noisy.Classroom-Days' is equal to 'Quiet.Classroom-Days'	
Average of PGR.28°C in 'Noisy.Classroom-Days' and 'Quiet.Classroom-Days' are equal to zero	
No data	–

Table 3-2.28: Averages of 'percentages of occasions that that indoor temperatures exceed 28°C' in noisy and quiet classroom-days based on cooling degree hours, solar irradiance and risk of receiving solar gain and thermal mass

A T test is carried out between the averages of 'percentages of occasions that indoor temperatures exceeds 28°C' in noisy and quiet classroom-days. As can be seen from Table 3-2.29, they are significantly different ($P < 0.05$) with an average difference of 9.38%. This difference varies from 2.17% to 16.59%. It is therefore suggested that aircraft noise is a predictor for 'percentages of occasions that indoor temperature' exceed 28°C and consequently indoor temperature. In this table, the 'standard deviation' of all data is 17.84. 'Standard error mean' is calculated by dividing 'standard deviation' to the square root of number of data. T value is calculated by the differences between the mean data in each group divided by 'standard error'. Degree of freedom (df) is calculated by subtracting 1 from number of data. P value is derived from a table which is calculated based on T value and Degree of freedom.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	N.PGR.28	12.8389	26	21.34592	4.18628
	Q.PGR.28	3.4535	26	9.57728	1.87826

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	N.PGR.28 - Q.PGR.28	9.38542	17.84018	3.49875	2.17962	16.59123	2.683	25	.013

Table 3-2.29: Comparison of the averages of 'percentages of occasions that indoor temperatures exceed 28°C' in noisy and quiet Classroom-Days using Paired Sample Test

b3) Results of objective survey based on detailed procedure:

The results of the above study are summarised in the following table (3-2.30):

Different techniques used for studying indoor temperature		Impact of aircraft on indoor temperature
Explanation	Code	
Average mean percentage of dissatisfaction from overheating	(Mean.PDH)	√
Average maximum percentage of dissatisfaction from overheating	(Max.PDH)	√
Average percentage of occasions that indoor temperatures exceed adaptive thermal comfort by at least 3K	(GR.CatII)	√
Average percentage of occasions that indoor temperatures exceed adaptive thermal comfort by at least 4K	(GR.CatIII)	x
Average percentage of occasion that indoor temperatures exceed 25°C	(GR.25°C)	√
Average percentage of occasion that indoor temperatures exceed 28°C	(GR.28°C)	√

Table 3-2.30: Summery of different method used for studying indoor temperature

As can be seen from Table 3-2.30, in all of the techniques of assessing indoor temperature, aircraft noise is a predictor except one. As it was explained earlier, this is due to the outside temperature. As the result, it can be suggested that the high level of aircraft noise significantly impacts indoor temperature as it reduces the buildings' potential for having natural ventilation.

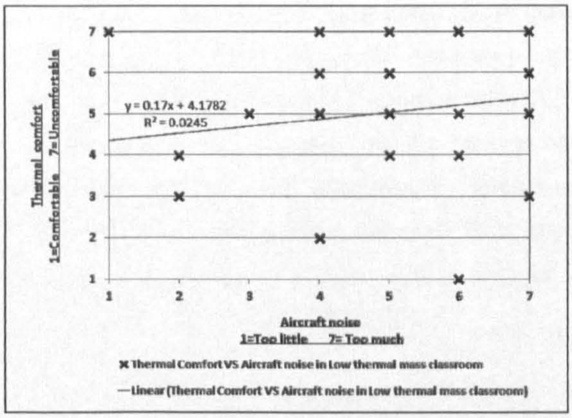
c) Results of objective survey

As per the results of objective surveys carried out under the general and detailed procedures, it can be concluded that the aircraft noise significantly impacts indoor temperature. For this reason, the likelihood that the schools located in noisy regions experience overheating and consequently their occupants become dissatisfied from overheating, is higher than those in quiet regions.

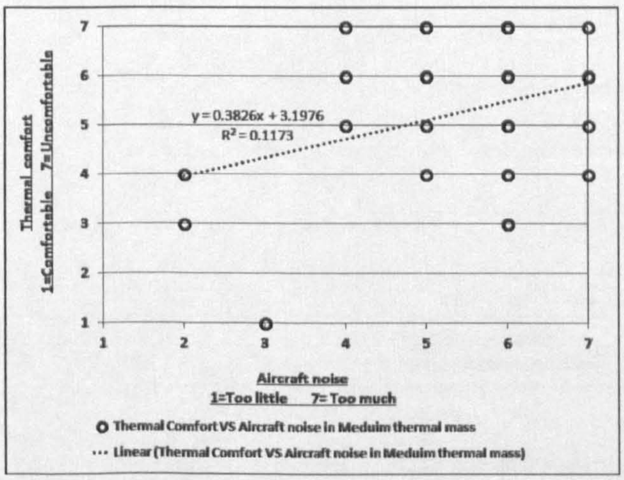
d) Subjective survey

A subjective survey was also carried out in order to test the results achieved from the objective surveys. In this survey, teachers were asked to rate different environmental noise sources (e.g. aircraft, lorries, cars etc.) and thermal comfort.

A regression analysis is carried out between teachers' perceptions towards environmental noise and thermal comfort in low and medium thermal mass schools. The result of this regression shows that the aircraft noise is the only predictor for thermal comfort in both low thermal mass schools ($p<0.05$, $r=0.323$) and medium thermal mass schools ($p<0.05$, $r=0.343$). The following two graphs (Graph 3-2.22 and Graph 3-2.23) separately show this relationship as thermal mass level is one of the factors that have an impact on the indoor temperature. The teachers' perceptions were elicited through a questionnaire (Appendix 10.9).



Graph 3-2.22: Relationship between teachers' perception toward aircraft noise and thermal comfort (in low thermal mass school)



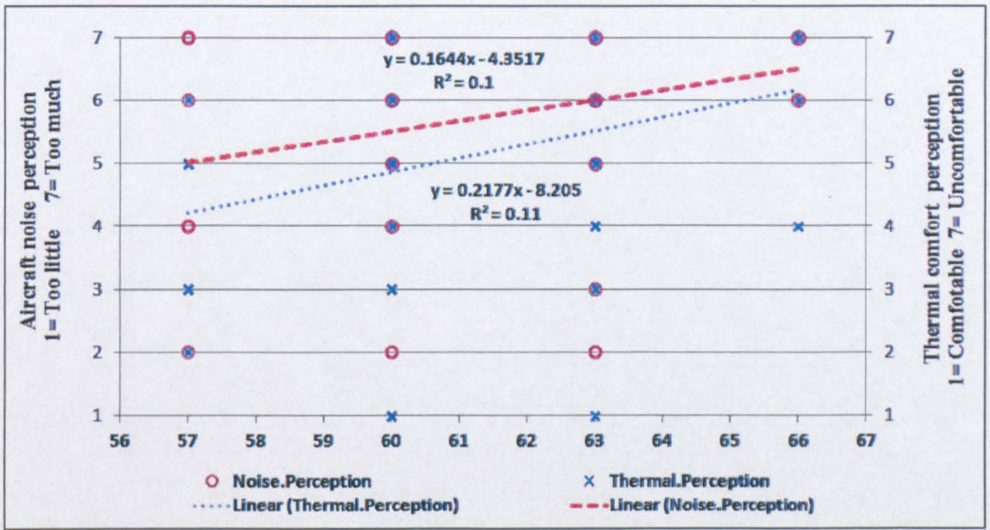
Graph 3-2.23: Relationship between teachers' perception toward aircraft noise and thermal comfort (in medium thermal mass school)

As can be seen from Graphs 3-2.22 and 3-2.23, the teachers who rated higher levels of aircraft noise, also rated lower levels of thermal comfort and vice versa. This subjective study confirms the objective survey that claims aircraft noise is a predictor for thermal comfort.

It should be noted that the schools in this study were chosen in such a way so as to be at a considerable distance from main roads and construction sites. For this reason, the ones located within a close distance to Heathrow Airport only suffer from aircraft noise and those located at a far distance to Heathrow Airport do not suffer from any kinds of environmental noises.

The reason that other environmental noise sources do not act as a predictor of thermal comfort in this study, may be related to the strategy that has been applied to select the schools (i.e. considerable distance from main roads and construction sites). To determine that whether there is any relationship between other environmental noises with thermal comfort, further research should be carried out.

In order to have a better understanding of how the level of aircraft noise impacts thermal comfort, the teachers' perceptions towards thermal comfort and aircraft noise are compared with the schools locations on the noise contour map of above 57 dBA. A regression analysis is carried out between 'thermal comfort' and 'aircraft noise' perception and school's location on the noise contour'. According to this regression, there is a significant relation between 'aircraft noise perception' with the schools' location on the noise counter map ($p<0.05$ and $r = 0.316$) [Appendix 10.3], and also there is a significant relation between 'thermal comfort perception' with the schools' locations on the noise counter map ($p< 0.05$ and $r= 0.337$) [Appendix 10.10].



Graph 3-2.24: The relation between schools' locations on aircraft noise with teachers' perception regarding aircraft noise and thermal comfort

Graph 3-2.24 shows the relation between the schools' locations on the aircraft noise contour map with the teachers' perceptions towards air craft noise and thermal comfort. As can be seen from this graph, the schools located on higher aircraft noise contours experience a lower thermal comfort and vice versa.

As a result, it can be suggested that not only do the schools located in noisy regions have a higher risk of experiencing overheating in comparison to those located in the quiet regions due to the aircraft noise, but also the schools located in the noisy regions suffer from different levels of overheating according to their location on the noise contour map. In other words, distance of the schools' buildings from Heathrow airport and the impact of aircraft noise on classrooms' background noise level have impacts on the level of thermal comfort. The high level of aircraft noise plays an important role on dissatisfaction from overheating as it reduces the buildings' potential for having natural ventilation.

3.3. Analysis: Impacts of buildings and climate factors (rather than ventilation) on summer overheating

Overview:

As mentioned earlier in the literature review, it is possible to minimise overheating by controlling the level of thermal mass, solar gain, internal gain & ventilation. The impact of lack of ventilation due to aircraft noise on summer overheating was discussed in the previous part (3.2). In this part (3.3), the impacts of other building and climate factors (other than ventilation) in summer overheating are studied. For this study, samples were chosen from the weekend days as the classrooms are unoccupied and all the windows are closed. Therefore, the impact of ventilation and internal gain on indoor temperature is considered as zero. This part of the study is carried out in two steps. In the first step, data are studied as a whole (General study) and in the second, data are studied based on case studies (Detailed study).

3.3.1. General study

In this study, the impacts of building and climate factors (rather than ventilation) on indoor temperature are assessed as a whole based on a regression analysis. The regression analysis is carried out between (a) the indoor temperatures and (b) the outside temperatures and Actual daily solar irradiances (climate's factors) and classroom thermal mass levels (building factors) [Appendix 10.11]. The results are as follows:

Indoor temperature	Year	Mean Out door Temperature	Daily Solar irradince	Thermal mass	R Square	Equation
Mean	2008	$P<0.05$ ß 1 = 0.380	$P<0.05$ ß 2 = -5.853E-5	$P<0.05$ ß 3 = 0.107	0.186	Y= 0.380 X1 + -5.853E-5 X2 + 0.107 X3 + 15.513
	2007	$P<0.05$ ß 1 = 0.289	$P<0.05$ ß 2 =5.916E-5	$P<0.05$ ß 3 = -0.222	0.127	Y=0.289X1 + 5.916E-5X2 + -0.222 X3 + 17.244
	2005	$P<0.05$ ß 1 = 0.226	$P<0.05$ ß 2 = 0.000	$P<0.05$ ß 3 = 0.409	0.316	Y= 0.226X1 + 0.000 X2 + 0.409 X3 + 17.409
Indoor temperature	**Year**	**Maximum Out door Temperature**	**Daily Solar irradince**	**Thermal mass**	**R Square**	**Equation**
Maximum	2008	$P<0.05$ ß 1 = 0.396	$P<0.05$ ß 2 = 0.000	$P<0.05$ ß 3 = 0.480	0.249	Y= 0.396X1 + 0.000 X2 + 0.396 X3 + 13.589
	2007	$P<0.05$ ß 1 = 0.317	$P<0.05$ ß 2 =7.836E-5	$P<0.05$ ß 3 = 0.261	0.255	Y=0.317X1 + 7.836E-5X2 + -0.261 X3 + 15.510
	2005	$P<0.05$ ß 1 = 0.050	$P<0.05$ ß 2 = 0.001	$P<0.05$ ß 3 = 1.056	0.421	Y= 0.050X1 + 0.001 X2 + 1.056X3 + 19.050

Table 3-2.31: The relation between (a) indoor temperatures and (b) outside temperatures, actual daily solar irradiances and thermal mass levels

According to the above table (Table 3-2.31), the indoor temperature mainly has a relationship with outdoor temperature, actual daily solar irradiance and also classroom thermal mass level.

As can be seen in 2005, the maximum indoor temperature does not have a relationship with the maximum outdoor temperature unlike in 2007 & 2008. This may be due to the fact that the numbers of days with a high level of solar irradiance is significantly higher in 2005 than 2007 and 2008.

The maximum daily global irradiance levels (from sunrise to sunset) on horizontal surfaces are 8200 & 7593 W/m² when the sky is clear in the months of June and July respectively. The numbers of days that have more than 95% of the maximum daily global irradiance on horizontal surfaces on a clear day are counted for different years (2005, 2007 & 2008). This would be the days that have a maximum daily global irradiance level of higher than 77900 W/m² _(8200 X 95% = 7790)_ on horizontal surfaces for the month of June and 7213 W/m² _(7593 X 95% = 7213)_ for the month of July.

2008	Day	Radiation - Daily global amount (KJ/sq m)	% days >95	2007	Day	Radiation - Daily global amount (KJ/sq m)	% days >95	2005	Day	Radiation - Daily global amount (KJ/sq	% days >95
14/06/2008	Saturday	6099		16/06/2007	Saturday	5056		18/06/2005	Saturday	**7837**	
15/06/2008	Sunday	6341		17/06/2007	Sunday	4911		19/06/2005	Sunday	**8188**	
21/06/2008	Saturday	1945		23/06/2007	Saturday	4147		25/06/2005	Saturday	1154	
22/06/2008	Sunday	7468		24/06/2007	Sunday	2656		26/06/2005	Sunday	5096	
28/06/2008	Saturday	7417		30/06/2007	Saturday	1596		02/07/2005	Saturday	1958	
29/06/2008	Sunday	5166		01/07/2007	Sunday	5590		03/07/2005	Sunday	2900	
05/07/2008	Saturday	5785		07/07/2007	Saturday	**7385**		09/07/2005	Saturday	3436	
06/07/2008	Sunday	3068		08/07/2007	Sunday	7103		10/07/2005	Sunday	**7604**	
12/07/2008	Saturday	4174		14/07/2007	Saturday	5527		16/07/2005	Saturday	**7576**	
13/07/2008	Sunday	6202		15/07/2007	Sunday	3802		17/07/2005	Sunday	**7754**	
19/07/2008	Saturday	5451		21/07/2007	Saturday	4822		23/07/2005	Saturday	2639	
20/07/2008	Sunday	4865		22/07/2007	Sunday	6430		24/07/2005	Sunday	2101	
Number of days that have more than **95%** of the maximum daily irradiance on horizontal surfaces on a clear		0	0%	Number of days that have more than **95%** of the maximum daily irradiance on horizontal surfaces on		1	8%	Number of days that have more than **95%** of the maximum daily irradiance on horizontal surfaces on a		5	42%

Table 3-2.32: Actual daily solar irradiance (from sunrise to sunset) on horizontal surfaces for the weekend days of 2005,2007 &2008

As it can be seen from Table 3-2.32, 42% of the days had a high solar irradiance on horizontal surfaces in 2005. This is the reason that, instead of the maximum outdoor temperature and solar irradiance, only the solar irradiance (followed by thermal mass) becomes the predominant factor for the maximum indoor temperature.

It should be noted that the impact of actual daily solar irradiance on indoor temperature varies for each classroom and depends on the classroom's potential for receiving solar gain. It should be reminded from the literature review that a classroom solar gain potential depends on the following factors:

- Classroom's direction
- Classroom's window size
- Classroom's shading and overshadowing
- Classroom's glazing type

As a result of this part of the study, it can be concluded that the outside temperature, actual daily solar irradiance and thermal mass have significant impacts on indoor temperature. In the next part, it is illustrated how each of these factors impact the indoor temperature.

3.3.2. Detailed study:

The relationship between (a) indoor temperature and (b) 'outside temperatures', 'actual daily solar irradiance' and 'classroom's thermal mass level' is studied under two scenarios. In the first scenario, the impact of climate factors on indoor temperature and in the second scenario the impact of building factors on indoor temperature are discussed.

3.3.2.1. Scenario 1: Impact of climate on indoor temperature:

This scenario is carried out under two case studies. In the first case study, the impact of outside temperatures on indoor temperature is discussed and is the second case, the impact of actual daily solar irradiance on indoor temperature is discussed.

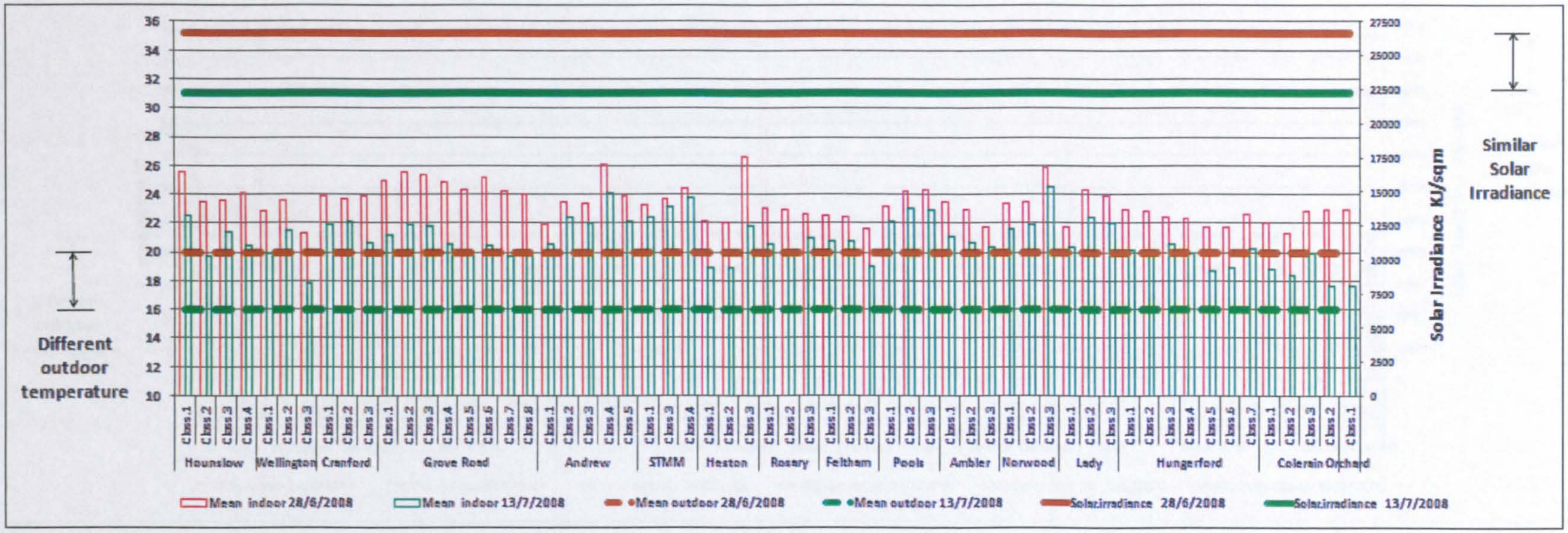
a) Case study 1.1: Impact of outside temperature on indoor temperature:

The aim of this part of the research is to show the impact of outside temperature on indoor temperature. As it was mentioned earlier, indoor temperature is affected by various building and climate factors. In order to study the impact of outside temperature on indoor temperature, classrooms with similar buildings factors, on occasions with similar climate factors. Which have a significant impact on indoor temperature (other than outside temperature) should be studied. In order to eliminate building factors, each classroom is compared with itself but on different days. In order to eliminate the impact of solar irradiance (i.e. actual daily solar irradiance), the days with similar solar irradiances are chosen. Internal gain and ventilation have no impact on indoor temperature due to the fact that the indoor temperatures are studied during weekends when the schools are unoccupied (i.e. there is nobody at the schools to produce internal gain and to open windows to gain natural ventilation).

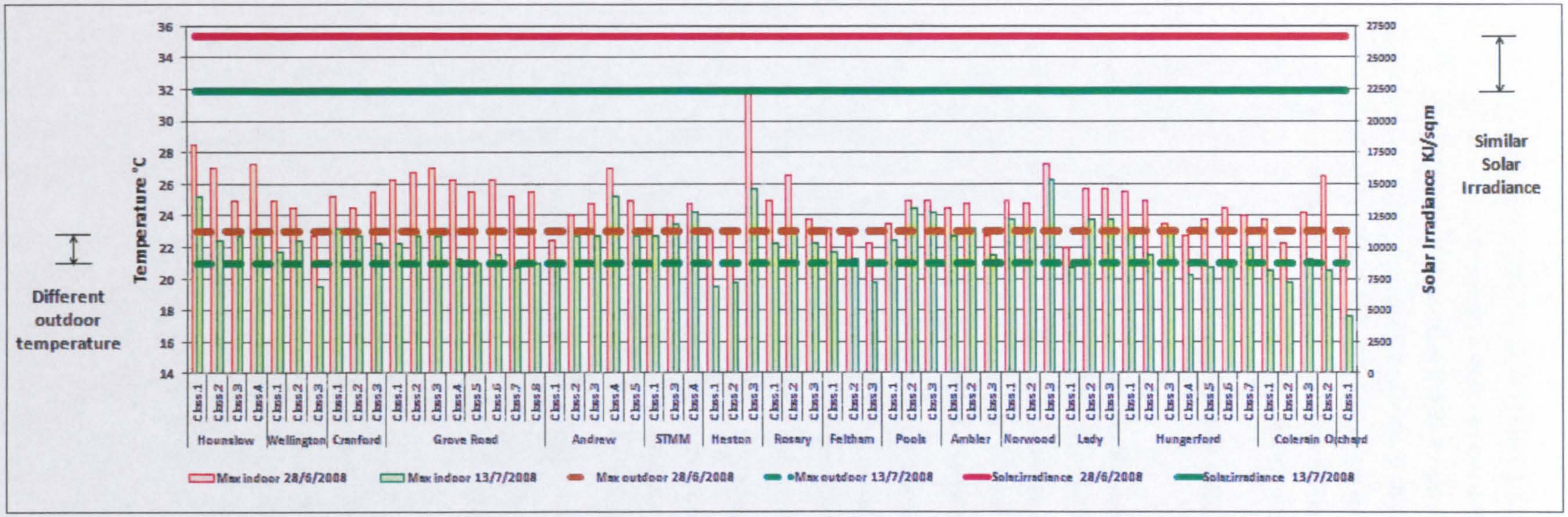
The indoor temperatures of 58 classrooms from 16 primary schools were studied on two different weekend days (28^{th} of June and 13^{th} of July) with nearly the same actual daily solar irradiance [which are above 20000 KJ/sq m (i.e. 5556 Watt-hour)] but different outside temperatures. The max and mean outside temperatures on 28^{th} of June were 23°C & 20°C respectively, while they were 21°C & 16 °C on 13^{th} of July.

The actual daily solar irradiances for 28th Jun and 13^{th} of July were 26700 KJ/sq m (i.e. 7417 Watt-hour) & 22327 KJ/sq m (i.e. 6202 Watt-hour) respectively.

Paired sample T tests were run between the classrooms' indoor temperatures (mean and maximum) on two days that have similar solar irradiances but different outdoor temperatures. The results show that the indoor temperatures on these two days are scientifically different from each other which is due to the impact of outside temperature (as one of the climate factors) on indoor temperature (Appendix 10.12.a).



Graph 3-2.25: Comparison of the mean indoor temperature in each classroom on two different days with different outside temperatures



Graph 3-2.26: Comparison of the max indoor temperature in each classroom on two different days with different outside temperatures

The above two graphs (Graph 3-2.25 and Graph 3-2.26) show the mean and maximum temperature of 59 classrooms from 16 primary schools on two different days (28th of June and 13th of July). As can be seen, the mean and maximum indoor temperatures of all the classrooms on 28th of June are higher than the 13th of July. As all the factors such as thermal mass, ventilation, internal gain and solar irradiance (actual daily solar irradiance) are similar, it can be inferred that these differences are due to the differences between outside temperatures. In the other words, the above graphs confirm the impact of outside temperature on indoor temperature.

b) Case study 1.2: Impact of solar irradiance (actual daily solar irradiance) on indoor temperature

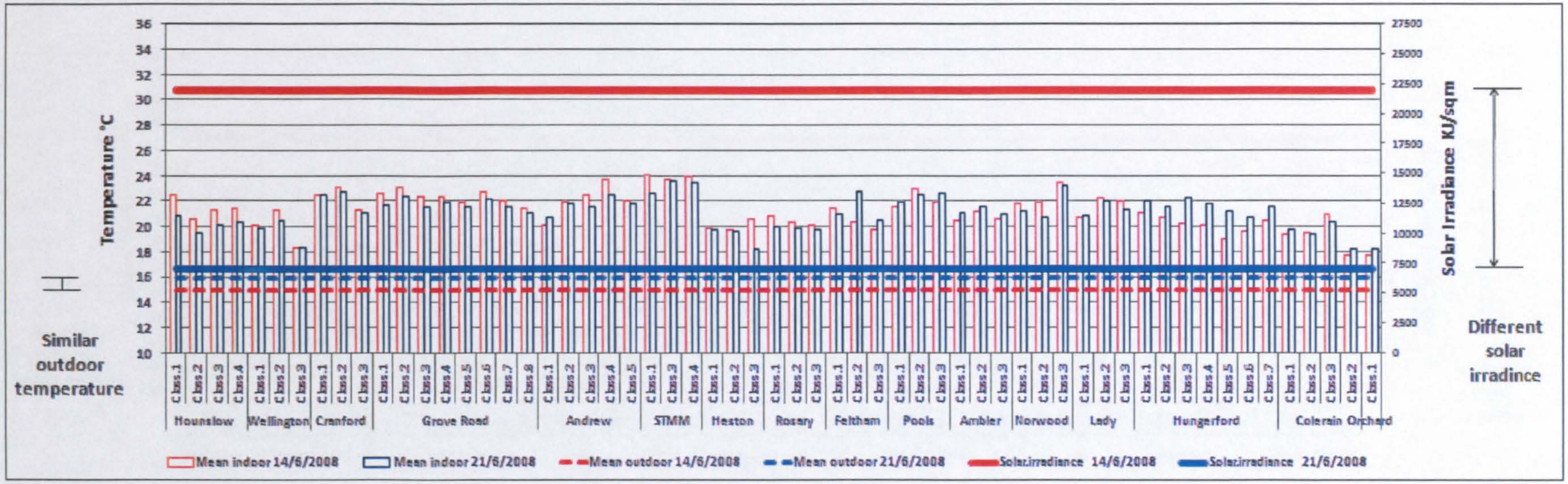
The aim of this part of the research is to show the impact of solar irradiance on indoor temperature. As it was mentioned earlier, indoor temperature is affected by various building and climate factors. In order to study the impact of solar irradiance on indoor temperature, classrooms with similar buildings factors, on occasions with similar climate factors, which have a significant impact on indoor temperature (other than solar irradiance) should be studied .

In order to eliminate the impact of outside temperature, the days with similar outside temperatures are selected. Internal gain and ventilation have no impact on indoor temperature due to the fact that the indoor temperatures are studied during weekends when the schools are unoccupied (i.e. there is nobody at the schools to produce internal gain and to open windows to gain natural ventilation).

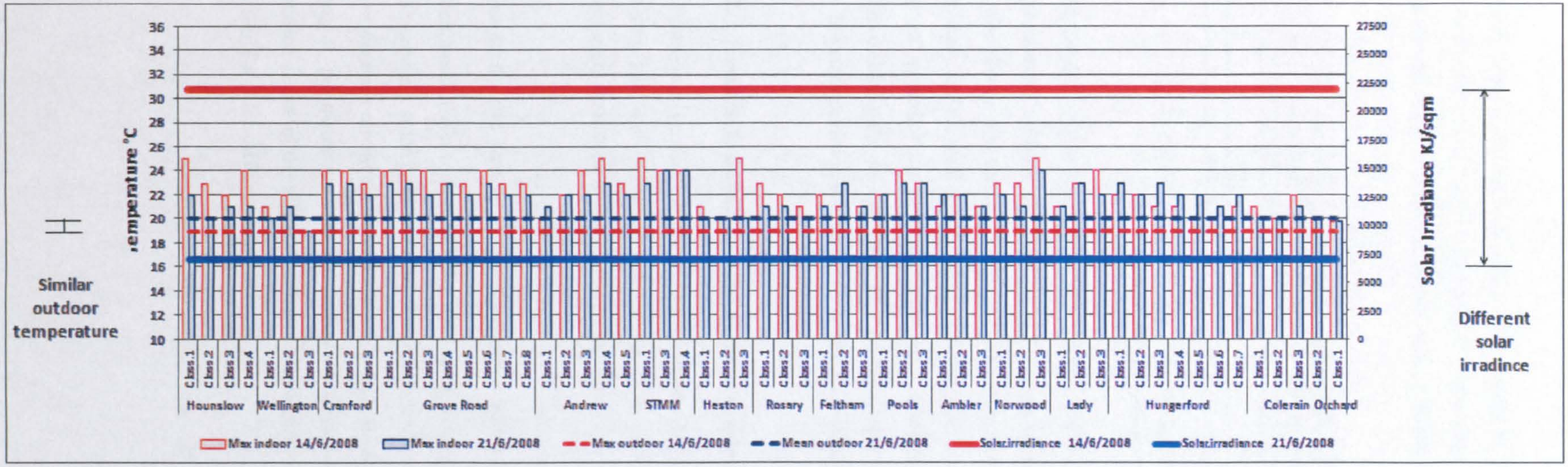
The indoor temperatures of 58 classrooms from 16 primary schools were studied on two different weekend days (14th and 21st June) with nearly similar outside temperatures but different solar irradiances. The solar irradiance for 14th of June was 21995 KJ/sq m (i.e.6099 watt-hour) while it was 7003 KJ/sq m (i.e.1945 Watt-hour) on 21st of June.

The mean and max outside temperature for 14th and 21st June were 20°C, 15°C, 19°C and 16°C respectively, which are almost similar. The following two graphs (Graph 3-2.27 and Graph 3-2.28) show the mean and maximum temperatures of 58 classrooms from 16 primary schools on two different days (14th and 21st June).

Paired sample T tests were run between the classrooms' indoor temperatures (mean and maximum) on two days that have similar outdoor temperatures but different solar irradiances. The results show that the maximum indoor temperatures in these two days are significantly different from each other which is due to the impact of solar irradiance on indoor temperature. As one of the climate factors the mean indoor temperatures in these two days are not significantly different from each other (Appendix 10.12.b). The reason is explained below.



Graph 3-2.27: Comparison of the mean indoor temperatures in each classroom on different days with different solar irradiances



Graph 3-2.28: Comparison of the max indoor temperatures in each classroom on two different days with two different solar irradiances

A further study of the above graphs and the results of T tests indicate that although all the building and climate factors are similar, the indoor temperatures of classrooms were not always higher on 14th compared to 21st of June. For details, refer to Table 3-2.33.

	The percentage of the classrooms that their indoor temperature were higher on 14th compared to 21th	The percentage of the classrooms that their indoor temperature were lower on 14th compared to 21th	The percentage of the classrooms that their indoor temperature were equal on both days
Mean	68%	32%	0%
Max	69%	21%	10%

Table 3-2.33: The percentage of classrooms which their indoor temperatures were higher, lower and equal on two specific days

As the results suggest, the indoor temperatures of the majority of classrooms are higher on 14th compared to 21st of June which confirms the impact of daily solar irradiance on indoor temperature. This was also proven through a regression analysis as seen in part 1. However, a small minority of classrooms experienced lower indoor temperatures on the 14th of June. This is related to the buildings' potential for receiving solar gain. Some classrooms have the benefit of controlling excessive solar gain. In this case, 31% of the classrooms seem to have controlled the excessive gain. The classroom's potential for receiving solar gain is discussed in the next chapter.

3.3.2.2. Scenario 2: Impact of building factors on indoor temperature

This scenario is carried under two case studies. In the first case study, the impact of building's solar gain potential on indoor temperature is discussed, and in the second case, the impact of thermal mass on indoor temperature is discussed.

a) Case study 2.1: Impact of building's solar gain potential on indoor temperature

As mentioned, the actual daily solar irradiance has an impact on indoor temperature according to the classroom's solar gain potential. The amount of solar gain that a classroom could potentially receive depends on the classroom's window area, orientation, shading and overshadowing, type of glazing & perimeter area. In the following case studies, the impact of classrooms' window orientation as one of the factors that have a significant impact on classroom's solar gain potential is discussed for three different schools.

- **Impact of classrooms' window orientation at Grove Road primary school:**

In this section, the impact of classrooms' window orientation on indoor temperature is shown using Grove Road School as an example. In this school, classrooms face different directions (Figure 3-2.28).

The impact of window size, perimeter zone, shading and over-shadowing are similar in all the classrooms. The impact of the following factors on indoor temperature is also found to be similar in this part of the study:

- The impact of ventilation and internal gain on indoor temperature is similar. This is due to the fact that the study is carried out on a weekend day.
- The impact of solar irradiance and outside temperature on indoor temperature is similar. This is due to the fact that the study is carried on a single day.
- The impact of thermal mass on indoor temperature is similar. This is due to the fact that the study is carried out for a single school which has the same level of thermal mass for all the schools' building.

In order to study the impact of classrooms' window direction on indoor temperature with accurate results, a weekend day with the highest solar irradiance and outside temperature was selected. Saturday 28th of Jun 2008 with a total (sum) horizontal solar radiation of 26700 W/m² (i.e.7417 W/m²) and the mean of 20°C and maximum of 23° temperature.

It can be seen from the following table (Table 3-2.34) that 28th of June 2008, is the weekend day which has the highest solar irradiation as well as outside temperature in this duration.

Day	Date	Radiation Daily global amount (KJ/sq m)	Radiation Daily global amount (watt.hour/sq m)	Max °C	Mean °C
Saturday	14/06/2008	21955	6099	20	15
Sunday	15/06/2008	22828	6341	18	15
Saturday	21/06/2008	7003	1945	19	16
Sunday	22/06/2008	26884	7468	21	19
Saturday	28/06/2008	26700	7417	23	20
Sunday	29/06/2008	18598	5166	21	18
Saturday	05/07/2008	20826	5785	22	19
Sunday	06/07/2008	11043	3068	19	16
Saturday	12/07/2008	15025	4174	17	14
Sunday	13/07/2008	22327	6202	21	16
Saturday	19/07/2008	19625	5451	21	19
Sunday	20/07/2008	17515	4865	18	16

Table 3-2.34: Solar irradiation and outside temperature during the chosen weekend in 2008

It should be noted that the sum of the maximum possible daily global solar irradiances on horizontal surfaces are 8200 and 7593 W/m² for the months of June & July which were derived from the Appendix.6 which is derived from CIBSE Guide A (Table 3-2.35). These data are for a day with a clear sky and therefore the maximum possible daily (sum) global solar irradiance.

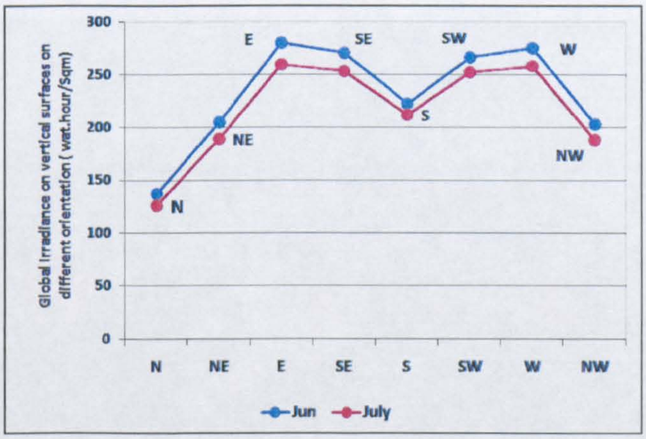
June																				
Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Sum W/m²
		Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																		
H	Beam	1	17	91	214	362	493	610	694	735	738	679	590	465	339	205	92	18	1	
	Diffuse	16	37	71	104	120	132	140	141	144	146	146	149	146	131	107	72	38	16	
	Globe	17	54	162	318	482	625	750	835	879	884	825	739	611	470	312	164	56	17	8200

July																				
Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Sum W/m²
		Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																		
H	Beam	0	14	83	191	319	449	554	627	658	668	626	545	439	323	190	82	14	0	
	Diffuse	13	31	60	90	116	130	143	154	162	162	153	150	137	114	97	58	29	12	
	Globe	13	45	143	281	435	579	697	781	820	830	779	695	576	437	287	140	43	12	7593

Table 3-2.35: Maximum possible daily global solar irradiances on horizontal surfaces in the months of June and July

Graph 3-2.29 (extracted from CIBSE Guide A, 2006) and Table 3-2.36 show the 'average' of the 97.5 percentile of the global irradiance on vertical and horizontal surfaces for London in June & July for the duration between sunrise and sunset (3:30-20:30) on a clear day.

For more details regarding Graph 3-2.24 and Table 3-2.38 refer to Tables 3-2.4 and 3-2.5.



Graph 3-2.29: Average daily global solar irradiance for June & July in London on different surfaces

Orientation	Average (Wat.hour/Sqm) June	Average (Wat.hour/Sqm) July
N	137	126
NE	205	189
E	280	259
SE	270	253
S	222	212
SW	266	252
W	275	258
NW	203	188

Table 3-2.36: Average daily global solar irradiance for June & July in London on different surfaces

As can be seen from the table above, the 'North' orientation has the lowest global irradiance while the 'East' & the 'West' orientations have the highest. In the following pages, the impact of classrooms' window orientation on indoor temperature is studied in Grove Road primary school, and it is assessed whether the indoor temperatures are higher in the classrooms that have windows facing the East and West when compared to those with windows facing North.

The following photo shows the bird's eye-view of Grove Road primary school and the orientation of its classrooms.

As can be seen, 8 classrooms are placed in a circular shape, each of which receives different amount of global solar irradiance according to their orientation.

Figure 3-2.28: Plan view of different classrooms in Grove Road primary school

Figure 3-2.29: Elevation of different classrooms in Grove Road primary school

Graph 3-2.30 shows the percentage of occasions that the indoor temperatures exceed 25°C, 26°C & 27°C on a weekend day (28th of June from sunrise to sunset) in different classrooms of Grove Road primary school. On this day, the classrooms experienced indoor temperatures of above 25°C, 26°C & 27°C while none reached 28°C. The percentage of occasions that the classrooms' indoor temperatures exceeded 25°C and 26°C were compatible with the amount of the global solar radiation each classroom received.

Three regression analyses are carried out between indoor temperatures and global solar irradiances (Appendix 10.13) as follows:

- A regression analysis is carried out between the percentages of occasions that indoor temperatures exceed **25°C (Y1)** and global solar irradiance **(X1)**. The result shows that there is a significant relation between them ($n=6$, $p<0.05$, R square = 0.782) and the relation is based on the following equation:

$$Y1 = 1.640\ X1 + 116.229$$

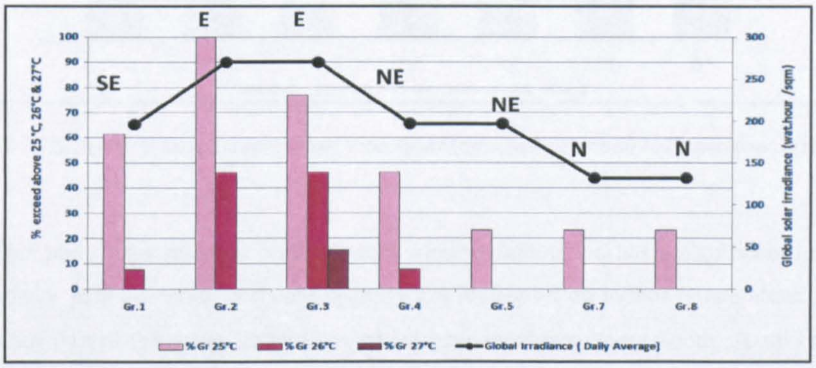
- A regression analysis is carried out between the percentages of occasions that indoor temperatures exceed **26°C (Y2)** and global solar irradiance **(X2)**. The result shows that there is a significant relation between them ($n=6$, $p<0.05$, R square = 0.814) and the relation is based on the following equation.

$$Y2 = 2.388\ X2 + 162.404$$

- A regression analysis is carried out between the percentages of occasions that indoor temperatures exceed **27°C (Y3)** and global solar irradiance **(X3).** The result shows that there is a significant relation between them (n=6, $p<0.05$, R square = 0.307) and the relation is based on the following equation.

$$Y3 = 5.373\ X3 + 187.33$$

As all other factors such as thermal mass, ventilation, internal gain & solar gain (due to similar window area, window size and perimeter zone & glaze type) are similar; therefore the results of regression analysis confirm the impact of global solar irradiance on indoor temperature. Moreover, the only classroom that experienced a temperature of above 27°C was located in the East direction.



Graph 3-2.30: The relation between indoor temperatures exceeding 25°C, 26°C & 27°C and classrooms' orientations

The following graph (Graph 3-2.31) shows the mean and maximum of indoor temperatures on a weekend day (28th of June from sunrise to sunset) in different classrooms of the Grove Road primary school. The mean and maximum indoor temperatures in different classrooms are compatible with the amount of global solar radiation each classroom receives.

Two regression analyses are carried out between indoor temperature and global solar irradiance (Appendix 10.14) as follows:

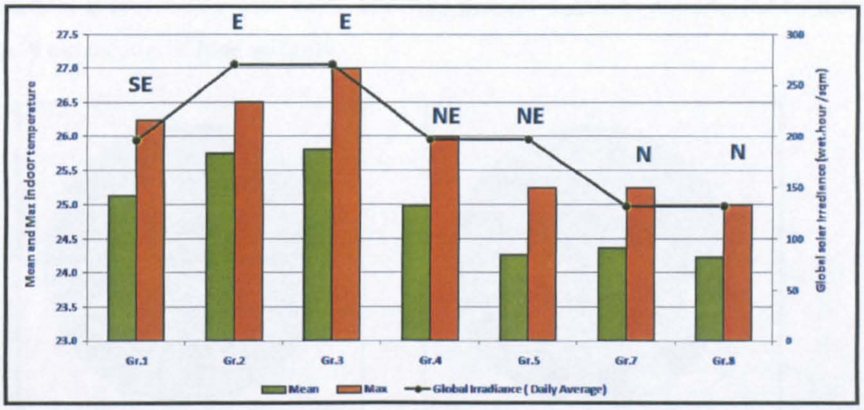
- A regression analysis is carried out between '**mean**' indoor temperature (Y1) and global solar irradiance (X1). The result shows that there is a significant relation between them (n=6, $p<0.05$, R square = 0.813) and the relation is based on the following equation:

$$Y1 = 75.352\ X1 - 1679.682$$

- A regression analysis is carried out between '**maximum**' indoor temperature (Y2) and global solar irradiance (X2). The result shows that there is a significant relation between them (n=6, $p<0.05$, R square= 0.788) and the relation is based on the following equation.

$$Y2 = 66.904\ X2 - 1533.199$$

As other factors such as thermal mass, ventilation, internal gain & solar gain component (window area, window size, and perimeter zone & glaze type) are similar, therefore the results of regression analyses confirm the impact of global solar irradiance on indoor temperature.



Graph 3-2.31: The relationship between indoor temperature (mean and maximum) and classrooms' orientation

Result: This part of the research confirms that window orientation has a significant impact on a building's solar gain potential, and consequently has an impact on indoor temperature. As can be seen from this part of the study, classrooms which have windows facing South, South East & East are warmer and they have a higher potential of experiencing overheating than the classrooms which have windows facing the North & North East.

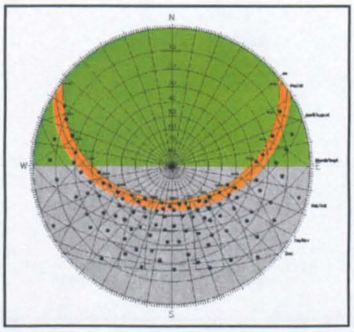
- Impact of classrooms' window orientation at Heston & Cranford primary school:

In this section, the impact of window orientation as well as overshadowing on indoor temperature is studied in two schools. In order to show the impact of overshadowing as one of the factors affecting classrooms' solar gain potential, the mean and maximum of classrooms' indoor temperatures of two primary schools were compared with each other. The Heston and Cranford primary schools have similar building characteristics as follow:

- Thermal mass level (low)
- Window size (which have impact on classrooms' solar gain potential)
- Schools layout
- Ventilation level (which is not discussed in this part)

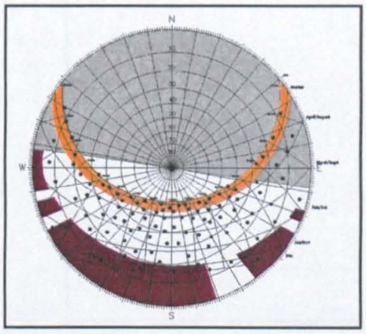
The only difference between these two schools is that the classrooms in Heston primary school have all the windows facing the north and are overshadowed by tress which have been planted within a close distance to the classrooms, while the windows in Cranford primary are facing the south and are not over-shadowed (although there are buildings located to the South of this school, this school is not overshadowed by these buildings in the months of June and July).

Graph 3-2.32 shows the sunlight availability in Heston primary school and Graph 3-2.33 shows the sunlight availability in Cranford primary school. As can be seen, the sunlight availability in Heston primary school is blocked by trees while Cranford primary school is not affected by the adjacent buildings in the mouths of June and July.



Graph 3-2.32: Sunlight availability

(Heston Primary School)



Graph 3-2.33: Sunlight availability

(Cranford Primary School)

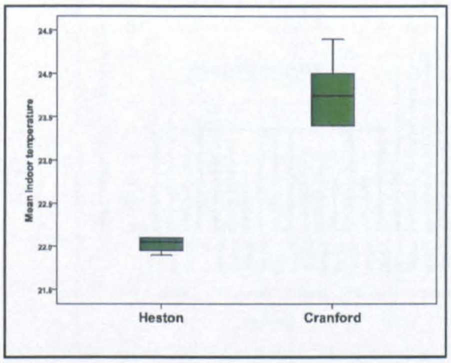
Figure 3-2.30: Plan view of studied classrooms in Heston primary school (left)

Figure 3-2.31: Photo of a close distance of trees and Heston primary school (right)

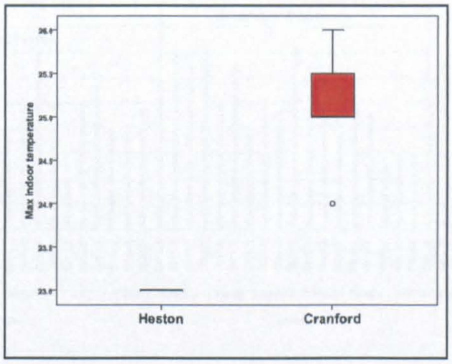
Figure 3-2.32: Plan view of studied classroom in Cranford Primary School

In the previous section, it is confirmed that the classrooms which have windows facing the south experience a higher indoor temperature when compared to those facing the North.

The following graphs (Graph 3-2.34 and Graph 3-2.35) show the mean and maximum indoor temperatures of Heston and Cranford Primary Schools on a weekend day (28th of June).



Graph 3-2.34: Comparison of the mean indoor temperatures



Graph 3-2.35: Comparison of the maximum indoor temperatures

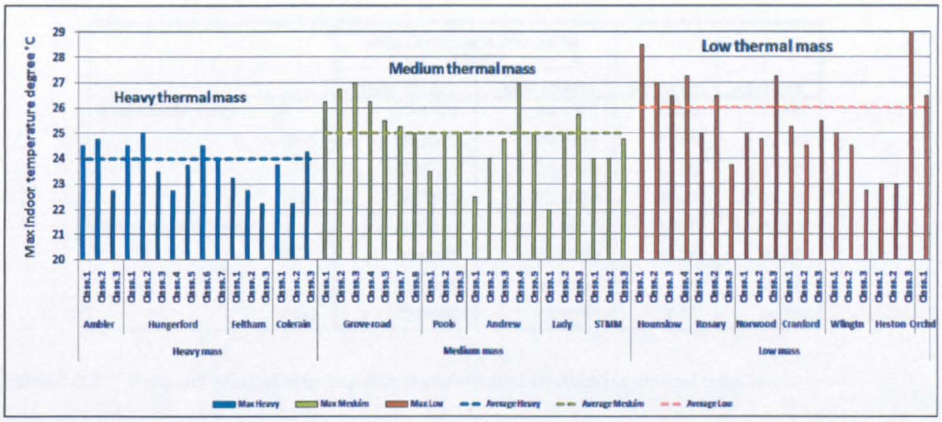
As can be seen from the above graphs (Graph 3-2.29 and Graph 3-2.30), the mean and maximum indoor temperatures are significantly lower in the classrooms of the Heston School than those in the Cranford school on Saturday 28th of June in 2008. This is due to the fact that the classrooms of Heston have windows facing the North which are also overshadowed by trees.

Result: This part of this research confirms that window orientation has a significant impact on the building solar gain potential which consequently has an impact on the indoor temperature. As it can be seen from this part of the study, the classrooms of Cranford Primary School which have windows facing the South were warmer and had a higher potential of experiencing overheating, when compared to the classrooms of Heston Primary School which have windows facing the North and are also over-shadowed by trees.

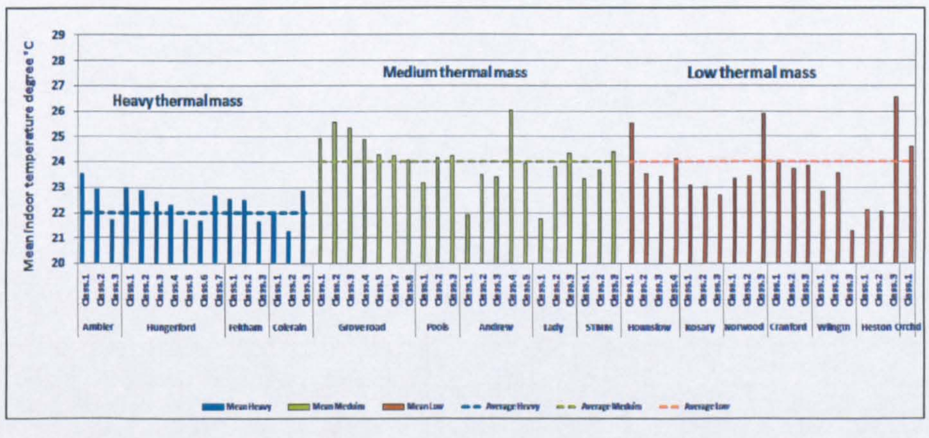
b) Case study 2.2: Impact of building's thermal mass on indoor temperature

As mentioned in earlier part of this paper, indoor temperature is affected by building and climate factors. In order to study the impact of classrooms' thermal mass level on indoor temperature, the impact of all the building and climate factors, other than thermal mass level on indoor temperature, should be eliminated.

For this reason the indoor temperatures of all classrooms with different levels of thermal mass were studied during one weekend day. Therefore, the impact of internal gain and ventilation on indoor temperatures are similar in all classrooms in this study due to the fact that indoor temperatures are studied during a weekend. The outdoor temperatures and solar irradiances also are similar as the classrooms' indoor temperatures are compared on a single day (28th of June, 2008). Schools are divided to 3 groups of high, medium and low thermal mass.



Graph 3-2.36: Comparison of the maximum indoor temperatures on different thermal mass levels



Graph 3-2.37: Comparison of the mean indoor temperatures on different thermal mass levels

The above two graphs (Graph 3-2.36 and Graph 3-2.37) show the mean and maximum indoor temperatures on a weekend day (with a high outside temperature and solar irradiance) for 3 groups of schools classified in terms of thermal mass (High, Medium & Low). As can be seen, the higher the thermal mass level, the lower the level of indoor temperature and vice versa.

One way ANOVA T test is carried out between the indoor temperatures (mean/maximum) and their relation to the thermal mass level (Appendix 10.15). The results show that there are significant differences between indoor temperatures considering their thermal mass level ($P<0.05$).

This part of the study confirms the impact of classrooms' thermal mass level on indoor temperature. As can be seen from the following table (Table 3-2.37), the higher the thermal mass level, the lower the mean and maximum indoor temperatures, and similarly, the lower the thermal mass level, the higher the mean and maximum indoor temperatures.

		95% Confidence Interval for Mean			
		Lower Bound	Upper Bound	Minimum	Maximum
Max.Indoor.Temp	H	23.1750	24.1375	22.25	25.00
	M	24.3565	25.5721	22.00	27.00
	L	24.6702	26.6548	22.75	31.75
	Total	24.3804	25.3038	22.00	31.75
Mean.Indoor.Temp	H	22.0210	22.6844	21.26	23.52
	M	23.5805	24.5290	21.76	26.06
	L	23.0285	24.2308	21.29	26.56
	Total	23.0982	23.7575	21.26	26.56

Table 3-2.37: Mean and Maximum indoor temperatures based on different thermal mass level

Chapter 4: Acoustic comfort

Chapter 4.1. Acoustic comfort literature review

Chapter overview:

The aim of this section is to review the principles of acoustic comfort inside classrooms, followed by an explanation regarding noise sources inside classrooms. Different methods have been suggested in order to provide better acoustic comfort inside schools and classrooms. The relationship between internal and external classrooms' noise (environmental noise) is also discussed. Children's perception of environmental noise and their annoyance level are reviewed, followed by an examination of how poor acoustic' classrooms have a higher impact on impaired children and the ones that do not speak in their first language.

4.1.1. Acoustic principles:

The main requirement of acoustic comfort is a sufficiently 'quiet' environment which enables communication tasks to be carried out comfortably and without distraction, i.e. with no unwanted sounds (noise) or vibration. Poor acoustic factors affect speech intelligibility inside classrooms meaning that children would be unable to hear their teacher, peers and also their classmates and hence transfer of information between them would be impaired. The acoustic factors which affect speech intelligibility are background noise level and reverberation time (Shield et al, 2003a):

1. Background noise level: Background noise commonly refers to any undesired sounds that impedes what a child wants or needs to hear (Knecht et al 2002).

2. Reverberation time is the time taken for the sound to decay by 60dB. This time depends on room size, amount of sound absorption and frequency of sound (Sharples.S and Bougdah. H, 2009).

The most important parameter for speech intelligibility is the signal to noise ratio (Bradley et al 1999). Signal-to-noise is the ratio that compares the level of a desired signal (such as music) to the level of background noise. As background noise level has a relationship with speech indelibility, it can be concluded that it has a high impact on acoustic comfort.

4.1.2. Background noise benchmark

As it was mentioned earlier, the lower the background noise, the better the speech intelligibility and the higher acoustic comfort, and vice versa. Ambient noise level is also recognised by the following expressions: background noise level, reference sound level and room noise level (ITS, 2001).

In Building Bulletin 93 (2003), the ambient noise level refers to noise transmitted from outside the school premises, building services, adjacent spaces, equipments used in the space, rain noise, etc.

Many national and international guidelines are in place regarding classrooms' acoustics. These guidelines mainly focus on three factors which are reverberation time, background noise level in teaching spaces and sound insulation between spaces inside schools.

In the UK, the required acoustic condition in schools is mentioned in Building Bulletin 93. According to this document, the maximum ambient level (i.e. background noise level) is 35 dB LAeq 30 minute, in an unoccupied teaching space.

Type of room	Upper limit for the indoor ambient noise level LAeq,30min (dB)
Primary school: classrooms, class bases, general teaching areas, small group rooms	35

Table 4-1.1: Recommended indoor ambient noise level for primary school classroom (Sources BB93)

Not only does the BB98 recommend maximum ambient level as 35 dB LAeq 30 minute, for the background noise in teaching spaces, but so does the World Health Organization (WHO) Guidelines for Community Noise, which specify the appropriate background noise level for classrooms as 35dB LAeq during teaching sessions (WHO, 1999).

4.1.3. Noise inside a classroom

A lower undesired noise (i.e. background noise) inside a classroom results in a higher speech intelligibility and better acoustic comfort. In order to better understand background noise, different noise sources inside a classroom are discussed. It should be considered that the classroom noise sources are the combination of noises from inside and outside the classroom, which are discussed as follows:

4.1.3.1. Noises from 'outside' a classroom:

Noises from outside a classroom can be divided in to the following categories:

a) Noise sources from outside a classroom but inside a school

This noise source usually refers to the noises that are transferred from different parts of the school such as adjacent rooms, corridor, halls and playground.

Disturbing noises are transferred in to a classroom and cause the classroom to experience a poor acoustic comfort as a result of followings:

1. Poor layout
2. Poor airborne sound insulation between the classroom and other classrooms and spaces

3. Poor impact sound insulation between the classroom and spaces above it (BB93, 2003).

Figure 4-1.1: Poor layout, poor airborne sound and impact sound insulation and poor acoustic comfort (Sources BB93, 2003)

b) Noise sources from outside a school

These noise sources usually refer to the environmental noises such as those from transportation systems, industrial, plant and also rain fall on lightweight roofs, which are transmitted through the building envelope.

4.1.3.2. Noise sources from 'inside' a classroom

Noise sources inside a classroom are teachers, students and the classroom's equipments.

a) Teachers as a noise sources

The level of noise that is produced by teachers' speech varies between 40-80 dB (A) (Hodgson et al 1999). From published data, it is estimated that the speech noise level is 60.1 dB within a two meter distance from the teacher (Picard and Bradley, 2001).

b) Students as noise sources

Primary School children are exposed to the noise that is produced by other students inside the classroom. This is also called 'classroom babble'. The noise level from 'classroom babble' is around 65 dB(A) Leq, while the overall noise level that students are exposed to is around 72 dB(A) Leq (Shield, 2008). It can be concluded that students can have a significant impact on background noise level in different ways which are discussed as follows:

Students' presence

The presence of students, even if they are silent, causes the classrooms' noise level to increase to a level above the unoccupied classroom noise level (Shield & Dockrell, 2003a) as students always produce noise when moving chairs and rustling paper, but not necessarily through their voice (Hodgson, 1994). For example, in primary school classrooms, the noise level increases with the presence of students from 47 to 56.3 dB even when the students are quiet, according to a study carried out by Shield and Dockrell (2003a).

Students activities

According to Shield and Dockrell (2004b), the ambient noise in occupied primary school classrooms is closely related to students' activity. In order to evaluate the classrooms' noise, Shield and Dockrell (2004b) proposed a method. In their method, classroom activities are broken down to the 6 activities mentioned below, drawing which different noise levels varying from 56 dB at silent activities to 77dB LAeq. When people are engaged in noisier activities involving group works and movement around the classroom are produced. However, according to three numbers surveys conducted by Moodley (1989) and Hay (1995), it is demonstrated that the representative value for a typical classroom activity in UK primary schools is 65 dB (A) Leq.

Shield and Dockrell classification of activities:

Activity 1: Children sitting at table doing silent reading to test.

Activity 2: Children sitting at table or on the floor, with one person (teacher or child) speaking at any one time.

Activity 3: Children sitting at tables working individually, with some talking.

Activity 4: Children working individually, moving around the classroom, with some talking.

Activity 5: Children working in groups, sitting at table, with some talking

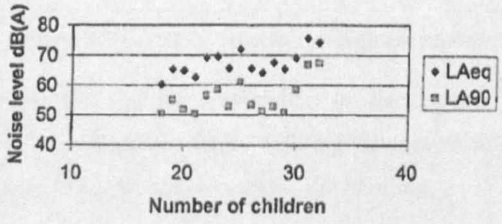
Activity 6: Children with commonly occurring noise sources in empty classrooms.

Student's age

There is a negative correlation between the noise level produced by pupils and their age in classrooms (Pichard and Bradley, 2001, Moodley, 1989). They found out that the noise level in primary school classrooms is higher than secondary school classrooms, as the children are younger and produce higher level of noise. However the relationship between students' age and their noise level is not shown in the study carried out by Shield and Dockrell (2004b).

Students number

According to the study carried out by Shield and Dockrell (2004b), it is demonstrated that there is a positive correlation between the number of students and the noise that they produce. This can be observed from the graph that is extracted from their study. As can be seen, the more the number of students, the more the noise produced.



Graph 4-1.1: Relationship between classroom LAeq and LA90 levels and number of children (Source Shield and Dockrell , 2004b).

c) Equipment and Mechanical noise

Equipment noise inside a classroom refers to the noise from computers, printers, audio-visual equipment etc. Mechanical noise inside a classroom refers to the noise from HVAC system, fans, air conditioning, air pumping, heating duct, faulty lighting devices etc. (CISCA, n.d.).

4.1.4. Improving acoustic comfort

Acoustic comfort inside a classroom could be improved by different methods explained as follows

4.1.4.1. Teachers' experience and acoustic comfort

The classrooms' acoustic comfort could be improved by having an experienced teacher rather than a trainee. An experienced teacher could have a significant impact on classrooms acoustic comfort as he/she could better manage the classroom and consequently decreases the noise level inside the classroom. According to the study carried out by Hay (1995) in 7 schools, it was discovered that the noise level is lower in classrooms which are managed by experienced teachers as compared to those managed by a trainee teacher.

4.1.4.2. Controlling equipments / mechanical noise and acoustic comfort

Classrooms' acoustic comfort could be improved by controlling the noise from equipments and mechanical devices which are explained as follows:

a) Equipments noise control

To control noises from 'equipments', the followings are recommended [CISCA, n.d]:

- The equipments should be located away from the critical environment,
- Padding should be installed under equipments to reduce vibratory noise,
- Computers and equipments with low operating noise should be selected and instructional equipments that is needed for long-term use, in areas of the classroom that are noise-sensitive, should be covered with noise insolating enclosures,
- Etc

b) Mechanical devices noise control

To control noises from 'mechanical devices', the followings are recommended (CISCA n.d):

- The mechanical devices that can have an impact on background noise level such as fans, plumbing, conditioning, heating ducts, faulty lighting devices should be located away from critical environments, in the hallway or even outside the building,
- Low noise-blast florescent should be used

- Etc

4.1.4.3. Classroom acoustic treatment and acoustic comfort

Classrooms according to their size and acoustical treatment could have a significant impact on the level of background noise level.

The background noise levels in Victorian schools are slightly higher than modern schools. This is because of larger their room volumes and more reflective surfaces that have significant impacts on reverberation time (Shield and Dockrell, 2004b).

Acoustic treatment can have a positive impact on background noise level. For example a study conducted by Airey and MacKenzie (1999) shows that when the background noise level in an untreated classroom is 44.7dB (A), this could drop to 40.1dB (A) after being treated. However, in a survey of primary school classrooms, Mackenzie (1999) demonstrated that the average noise level was 56dB (A) in acoustically untreated classrooms when pupils were silent, which dropped to 46.5 dB(A) in treated rooms.

4.1.4.4. School construction and acoustic comfort

Classrooms' acoustic comfort could be improved by choosing the correct insulation for airborne sound and structure borne sound (BB93, 2003).

Airborne sound

Airborne sound mainly refers to the sound that travels, but not exclusively, through the air and is heard by the ear. Sound from an external noise source can therefore enter a building not only through open windows but also through any cracks and gaps in the structure. Internal noise can carry through a space and can also be transferred through false ceiling voids and through ventilation ductwork. The amount of noise transmitted is not directly proportional to the size of opening. Even very small gaps and cracks can have a large detrimental effect on the ability of an element to reduce sound transmission.

Structure-borne sound

Sound borne sound mainly refers to the sound that travels by vibration through solid structures and is 'felt' (although we still usually interpret this as a 'sound') or re-radiated on the other side as air borne sound. Its causes include machinery, or anything that can cause an impact on hard floors such as footsteps.

a) Selecting the airborne sound insulation

In order to attenuate airborne sound transmitted between spaces through walls and floors, airborne sound insulation should be used.

The following table (Table 4-1.2) contains the required minimum airborne sound insulation values [DnT (Tmf,max), w (dB)] between rooms. These values are defined by the activity noise in the source room and the noise tolerance in the receiving room (BB93, 2003).

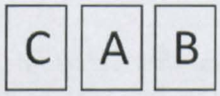
Minimum *DnT* (*T*mf,max),w (dB)		Activity noise in source room (see table 4-1.3)			
		Low	Average	High	Very high
Noise tolerance in receiving room	High	30	35	45	55
	Medium	35	40	50	55
	Low	40	45	55	55
	Very low	45	50	55	60

Table 4-1.2: Minimum sound insulation considering the activity noise and noise tolerance for a room (source BB93)

	Activity noise (Source room)	Noise tolerance (Receiving room)
Primary school: classroom, class bases, general teaching area, small group rooms	Average	Low
Music classroom	Very high	Low

Table 4-1.3: Activity noise (source room) and noise tolerance (Receiving room) for a primary school classroom and music room (source BB93)

For example, classroom A is located in between classrooms B and C. Classroom B being a music classroom is located on the right hand side of classroom A and classroom C is located on the left hand side of classroom A. The Airborne sound insulation between classroom 'C&A' and 'A&B' are as follows:



The airborne sound insulation between the classroom (A) and music classroom (B) should be '55' (Table 4-1.2), as the activity noise in the music room is very high and the noise tolerance in the receiving room is low (Table 4-1.3). The airborne sound insulation between classroom (A) and the other classroom (C) should be '45' (Table 4-1.2), as the activity in this classroom is classed as average and the noise tolerance in the receiving room is low (Table 4-1.3).

Airborne sound insulation for separating wall construction, any door set in the wall and any ventilators in the wall is shown with the weighted sound reduction index *R*w which can be obtained from Table 4-1.4 (BB93, 2003). The performance standard is set using a laboratory measurement because of the difficulty in accurately measuring the airborne sound insulation between rooms and corridors, or rooms and stairwells on the field.

Type of space used by student	Minimum Rw (dB)	
	Wall including glazing	Door set
All spaces expect music rooms	40	30
Music rooms	45	35

Table 4-1.4: Minimum sound reduction index (Rw) for school spaces (source BB93)

b) Selecting impact sound insulation

The airborne sound insulation is shown with Minimum LhT (Tmf,max),w (dB).The objective is to attenuate impact sound (e.g. footsteps) transmitted into spaces via the floor. As can be seen from the following table (Table 4-1.5), the maximum weighted impact sound pressure level in a primary school is 60dB, on the basis of which the impact sound insulation should be designed (BB93, 2003).

Type of room (receiving room)	Maximum weighted BB93 standardized impact sound pressure level L'nT(Tmf,max),w (dB)
Primary school: classrooms, class bases, general teaching areas, small group rooms	60

Table 4-1.5: Maximum weighted BB93 standardised
impact sound pressure for a primary school classroom (BB93, 2003)

Hence, it can be inferred that choosing the correct airborne and impact sound insulation is one of the criteria that could have an impact on providing better acoustic comfort inside a classroom.

4.1.4.5. School layout and acoustic comfort

Classrooms' acoustic comfort could be improved by paying extra attention to the schools' layout from the early design stages.

4.1.4.6. Site selection / school location and acoustic comfort

Classrooms' acoustic comfort could be improved by choosing a quiet site for the purpose of school construction during the early stages of design. It should be noted that choosing a quiet site is not always possible in urban areas. In addition, based on Building Research Establishment's Environmental Assessment Method (BREAM) targets, the best sites are those that are close to public transport. This would mean that there could be a conflict between choosing a quiet site and a site which meets the BREAM targets.

Two techniques are proposed by BB93 (2003) in order to overcome the impact of noise from 'rail and road' noises which are explained as follow:

✓ **Distance solution:** In general, it is advisable to locate a school at least 100 m away from busy roads and railways, but in towns and cities, this is often not possible. However, the use of distance alone is a relatively ineffective way to reduce noise.

✓ **Noise Barrier:** Noise barriers are much more effective than distance in reducing noise from road or rail traffic. In the following figure (Figure 4-1.2), earth bound acts as an acoustic barrier.

Figure 4-1.2: A noise barrier technique to overcome the impact of noise from roads (source BB93)

a) Environmental noise and its impact on internal noise

According to the study carried out by Bridget and Dockrell (2003 a), classrooms' noises were dominated by the sound of children's activities and were therefore independent of the external environmental noises. It should be noted that in the survey, the focus was on the classrooms that were located in the areas of London that had a range of external noise levels except aircraft noise. In their study, the relationship between external environment and internal noise was examined by only comparing the average internal and external noise levels. Based on this comparison, it appeared that when children are engaged in quiet activities in the classroom, the ambient classroom noise level is closely related to the background noise level and underlying levels outside. In other words, environmental noises have an impact on internal noise level only when occupants are occupied with quiet activities. It should be noted that in this study all windows were shut. In this study, children, particularly in the older age group (11 years), reported being able to hear a variety of environmental noise sources while being in the classroom, and over 90% of teachers questioned, felt that environmental noises affected the pupils' concentration.

Hence, it can be inferred that environmental noise has a significant impact on internal noise and consequently on the students. As per the review in chapter 2 of this study, there is a significant relationship between environmental noise on students' health and academic performance.

b) Environmental noise and students' perception

Young children are sensitive to noise in the environment and can discriminate noise source that annoy them. Children's perception regarding environmental noise was studied and it has been found that children are able to *discriminate* between environmental noise sources such as cars, sirens, lorries, motorbike etc, according to the study carried out by Bridget and Dockerll (2004a). In their study, teachers were tested in order to evaluate the children's report and it was realised that both children and teachers reported hearing similar noise sources both at home and school.

It should be noted that there is a difference between noises which are only heard and noises which are annoying. Children's reported level of *annoyance* was related to the maximum noise levels recorded outside the schools. Children defined annoyance as 'disturbing, being bothered, annoyed, feeling stressed out and upset and even fear (Jones, 2010).

A clear hierarchy was discovered for the sounds that students found annoying. In this hierarchy, train, motorbike, trucks and sirens were ranked as the most annoying sound, while trees were ranked as the least annoying according to the study conducted by Bridget and Dockrell (2004c). Noises heard by children are assessed with LA90 and LA99 of external noise, however for assessing annoying noise heard by children LAmax is considered.

Based on a study carried out in schools which are located under flight paths, children's responses to aircraft noise indicate that the children were consistently found to be annoyed by chronic aircraft noise exposure (Haines et al.2002).

A significant relationship was found between students' age and the distraction level caused by the high level of background noise when carrying out their academic tasks as per the study carried out by Gumenyuk et al. (2001). Based on this study, older children are less affected than the younger ones as they absorb most of the information from teachers' face and are more distracted by speech-like interference (Gumenyuk et al. 2001). Generally, younger children are more distracted in comparison to older ones (Gumenyuk et al. 2001). This means that the effect of environmental noises can become even more pronounced resulting is distracted behaviour (Blatchford et al, 2003) or a result in reduced attention span due to the continuous activity of tuning out the noise to reduce annoyance (Stanfeld et al, 2000). Hence, it can be suggested that a high level of environmental noises and consequently high levels of background noise not only could be annoying but also could have negative impacts on children's health and their academic attainment which are discussed in the chapter 2 of this study.

c) The impact of poor acoustic comfort on impaired children and those not taught in their first language

As it was explained earlier in chapter 2, poor acoustic classrooms (i.e. long reverberation time and background noise) have negative impact on students' health and performance. A comprehensive review is carried out in this chapter regarding the impact of environmental noises on students as they have a significant impact on background noise level inside classrooms.

According to Nelson (2003) and Niskar et al (1998) the impact of high level background noise and long reverberation time is higher on children with hearing impairment than on the ones with a normal hearing. The percentage of primary school children who are hearing impaired is about 40 in the UK and USA.

Hearing impairment in students can be temporary which is related to cold and ear infections (Shield & Dockrell 2003a) or could be a permanent impairment. Students with permanent hearing impairment are educated in the same school as students without hearing impairment (Shield & Dockrell 2003a). In each school some classrooms are allocated to such students.

Hearing impaired children are not the only group who suffer more than healthy people from the poor acoustic classrooms. Other children affected by poor acoustic are those who are not taught in their first language according to a study by Nelson (2003) and Mayo et al (1997). In Hounslow Borough, which is located under the Heathrow flight path, a proportion of students are asylum seeker whose first language is not English, and consequently suffer in poor acoustic classrooms as a result of the high level of background noise (due to the aircraft noise).

4.1.5. Conclusion

As explained in this chapter, a good acoustic classroom has a low background noise and reverberation time and consequently high speech indelibility. As per the review of the extant literature available, it has been seen that poor acoustic classrooms have significant negative impacts on students' health and performance. This negative impact is more on the students with impaired hearing who have been allocated to almost 40% of the places in the UK and USA primary schools (Shield & Dockrell, 2003a). This is also true for the students whose first language is not English and are thus taught in a language that they don't think in (Nelson, 2003, Mayo et al, 1997). Therefore, it is extremely important to provide good acoustic comfort inside classrooms.

Different methods are proposed to maintain classrooms' acoustic condition. Internal noise is the combination of noises from outside (whether from outside the school or inside) and inside classrooms.

As environmental noise has significant impacts on students' health and academic attainment, it is crucial to attenuate the environmental noise by choosing the correct airborne insulation on the buildings' envelop and maintaining an indoor background noise of around 35dB (only applicable when windows are closed).

Environmental noise could have an impact on internal noise, only when occupants are occupied with quiet activities (under the condition that all the windows are shut) as per studies that were carried out by Shield and Dockrell (2004b). In the situation where classrooms rely on opening the window for natural ventilation, meeting the 35dB (A) background noise as a recommended background level will be critical. According to the new regulation (BB93, 2003), 35dB (A) could increase to 40dB (A) under the purge ventilation.

Chapter 4.2. Acoustic comfort analysis

• Chapter overview

This chapter is conducted in two parts. The impact of high level of aircraft noise on classrooms' opening status is assessed in Part One and the impact of classrooms' poor layout on opening status is assessed in Part Two of this chapter.

4.2.1. Part One- Analysis of the impact of high level of aircraft noise on opening status

Overview

The main aim of this part of the research is to evaluate whether occupants tend to close classrooms' windows when they are engaged with different types of activities, in order to provide a better acoustic condition inside the classrooms. This part of the study is carried out in the following parts:

Objective survey: Three types of study are carried out to study the impact of high level of aircraft noise on schools located under flight paths in two situations: where the windows are open and where the windows are closed. These studies are pilot, random and detailed study.

Subjective survey: In the subjective survey, teachers' and students' perceptions regarding the high level of aircraft noise and their reactions are studied.

4.2.1.1. Objective survey

Building Bulletin 93 is a UK guideline written by the Department for Education and Skills for acoustic design of schools. In this guideline, the proposed standards for background noise is difficult to achieve in naturally ventilated schools as the indoor background noise levels are subject to significant levels of external noise (Parkin, 2005). Thus, additional guidance is provided by Building Bulletin 101(2006)to facilitate the use of natural ventilation. The BB101 is a UK guideline which is written by the Department for Education and Skills for ventilation design of school buildings. According to this guideline, the indoor ambient noise level should not exceed 35 dB in classrooms if there is a minimum supply of fresh air equal to or greater than 3l/s per person provided. The indoor ambient noise level can be increased by 5 dB (reaching to 40 dB) if a ventilation rate of higher than 8l/s per person is required, for example during overheating on hot summer days when it may be necessary to open all the windows. Three types of study are carried out as followed to assess the impact of the high level of aircraft noise on schools located under flight paths:

Pilot study: In the pilot study, a comparison is carried out between the monitored aircraft noise and occupants' noise levels when windows are open and closed. In order to measure the occupants' noise level the method (i.e. breaking down classroom sessions to different activities) which is proposed by Sheild et al (2004 b) explained earlier is adapted (a).

Random study: In the random study, the windows' statues and the indoor activities are randomly studied against each other (b).

Detailed study: The detailed study is carried out into two parts. The first part of the study evaluates the impact of aircraft noise on occupants' speech intelligibility and the second part evaluates the impact of aircraft noise on occupants' complaint level (c).

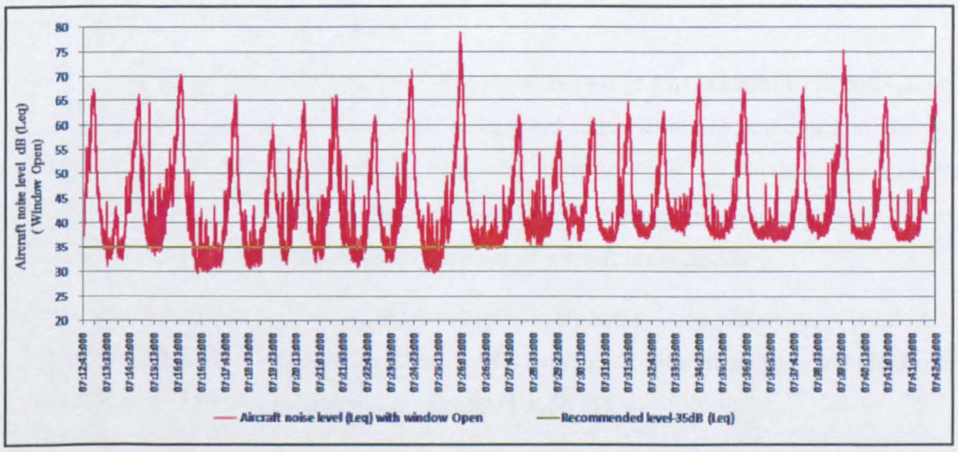
a) Pilot study:

The pilot study is carried out in Grove Road primary school in the following three steps:

- Aircraft noise study (a1)
- Activity noise study (a2)
- The Comparison between noise from student activities and aircraft noise level (a3)

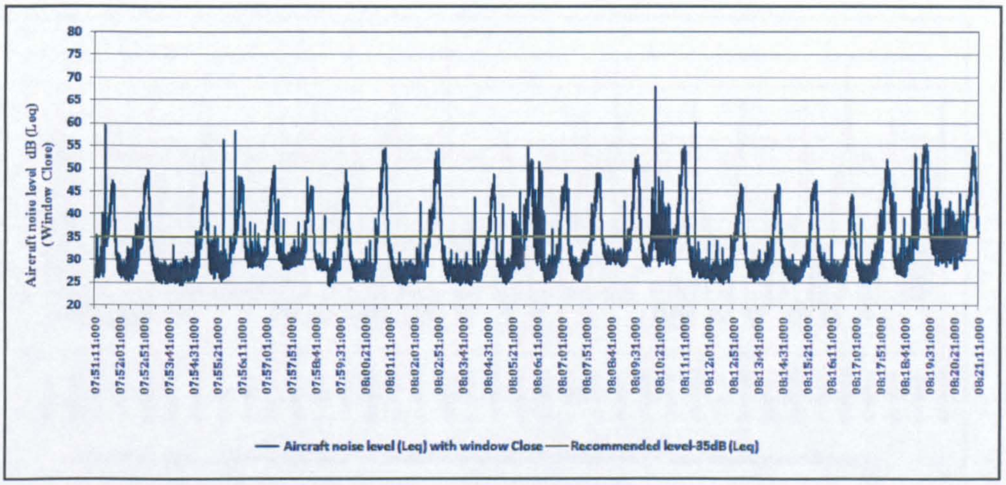
a1) Aircraft noise study

The following graph (Graph 4-2.1) shows the level of aircraft noise recorded in Y4 classroom while it was unoccupied and windows were OPEN between 07:12:43am until 07:42:02am on 3rd of June 2008. On this day, aircrafts passed over the building at 1 to 2 minute intervals.



Graph 4-2.1: Comparison between the levels of aircraft noise inside the classroom and the recommended benchmarks of 35 dB when the window is open

The following graph (Graph 4-2.2) shows the level of aircraft noise recorded for the same classroom while it was unoccupied and windows were CLOSED between 07:51:11am until 08:20:30am.



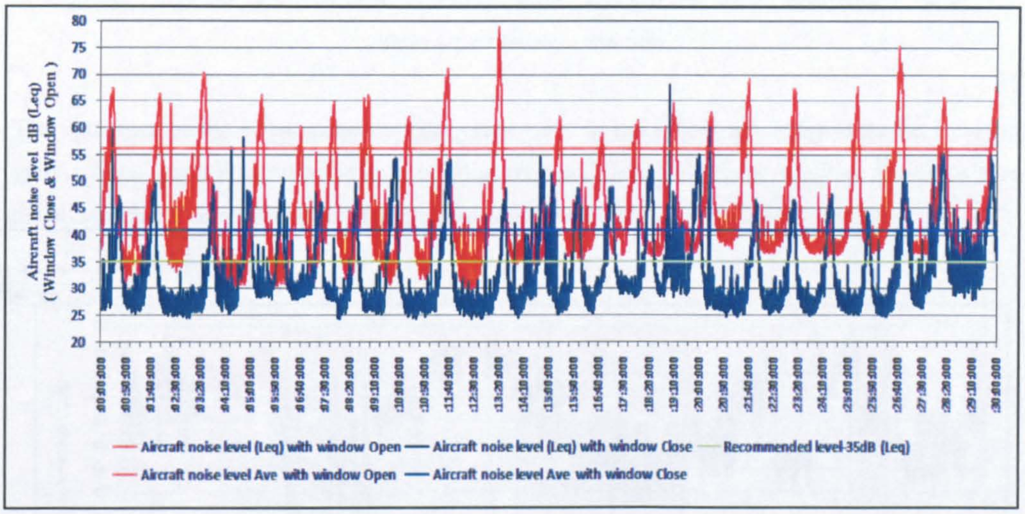
Graph 4-2.2: Comparison between the levels of aircraft noise inside the classroom and the recommended benchmarks of 35 dB when the window is closed

As mentioned earlier, Building Bulletin 93 requires the background noise level to be no more than 35dB LAeq in unoccupied teaching spaces.

In order to enable comparison, the results of the previous two graphs (Graph 4-2.1 and Graph 4-2.2) and the BB93 maximum recommended background noise level are combined in the graph shown below. The table shows the overlapped results from time 0 to 30 minutes. The horizontal axis represents the total duration of 30 minutes for each measurement shown in mm:ss:ms format at 100ms intervals. The vertical axis represents the level of aircraft noise in dB.

- The fluctuating red line shows the level of aircraft noise when classroom's window was OPEN and the horizontal red line shows the average of aircraft noise when classroom`s window was OPEN. The average is calculated at 56 dB.
- The fluctuating blue line shows the level of aircraft noise when classroom's window was CLOSED and the horizontal blue line shows the average of aircraft noise when classroom's window was CLOSED. The average is calculated at 41 dB.
- The Green line shows the BB93 standard level of background noise (35 dB).

The result of the study shows that, although closing the windows discounted the level of aircraft noise by approximatley15 dB, it still did not meet the standard level of 35dB.



Graph 4-2.3: Graphs 4-2.1 and 4-2.2 overlapped

a2) Activity noise study

Activity noise measurements were carried for four different classrooms in Grove Road primary school (i.e. Year 2, 4, 3 & 6) out on the 24th, 25th, 26th &27th of June 2008 respectively. The measurements were carried out in a week where no airplanes passed over the building (airplanes had changed direction); hence, there was no noise inside the classrooms as a result of aircrafts. For the purpose of these measurements, activities were recorded in 6 groups. The table below (Table 4-2.1) shows the colour coded categories:

Different activities	Colour coding
When children are moving in and out	
Act 1: Silent activity	
Act 2: One person speaking	
Act 3: Individual activity	
Act 4: Group activity	
When classroom is unoccupied	

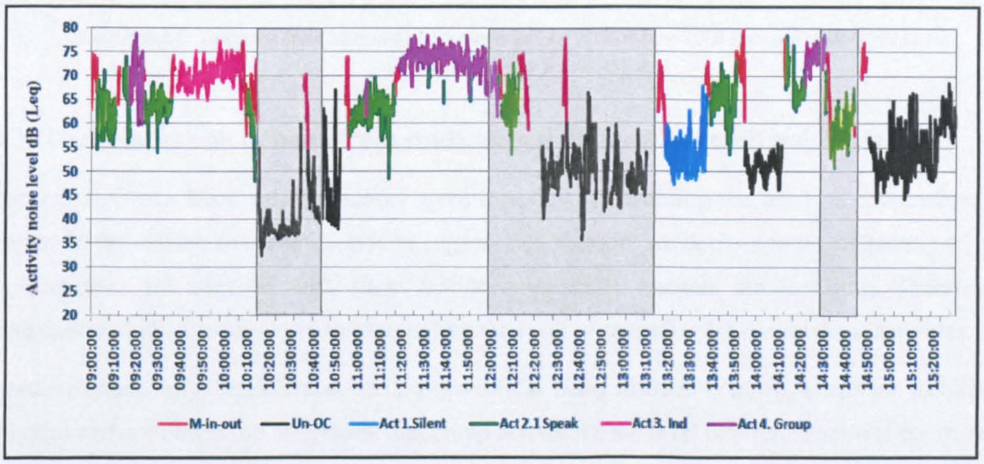
Table 4-2.1: Activities colour coding

The Grove Road primary school working hours are 9:00 am to 3:30 pm. The table below shows the school daily time-table and illustrates the sessions and break times. The highlighted cells show the classrooms unoccupied hours.

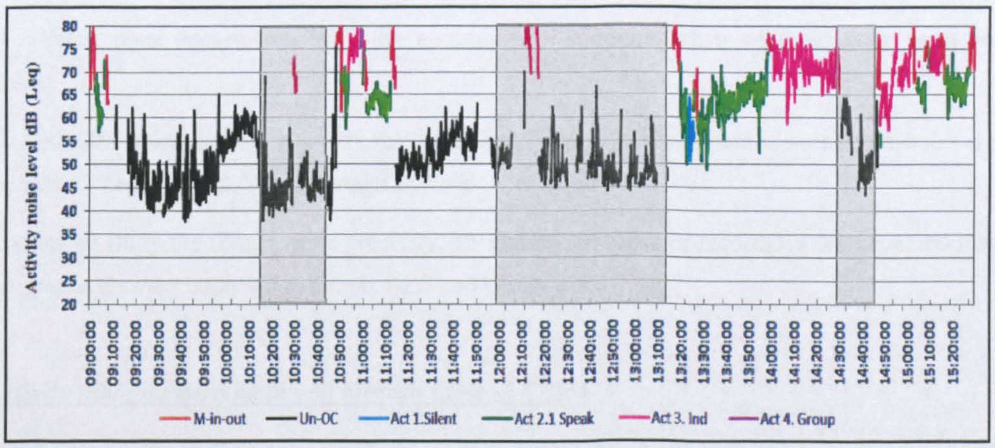
	Class-time	Class assembly	Play time	Class-time	Lunch	Class-time	Play time	Class-time
Time	9:00-10:15	10:15-10:30	10:30-10:45	10:45-12:00	12:00-1:15	1:15-2:30	2:30-2:45	2:45-3:30
Occupancy	Occupied	Un-Occupied	Un-Occupied	Occupied	Un-Occupied	Occupied	Un-Occupied	Occupied
Duration	01:15			01:15		01:15		00:45

Table 4-2.2: Classroom time table

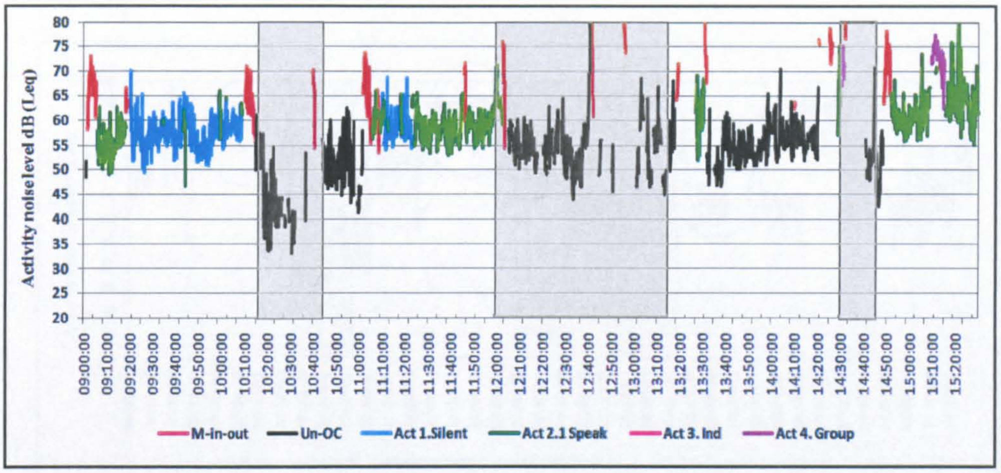
The outcomes of the noise measurements carried out in the school are outlined in the following graphs. Each graph illustrates the level of noise recorded during different activities as well as when the classrooms were unoccupied. The highlighted parts show the unoccupied durations.



Graph 4-2.4: The noise level recorded in Y4 classroom on 25th of June 2008 between 0900-1530 hours when there was no aircraft noise



Graph 4-2.5: The noise level recorded in Y3 classroom on 26th of June 2008 between 0900-1530 hours when there was no aircraft noise



Graph 4-2.6: The noise level recorded in Y6 classroom on 27th of June 2008 between 0900-1530 hours when there was no aircraft noise

a3) The comparison of noise from students activities and aircraft noise level

Teachers at Grove Road primary school were interviewed regarding the level of environmental comfort in the classrooms. The interviews suggest that aircrafts are deemed to be distracting when the occupants are engaged with silent activities or while teachers are lecturing. Therefore, occupants tend to close windows so as to reduce the level of aircraft noise during these activities.

In order to study why the aircraft noise is considered as being distracting during silent and lecturing activities and not others (i.e. individual and group activities), the level of aircraft noise is compared with the level of noise that is produced by all activities.

Therefore, the following two sets of noise measurements are compared with each other:

1- Aircraft noise measurements in the unoccupied classrooms when windows were open and closed.

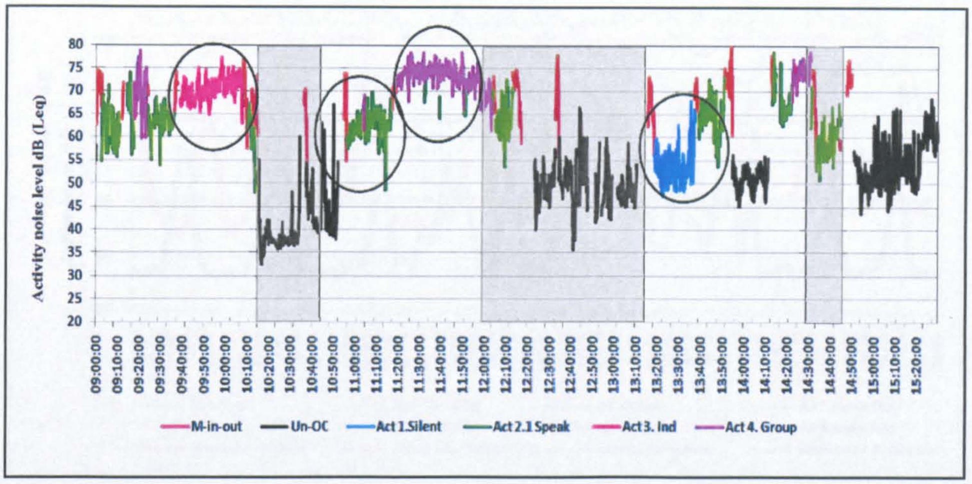
2- Activities noise measurements in the occupied classrooms when there is no aircraft noise (i.e. records of Year 4, Y3 & Y6 mentioned earlier).

In order to study the results more precisely, 15-minute durations of recordings are extracted from the graphs above (Graph 4-2.4, Graph 4-2.5 and Graph 4-2.6).

Activity noise measurement and aircraft noise at Year4

In this section, the level of noise produced by each activity on 25th of June in Y4 are compared with the aircraft noise level both while windows were open and closed.

Graph 4-2.7 shows the level of noise produced by each activity on 25th of June in Y4.



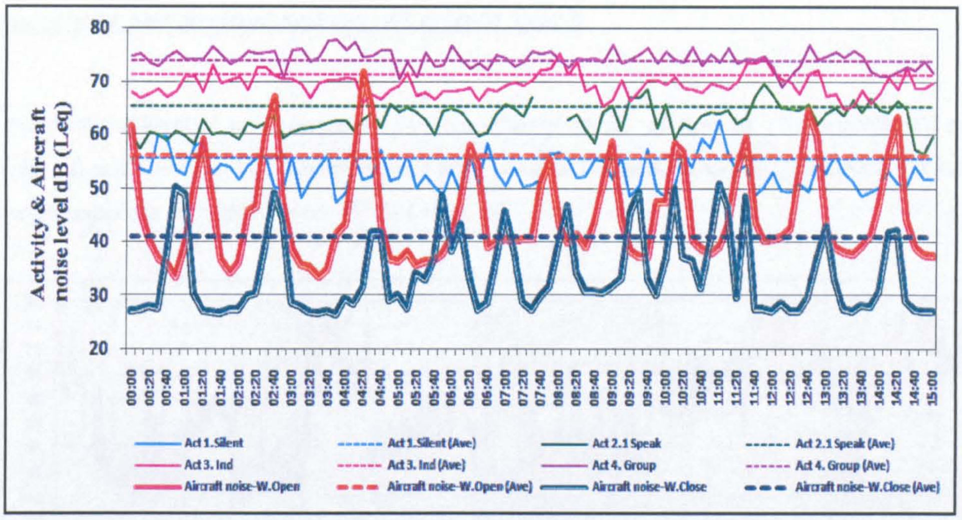
Graph 4-2.7: Records of noise produced by each activity on 25th of June in Y4

The 15-minutes duration of each type of activity is circled in the graph above (Graph 4-2.7). The extracted 15-minutes durations are combined with the 15-minutes duration of aircraft noise level monitored while windows were open and closed in Graph 4-2.8.

Table 4-2.3 shows the duration of each activity during a typical day. In this part of study as mentioned above, a 15 minutes monitoring of each activity is extracted. As can be seen, the duration of each activity is more than 15 minutes, so it is possible to extract the 15 minutes.

File	Y4_080625_085556.CMG						
Location	Classroom						
Data type	Leq						
Weighting	A						
Start	25/06/08 09:00:00:000						
End	25/06/08 15:30:00:000						
Source	Leq specific dB	Lmin dB	Lmax dB	Count	StdDev dB	L90 dB	Duration cumulated h:m:s:ms
M-in-out	71.7	41.8	91.5	24	6.7	58.0	00:33:26:200
1-TS	65.2	36.4	88.1	24	7.8	48.0	01:23:13:800
23-In-SM	71.3	48.7	89.1	2	5.2	61.4	00:29:04:600
34-G-SM	73.8	36.3	90.2	11	6.8	61.7	00:56:51:400
Un-OC	54.2	28.8	84.6	18	7.4	36.9	02:03:53:600
0-Silent	55.7	36.8	84.7	1	5.3	43.3	00:18:21:800

Table 4-2.3: Details of recorded noise produced by each activity on 25the of June in Y4



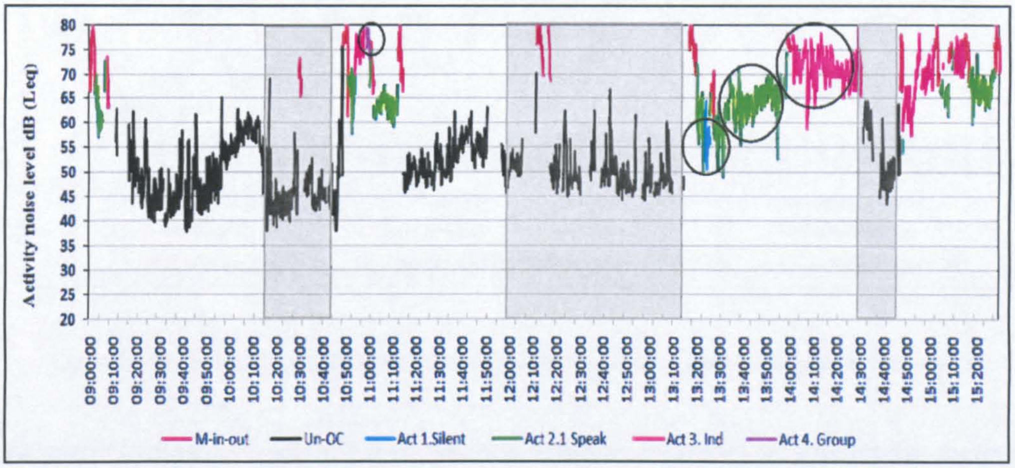
Graph 4-2.8: Comparing the level of aircraft noise with the level of noise produced by group activities at Y4

As seen in graph 4-2.8, the level of aircraft noise (windows open) does not intersect with the level of noise produced by group activities. However, they meet up at one point during 'individual activity' and at two points when 'one person is speaking', and the graph also shows several meeting points (every 1 or 2 minutes) with the level of noise produced by 'silent activities'. In other words, the level of aircraft noise is well above the level of noise produced by 'silent activities' and partially above 'one person speaking' (lecturing activity).

On the contrary, when windows are closed, the level of aircraft noise does not show intersections with any of the activities.

Activity noise measurement and aircraft noise at Year 3

In this part, the level of noise produced by each activity on 26th of June in Y3 are compared with the aircraft noise level, while windows were both open and closed. Graph 4-2.9 shows the level of noise produced by each activity on 26th of Jun in Y3.



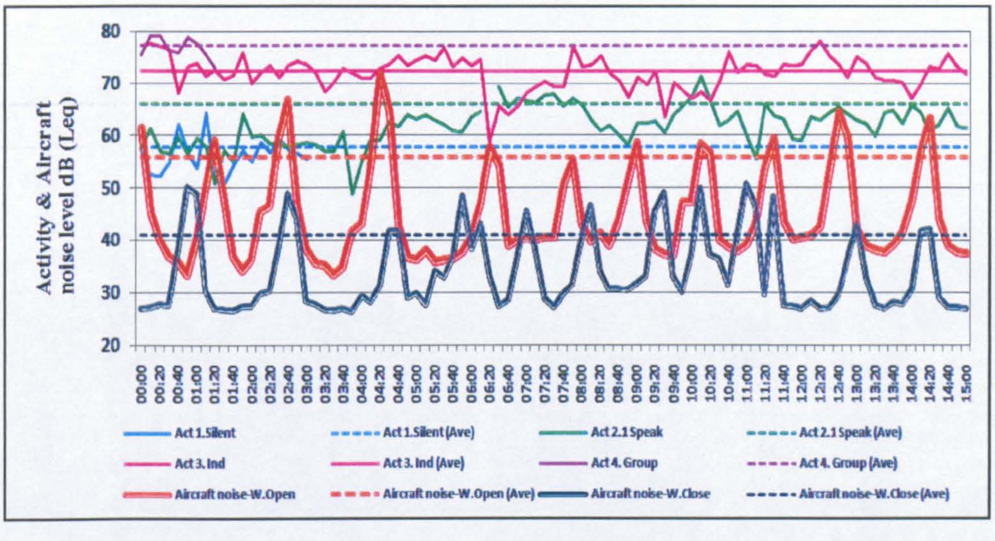
Graph 4-2.9: Records of noise produced by each activity on 26th of June in Y3

The 15-minutes duration of each type of activity is circled in the above diagram. The extracted 15-minutes durations are combined with the 15-minute duration of aircraft noise level monitored while windows were open and closed in Graph 4-2.9.

Table 4-2.4 shows the cumulative duration of each activity in a day. As mentioned earlier, a 15 minutes monitoring of each activity is extracted; however, some activities did not last long enough to provide a sum of 15 minutes e.g. silent and group activities. Therefore, the recorded sums of 3min and 1.5min are considered for silent and group activities respectively.

File	Y3_080626_085718.CMG						
Location	Classroom						
Data type	Leq						
Weighting	A						
Start	26/06/08 09:00:00:000						
End	26/06/08 15:30:00:000						
Source	Leq specific dB	Lmin dB	Lmax dB	Count	StdDev dB	L90 dB	Duration cumulated h:m:s:ms
M-in-out	76.1	47.0	95.2	22	6.9	61.8	00:29:06:200
1-TS	66.1	40.9	87.3	19	7.2	50.5	01:05:11:400
23-In-SM	72.3	46.9	89.0	12	6.3	59.5	00:46:52:600
34-G-SM	77.4	57.7	86.6	1	4.8	68.9	00:01:21:800
Un-OC	53.7	33.4	84.7	53	6.1	40.3	02:55:23:800
0-Silent	57.8	44.9	81.0	1	4.5	47.6	00:03:00:000

Table 4-2.4: Details of recorded noise produced by each activity on 26th of June in Y3



Graph 4-2.10: Comparing the level of aircraft noise with the level of noise produced by group activities at Y3

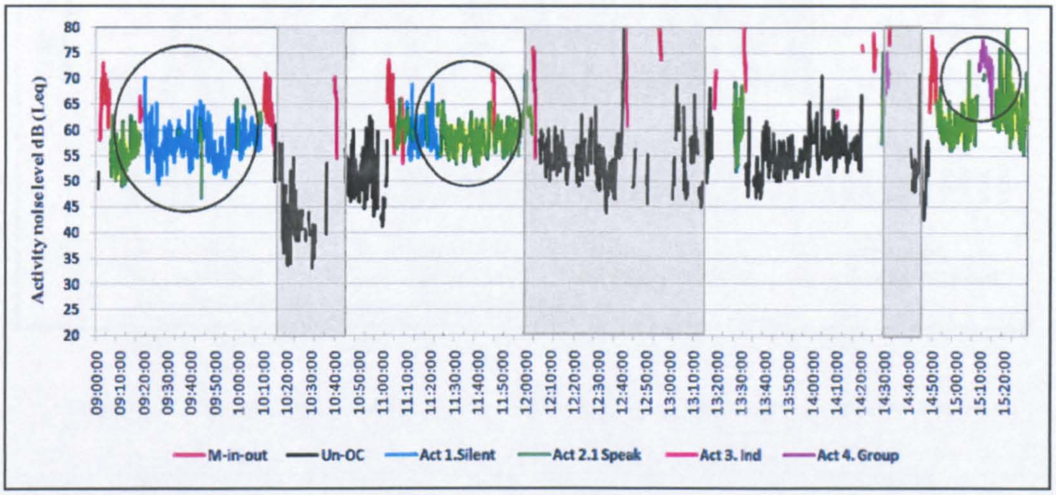
As seen in Graph 4-2.10, the level of aircraft noise (windows open) does not intersect with the level of noise produced by the group activities. However, they meet up at one point during 'individual activity' and at two points when 'one person speaking', and the graph also shows several meeting points (every 1 or 2 minutes) with the level of noise produced by 'silent activities'. In other words, the level of aircraft noise is well above the level noise produced by 'silent activities' and partially above 'one person speaking' (lecturing activity).

On the contrary, when windows are closed, the level of aircraft noise does not show intersections with any of the activities.

Activity noise measurement and aircraft noise at Year 6

In this section, the level of noise produced by each activity on 27th of June in Y6 are compared with the aircraft noise level while windows were both open and closed.

Graph 4-2.11 shows the level of noise produced by each activities on 27th of June in Y6.



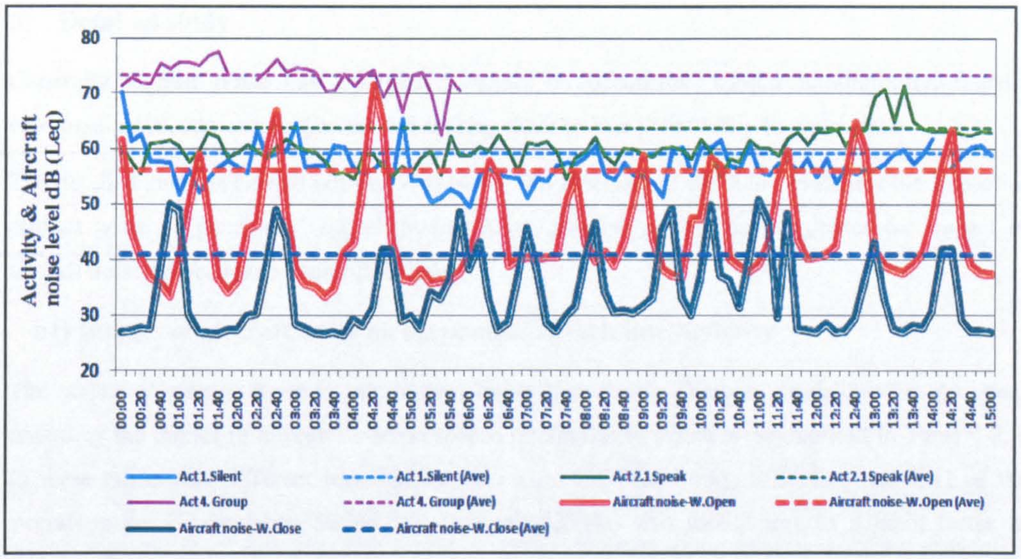
Graph 4-2.11: Records of noise produced by each activity on 27th of June in Y6

The 15-minutes duration of each type of activity is circled in the above diagram. The extracted 15-minutes durations are combined with the 15-minutes duration of aircraft noise level monitored while windows were open and closed in the Graph 4-2.11.

Table 4-2.5 shows the duration of each activity during a day. In this part of study as mentioned, a 15 minutes monitoring of each activities is extracted. As can be seen, the duration of each activity is more than 15 minutes, so it is possible to extract the required 15 minutes.

File	Y6_080627_090004.CMG						
Location	Classroom						
Data type	Leq						
Weighting	A						
Start	27/06/08 09:00:00:000						
End	27/06/08 15:30:00:000						
Source	Leq specific dB	Lmin dB	Lmax dB	Count	StdDev dB	L90 dB	Duration cumulated h:m:s:ms
M-in-out	74.8	44.5	98.3	26	7.6	56.8	00:23:15:200
1-TS	63.6	35.0	90.2	25	6.6	48.4	01:07:54:200
23-In-SM	58.6	38.9	82.2	23	4.9	48.8	01:04:15:200
34-G-SM	73.3	48.1	87.7	5	6.2	60.3	00:06:35:200
Un-OC	57.1	30.5	88.7	77	6.5	42.3	01:51:47:000
0-Silent	59.7	43.8	82.0	7	4.1	51.9	00:11:12:600

Table 4-2.5: Details of recorded noise produced by each activity on 27th of June in Y6



Graph 4-2.12: Comparing the level of aircraft noise with the level of noise produced by group activities at Y6

As seen in Graph 4-2.12, the level of aircraft noise (windows open) does not intersect with the level of noise produced by group activities, while it shows several meeting points (every 1 or 2 minutes) with the level of noise produced by 'silent activities' and 'one person speaking'. In other words, the level of aircraft noise is well above the level of noise produced by 'silent activities' and partially above 'one person speaking' (lecturing activity).

On the contrary, when windows are closed, the level of aircraft noise does not show intersections with any of the activities.

b) Detailed study

Generally aircraft noise has a negative impact on occupants' speech intelligibility, impairs communication, causes annoyances and making them to lose their ability to concentrate.

The detailed study is carried out into two parts. The first part of the study evaluates the impact of aircraft noise on occupants' speech intelligibility, and the second part evaluates the impact of aircraft noise on occupants' complaint level.

b1) Impact of aircraft noise on occupants' speech intelligibility

The nature of aircraft noise is intermittent rather than steady. Various guidelines are proposed regarding the impact of aircraft noise on speech intelligibility which is summarised in Table 4-2.6. In these guidelines, different benchmarks are set for the SIL, Lmax, SEL, Leq and LA1 of the aircraft noise. Furthermore, Shiled and Dockrell (2004a) also took Lamx as a main factor to estimate the annoyance level.

Criteria	Benchmarks	Proposed by
SIL maximum sound level in the frequency range of 500HZ to 20000 HZ	SIL < 45 dBA 90% of sentences intelligibility	Sharp et al- 1984
Lmax	Lmax <50 dBA 90% of the words would be understood	Lind et al-1998
SEL Sound exposure level	SEL < 60 dBA 95% of intelligibility	Bradly (n.d.)
Leq	Leq < 40dBA	ANSI123
LA1, 30min	LA1<55dBA	UKDFES

Table 4-2.6: Indoor noise level criteria in order to have good speech intelligibility

In Tables 4-2.7 and 4-2.8, the level aircraft noises inside classrooms against the criteria set for speech intelligibility in two situations (window closed and open) are shown in order to show that how acoustic difficulties arise in the schools located under the Heathrow flight path.

Schools	Days	Windows' status	Criteria and Recommended Benchmark					
			SIL		Lmax	SEL	Leq	LA1
			45dB		50 dB	60 dB	40 dB	55dB
			Lmax for 500 HZ	Lmax for 2000 HZ	Lmax			
Grove Road Primary School	Day 1: 2nd July	Open	62	60	69	84	53	64
		Meet the criterion	x	x	x	x	x	x
		Closed	60	54	65	74	44	55
		Meet the criterion	x	x	x	x	x	√
	Day 2: 3rd July	Open	64	76	79	89	56	69
		Meet the criterion	x	x	x	x	x	x
		Close	57	59	68	73	41	53
		Meet the criterion	x	x	x	x	x	√
	Day 3: 4th July	Open	70	62	75	88	55	68
		Meet the criterion	x	x	x	x	x	x
		Close	61	63	70	76	44	53
		Meet the criterion	x	x	x	x	x	√
Andrew Ewing Primary School	Day 4: 8th July	Open	66	51	70	81	49	61
		Meet the criterion	x	x	x	x	x	x
		Close	43	37	56	68	36	47
		Meet the criterion	√	√	x	x	√	√
	Day 5: 14th July	Open	56	50	63	76	46	54
		Meet the criterion	x	x	x	x	x	√
		Close	47	41	53	70	41	48
		Meet the criterion	x	√	x	x	x	√

Meet the criterion	√
Do not meet the criterion	x

Table 4-2.7: A study of aircraft noise based on different criteria when windows are open and closed in Grove Road and Andrew Ewing Primary schools.

A Chi-Square Test is carried out between window status and speech intelligibility outcomes. The result (n= 60, $P < 0.05$) shows that window status have a significant impact on occupants' speech intelligibility (Appendix 10.16).

According to the T Test result, it can be suggested that leaving the windows open almost always causes problems according to all criteria. According to these guidelines, the speech intelligibility is improved if windows are closed. The extent of the improvement varies depending on what guideline is referred to.

As can be seen, the level of speech intelligibility improvement on days 4 and 5 are better than days 1, 2 and 3 as a result of the windows being closed. This is due to the fact that the data for days 1-3 are related to Grove Road primary school which is directly located under the flight path and airplanes pass directly over the building. This school is located on the 63 dB(A) noise contour. The data for days 4-5 are related to the Andrew Ewing primary school which is located slightly away from the flight path and is located on the 60 dB(A) noise contour.

It should be noted that both the level of disturbing noise (e.g. aircraft noise) and the distance between speaker and listener have significant impacts on speech intelligibility. BS 8233 recommends a suitable maximum distance between speaker and listener in order to have good speech intelligibility. This distance is set based on the Lmax for a noise which is of a steady nature. As the nature of aircraft noise is intermittent, the duration in which the indoor aircraft noise exceeds a certain level (e.g background noise level), is as important as Lmax. For this reason, it is suggested the L10 and L5 of indoor aircraft noise are calculated instead of Lmax in order to show how the acoustic difficulties arise in the schools located under the Heathrow flight path. Based on this the 10% and 5% of high levels of aircraft noise are calculated in order to estimate the percentage of occasions that communication would fail due to the aircraft noise.

In every 90 seconds an aircraft passes over the schools which are within a close distance to Heathrow airport. The Table 4-2.9 shows the maximum suitable distances between speaker and listener based on BS 8233 (which is adapted for L5 and L10) and the percentage of occasions that communications would be failed. For example, if the distance between the speaker and listener (in the situation that the window is open) becomes higher than 0.7m. When an aircraft is passing over the school building, 4.5 out of 90 seconds of the communication is missed out. In other words, if pronouncing each word lasts for 1 second, it can be concluded that nearly five out of 90 words will be missed out which causes a negative impact on speech intelligibility.

Furthermore, if the distance between speaker (with a normal voice) and listener becomes higher than 1.32m, then 9 seconds out of 90 is missed out which even creates a more critical situation as nine out of 90 words will be missed out. In the situation that the window is closed, the distances are increased to 2.7 and 4.7 respectively.

Maximum distance between speaker and listener when windows are 'open'	Maximum distance between speaker and listener when windows are 'closed'	Duration that communication is failed
0.7	2.7	4.5 out of 90 seconds
1.3	4.7	9.0 out of 90 seconds

Table 4-2.8: Maximum distance between speaker and listener when windows are opene and closed and the durations of failed communication (speaker uses normal voice)

In the condition that the speaker raises his/her voice by up to 5 dBA, the recommended distances can be increased as per table 4-2.10.

Maximum distance between speaker and listener when windows are 'open'	Maximum distance between speaker and listener when windows are 'closed'	Duration that communication is failed
1.6	6.0	4.5 out of 90 seconds
2.4	8.0	9.0 out of 90 seconds

Table 4-2.9: Maximum distance between speaker and listener when windows are opene and closed and the durations of failed communication (speaker with a raised voice)

As can be seen, the suitable distance between speaker (with normal voice) and listener varies between 0.7m to 1.3m when windows are open. This amount can be increased to 1.6 to 2.3 if the speaker raises his or her voice by up to 5 dBA. As it can be seen from the Figures 4-2.1 and 4-2.2, the best condition in which good speech intelligibility is provided (while the windows are open and aircrafts fly over the school) is when the teacher sits on a chair at the centre, students sit around him/her and the teacher raises his/her voice. In this condition, teacher speech intelligibility is provided even for the students who sit in the second or third rows.

As it was observed several times in the classrooms of Grove Road and Andrew Ewing primary schools, teachers invited students to sit on the floor and they themselves sat on the chair during most of the lecturing activities in order to improve speech intelligibility.

Figure 4-2.1: A classroom layout and the distance between teacher and students when the teacher sits on the chair and students sit around her on the floor (A.Montazami) - Right.

(Photo source: Picture courtesy of Evening Gazette, Middleborough) - Left

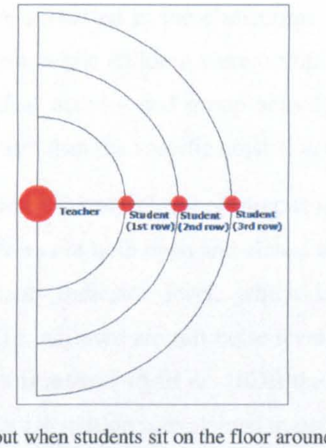


Figure 4-2.2: Classroom layout when students sit on the floor around a teacher (A.Montazami)

It should be noted that if the teacher wants to stand up or students want to sit at their desks, the speech intelligibility will be impaired even further and students will start to miss at least 4.5 seconds (or more) out of 90 seconds depending on their distance to the teacher as their distance exceeds the maximum recommended distance between speaker and listener [Table 4-2.9 (teachers with normal voice) and Table 4-2.10 (teachers with raised voice)]. In this situation, in order to improve speech intelligibility, classroom's windows should be kept closed. This confirms that the occupants of the school located under the flight paths tend to close the windows most of the time. Although closing window tends to improve the speech intelligibility, it reduces the buildings' potential for having natural ventilation, as the only means of ventilation in these schools are through windows.

In addition, in the situations when it is necessary to leave the windows open, the distance between speaker and listener should be kept as minimum otherwise the listeners start to miss out some parts of the communication which has an impact on speech intelligibility.

b2) Impact of aircraft noise on occupants' annoyance level

In terms of annoyance level, both BS 4142 and the Guides on Noise from Pubs and Clubs (I.O.A, 2003) use a criterion which looks at the difference between the specific noise (e.g. disco, aircraft) and background noise (e.g. students' activity). If this difference exceeds 10 dB, complains are likely. Before doing the subtraction, the specific noise should be corrected. The following procedure predicts the complaints level from the aircraft noise if the BS 4142 method is applied. For this reason, two types of noise level readings were carried out in six classrooms of two naturally ventilated primary schools in June and July of 2008 to determine the specific noise and background noise levels.

1. Specific noise levels (LAeq) were measured in the un-occupied classrooms when windows were both open and closed while aircraft noise (i.e. specific noise) was present (i.e. aircraft was passing over the building) and absent for, 30 minutes.

2. Background noise levels (LA90) were measured in the classrooms when they were occupied, and the specific noise (aircraft) was absent, while children were occupied with different activities (i.e. silent, one person speaking, individual activity and group activity). Note: The noises from children's activity are the background noise when the specific noise (i.e. aircraft) is absent.

The likelihood that occupants complain from the high level of aircraft noise inside classrooms are calculated for each classroom when windows are both open and closed and occupants are occupied with different activities. If the complaint indicator level, which is the difference between background noise level and rating level (i.e. adjusted aircraft noise level), is around (or more than) +10dB then complaints are likely and if it is around +5dB & -10DB the complaints are marginally significant and unlikely, respectively. This calculation is explained in detail on the following pages.

The calculation of occupants' complaint level

The calculation of occupants' complaints level is carried out in the following five steps:

- **Step 1:** 15 to 30 minute noise level readings were carried out inside two unoccupied classrooms from two different primary schools for 7 days, when the windows were open and closed, while *aircraft noise (i.e. specific noise) was present* (i.e. aircraft passing over the building). The measurements were carried out during the school hours when all the students and teachers from all the classrooms had left to the assembly hall.

The following table (Table 4-2.11) represents the average noise level inside the classrooms (LAeq) on various days in two situations (i.e. windows open and closed) when the specific noise (i.e. aircraft) was present.

Specific noise (i.e.aircraft noise) Present									
School	Duration	Classroom	Date	Open	Close	Each School Average Open	Each School Average Close	Total Average Open	Total Average Close
Grove Road	08:08 - 08:38	Y4	02.July.2008	LAeq(30min)=53 dB		55 dB	43 dB	54 dB	41 dB
	08:25 - 08:55	Y4	02.July.2008		LAeq(30min)=44 dB				
	07:13 - 07:43	Y4	03.July.2008	LAeq(30min)=56 dB					
	07:52 - 08:22	Y4	03.July.2008		LAeq(30min)=41 dB				
	07:22 - 07:52	Y4	04.July.2008	LAeq(30min)=55 dB					
	08:00 - 08:30	Y4	04.July.2008		LAeq(30min)=44 dB				
Andrew Ewing	07:43 - 08:13	Y4	08.July.2008		LAeq(30min)=36 dB	52 dB	38 dB		
	08:12 - 08:42	Y4	07.July.2008	LAeq(30min)=53 dB					
	09:15 - 09:45	Y4	07.July.2008	LAeq(30min)=51 dB					
	15:51 - 16:21	Y6	14.July.2008		LAeq(30min)=41 dB				

Table 4-2.10: Noise level when the windows were open and closed while aircraft noise (i.e. specific noise) was present

The results of 10 readings are summarised in the above table. As can be seen, the average noise level inside the classrooms was 54dB when windows were opened and 41 dB when they were closed while *aircraft noise (i.e. specific noise) was present.*

• **Step 2:** 20 to 30 minutes noise level readings were carried out inside two unoccupied classrooms from two different primary schools for 3 days, when the windows were open and closed, while *aircraft noise (i.e. specific noise) was absent* (i.e. no aircraft over the building). The measurements were carried out during the school hours when all the students and teachers from all the classrooms had left to the assembly hall.

The following table (Table 4-2.11) represents the average noise level inside the un-occupied classrooms (LAeq) in two situations (i.e. windows open and closed) on various days when the specific noise (i.e. aircraft) was absent.

Specific noise (i.e.aircraft noise) Absent									
School	Duration	Classroom	Date	Open	Close	Each School Average Open	Each School Average Close	Total Average Open	Total Average Close
Grove Road	15:46 - 16:06	Y4	01.July.2008	LAeq(20min)=45 dB		45 dB	36 dB	45 dB	37 dB
	11:36 - 11:56	Y2	09.July.2008		LAeg(20min)=38 dB				
Andrew Ewing	15:50 - 16:11	Y4	07.July.2008		LAeq(30min)=37 dB	45 dB	37 dB		

Table 4-2.11: Noise level when the windows were open and closed while aircraft noise (i.e. specific noise) was absent

The results of the 3 readings are summarised in the above table (4-2.11). As can be seen, while *aircraft noise (i.e. specific noise) was absent,* the average noise level inside classrooms was, 45dB when windows were open, and 37 dB when they were closed.

• **Step 3:** The difference between noise level readings when specific noise (i.e. aircraft) was present and absent is calculated in order to select the correction factor from the Table 4-2.12.

The correction factor should be subtracted from the noise reading when specific noise is present.

Corrections to noise level readings	
Difference between noise level readings with specific noise present and absent dB	Correction to be substracted from noise level reading with specific noise present dB
>9	0
6 to 9	1
4 to 5	2
3	3
<3	See BS 4142

Table 4-2.12: Correction table

The following table (Table 4-2.13) shows the differences between noises level readings while specific noise (i.e. aircraft) was present and absent:

Average noise level reading	Total Average Open	Total Average Close
Specific noise (i.e.aircraft) present	54 dB	41 dB
Specfict noise (i.e.aircraft) absent	45 dB	37 dB
Difference	9 dB	4 dB

Table 4-2.13: Finding the correction factor for noise level reading (aircraft noise level reading)

As can be seen from the above table, the differences are 9dB and 4 dB for which the correction factors of 0 and 2 are applicable respectively. By applying the correction factors to the average noise levels when specific noise (i.e. aircraft) was present, the corrected measured noise levels are *54dB* and *39db* respectively.

- **Step 4:** According to BS 4142, the rating levels are calculated by adding 5dB to the specific noise level, if one or more of the following features occur, or is expected to occur for new or modified noise sources:

- The noise contains a distinguishable, discrete, continuous note (whine, hiss, screech, hum, etc.)
- The noise contains distinct impulses (bangs, clicks, clatters, or thumps)
- The noise is irregular enough to attract attention.

In this study the *rating level* is calculated by adding 5dB to the specific noise level as the aircraft noise contains distinguishable note. So the rating levels are as follows:

	Window.Open	Window.Close
Rating level	59	44

Table 4-2.14: Rating level

- **Step 5:** In this step, the rating levels are compared with the background noise levels inside classrooms.

Note: the background noise levels inside the classrooms are calculated when different activities are happening inside the classroom and aircraft noise is absent.

According to BB4142:1997, the likelihood of complaint (i.e. from the high level of aircraft noise) is calculated by subtracting the measured background noise level from the rating level.

The greater this differences, the greater the likelihood of complaints.

- A difference of around +10dB or more indicates that complaints are likely.
- A difference of around +5dB is of marginal significance
- A difference of around -10dB or less indicates that complaints are unlikely.

Table 4-2.15 shows the background noise levels as a result of various activity inside the classroom.

Schools	Classrooms	Background noise level - LA90			
		Activity 1-Silent	Activity 2-1 Peson Speak	Activity 3- Individual	Activity 4. Group
School.1	Class1	49	48	50	58
	Class2	43	48	61	62
	Class3	48	51	60	69
	Class4	52	48	49	60
School.2	Class1	46	44	59	61
	Class2	47	45	56	49

Table 4-2.15: Background noise levels when different activities are happening in different classrooms

The following tables (Tables 4-2.16 and 4-2.17) show the complaint indicator level and the likelihood complaint inside 8 classrooms of two different primary schools when different activities are happening inside the classrooms when windows are open and closed.

Activity	Activity 1-Silent				Activity 2-1 Peson Speak			
Window	Open		Close		Open		Close	
Assessment	Complain indicator level	Complain	Complain indicator level	Complain	Complain indicator level	Complain	Complain indicator level	Complain
Schl1.Class1	10	Likely	-5	Unlikely	11	Likely	-4	Unlikely
Schl1.Class2	16	Likely	1	Unlikely	11	Likely	-4	Unlikely
Schl1.Class3	11	Likely	-4	Unlikely	9	Likely	-7	Unlikely
Schl1.Class4	7	Marginal	-8	Unlikely	11	Likely	-4	Unlikely
Schl2.Class1	13	Likely	-2	Unlikely	15	Likely	0	Unlikely
Schl2.Class2	12	Likely	-3	Unlikely	14	Likely	-1	Unlikely

Table 4-2.16: Complaint level from aircraft noise when 'Activity1: Silent' & 'Activity 2: one person speaking' are occurring inside the classrooms

Activity	Activity 3- Individual				Activity 4. Group			
Window	Open		Close		Open		Close	
Assessment	Complain indicator level	Complain	Complain indicator level	Complain	Complain indicator level	Complain	Complain indicator level	Complain
Schl1.Class1	9	Likely	-6	Unlikely	1	Unlikely	-14	Unlikely
Schl1.Class2	-2	Unlikely	-17	Unlikely	-3	Unlikely	-18	Unlikely
Schl1.Class3	-1	Unlikely	-16	Unlikely	-10	Unlikely	-25	Unlikely
Schl1.Class4	10	Likely	-5	Unlikely	-1	Unlikely	-16	Unlikely
Schl2.Class1	0	Unlikely	-15	Unlikely	-2	Unlikely	-17	Unlikely
Schl2.Class2	3	Unlikely	-12	Unlikely	10	Likely	-5	Unlikely

Table 4-2.17: Complaint level from aircraft noise when 'Activity 3: individual' & 'Activity 4: Group' are occurring inside the classrooms

As can be seen from Table 4-2.16, in both schools and in all the classrooms, the complaints are likely when windows are 'open' and occupants are engaged in 'Activity 1: Silent' & 'Activity 2: One person speaking'. However, under similar conditions, the complaints are unlikely if the windows are closed. As can be seen from Table 4-2.17, in 'Activity 3: Individual' & 'Activity 4: Group', the level of complaints are likely in 2 & 1 cases respectively (out of 6) when windows are open.

A regression analysis is carried out between annoyance levels and 'type of activity and window status' outcomes. The result ($n=48$, $P<0.05$, $R=0.461$) shows that there is a significant relation between them. The relation between annoyance levels and types of activity complies with the following equation:

$$Y = -0.308\, X_1 + 0.542\, X_2 + 2.229$$

- Y = Annoyance level (Likely = 1, Marginal = 2, Unlikely=3)
- X_1= Activity (Silent = 1, Lecturing=2, Individual=3, Group=4)
- X_2 = Wind status (Open= 1, Close = 2)

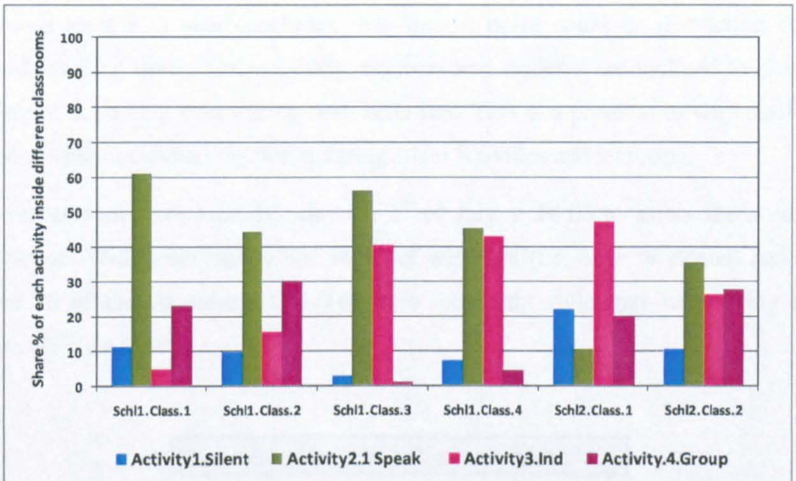
  (Appendix 10.17)

Therefore, it can be suggested that the level of complaint from aircraft noise is significant when windows are open and occupants are engaged with 'Activity1: Silent' & 'Activity 2: One person speaking' and the level of complaint would decrease from likely to unlikely by closing windows.

The findings confirm the teachers' claim that they close windows during the 'Silent' and 'One person speaking' activities. In addition, the results show that complaints are even probable during 'Activity 3: Individual' & 'Activity 4: Group' when windows are open.

Share of each activity inside classrooms

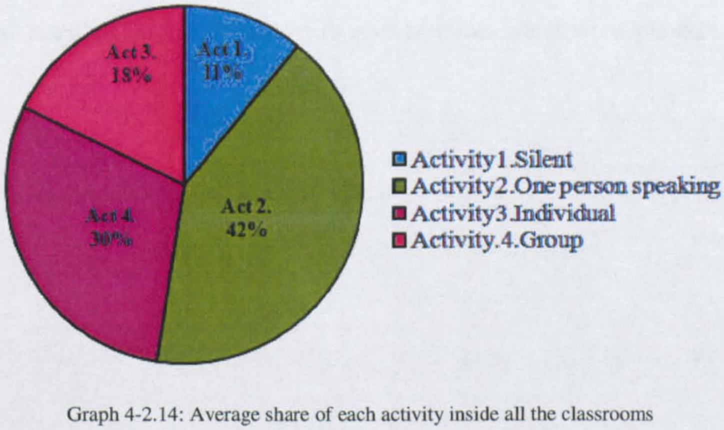
The following graph (4-2.13) shows the share of each activity inside different classrooms in different schools. As can be seen, the 'Activity 2: one person speaking' has the highest share between the four different activities which are carried out inside the classrooms.



Graph 4-2.13: Share of each activity inside different classrooms

In order to test whether Act.2 has the highest share of the occupied hours, a one-way ANOVAS T Test is carried out between the percentages of Act.2 with other activities. The result shows that the share of Act.2 is significantly higher ($n=6$, $P<0.05$) [Appendix 10.18].

The following pie-chart (Graph 4-2.14) shows the average duration of each activity inside classrooms. As can be seen, the share of activities 'Activity1: Silent' & 'Activity 2: One person speaking' are around 55% of all activities.



Graph 4-2.14: Average share of each activity inside all the classrooms

Hence, it can be suggested that there is a high possibility that classrooms located under the flight paths keep their windows shut for more than half of their duration due to the aircraft noise, and this consequently leads to the lack of ventilation.

c) Random study

In the previous section, it was concluded that aircraft noise could be distracting during silent activities and teaching times. Consequently, teachers and students are inclined to close windows when an aircraft is passing over during such activities. This is a proof as to why teachers believe that classroom windows should be closed during silent activities and lecturing.

A random survey was carried on Tuesday the 1st of July at 14:05 to assess the accuracy of the above in practice. Within the survey, the status of windows (i.e. open or closed) and the type of activities for all of the classrooms (Y1-Y6) were recorded, while they were being affected by aircraft noise (Table 4-2.19).

Classrooms	Window situation	Activities
Y1	Close	Quiet
Y2	Open	Noisy
Y3	Open	Noisy
Y4	Open	Noisy
Y5	Close	Empty
Y6	Close	Quiet

Table 4-2.18: Window status VS the level of noise in different classrooms

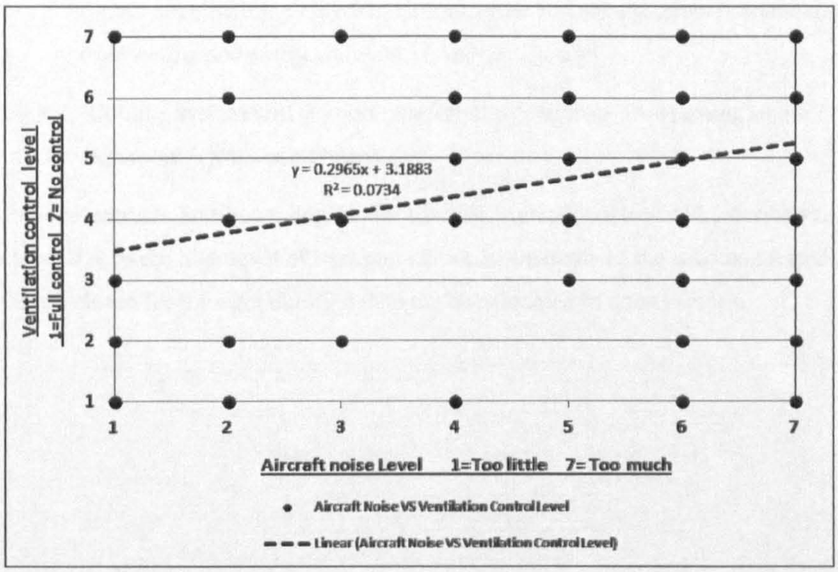
In this study, the 'quiet activities' mainly refers to the 'Activity 1: Silent' and 'Activity 2: one person speaking' and the 'noisy activities' mainly refers to the 'Activity 3: individual' & 'Activity 4: Group'. As can be seen from Table 4-2.19, only the windows of the classrooms with noisy activities stayed 'open' in contrast to those with quiet activities which were 'closed'.

4.2.1.2. Subjective survey:

a) Teachers' subjective survey:

The aim of this section of the study is to confirm the probability of closing windows due to the high level of aircraft noise according to teachers' perception. In the questionnaires, teachers were requested to rate the ventilation control and aircraft noise levels from one to seven. The regression analysis of perceived ventilation control level and aircraft noise confirmed that there is a small but significant negative relationship between ventilation control level and aircraft noise level ($P<0.05$, $r=0.270$) [Appendix 10.19]. Graph 4-2.15 shows the relationship between teachers' perceptions on the level of aircraft noise and ventilation control.

The only available ventilation system in the classrooms which are studied is window, as they are all naturally ventilated buildings. Although occupants of the buildings located under the flight path physically had the ability to open and close windows, however because of aircraft noise, there were some limitations to maintaining access to natural ventilation. Therefore, it could be concluded that ventilation in these classrooms are not fully controlled which causes the buildings to the lack sufficient ventilation due to the high level of air craft noise.



Graph 4-2.15: Ventilation control level vs. Aircraft noise in different schools

As a result, it is subjectively proven that the occupants of the classrooms which are located under the flight path tend to close windows more than the ones located in the quiet regions. The subjective results also confirmed the results of objective study.

The followings are extracted from the teachers' questionnaires (from the comment section) that show that they close windows as a result of the high level of aircraft noise:

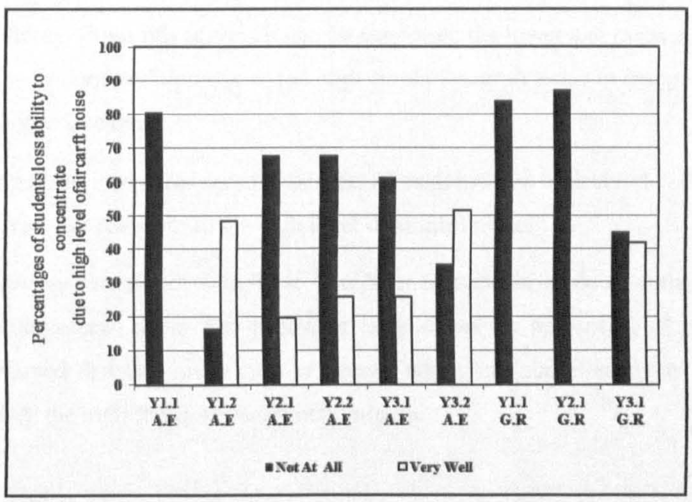
- 'Our main noise issue is aircraft noise because we are under the flight path of planes landing at Heathrow Airport. Our noise insulation is good, so lessons inside are not badly affected but this means doors and windows must be closed so the ventilation is poor. Classrooms are hot and stuffy in summer.' (Grove Road)
- 'At times, we stop until the plane has passed or we have to close windows to work and that makes it quiet stuffy to work in'. (Grove Road)
- 'I need to open doors and windows for fresh, cool air. However this means an increase in aircraft noise, which disturbs lessons.' (Cranford)
- 'Doors need to be open in summer due to the heat and then noise from outside (games lesson and mainly planes) makes it very difficult to hear or to be heard.' (Cranford)
- 'Over flying plane mean pauses in giving instruction, hearing, answering, during independent work it's not a problem.' (Cranford)
- 'I always confuse between opening and closing windows due to some students cannot cope with high level of aircraft noise and some students cannot cope with overheating and stuffy situation.' (Andrew Ewing)
- 'Cooling system will support comfortable conditions for learning in the classroom.'(Norwood Green).

From the above extracts and according to the teachers' questionnaires and interviews, it can be concluded that due to the high level of background noise, windows of the schools located under the flight paths are closed for a longer duration than the ones located in quiet regions.

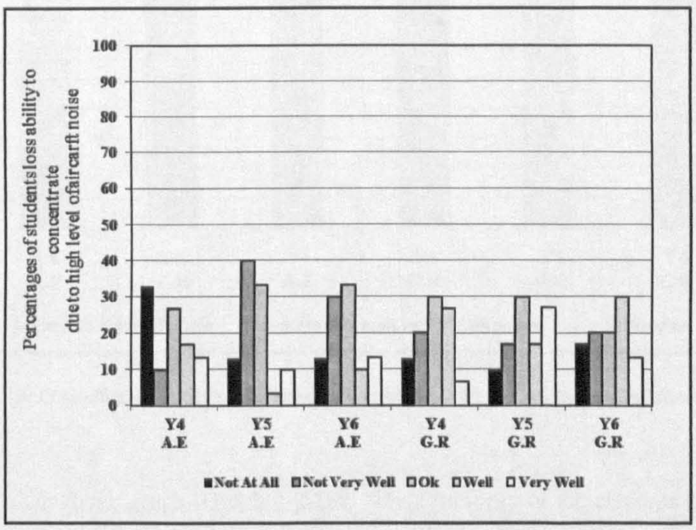
b) Students' subjective survey:

The aim of this part is to show the probability of closing windows due to the high level of aircraft noise according to the students' perception. In order to investigate the students' perception regarding the high level of aircraft noise and probability of lack of ventilation, this study is carried out *in three parts* as follows:

- **Part 1:** Rate of students' concentration vs. aircraft noise are studied for two different age rages, when they are occupied with quiet activities :
    - 7 to 9 years old who attend Year 1 to 3
    - 10 to 12 years old who attend Year 4 to 6



Graph 4-2.16: Percentage of students with the loss of ability to concentrate while affected by aircraft noise (Y1, Y2&Y3)



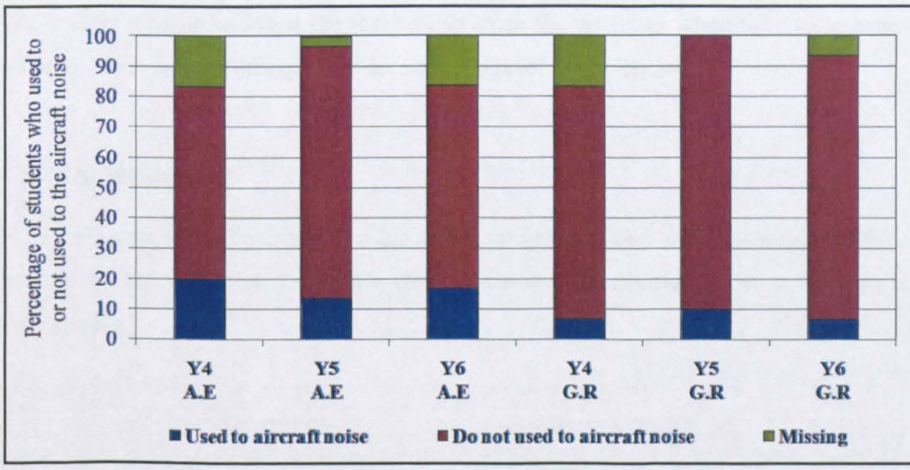
Graph 4-2.17: Percentage of students with the loss of ability to concentrate while affected by aircraft noise (Y4, Y5&Y6)

The Graphs 4-2.16 and 4-2.17 show the students loss of ability to concentrate due to the high level of aircraft noise for two different age range groups. As can be seen, in the age range of 7 to 9 years, a considerable percentage of students found it difficult to concentrate when they were occupied with quiet activities. In the age range of 10 to 12 years, the responses varied considerably and covered all ranges, but in each classroom there were a considerable number of students who responded that their ability to concentrate were not good when they were occupied with quiet activities and an airplane passed over the building.

Overall, it can be concluded that in each classroom there were a considerable number of students who lost their ability to concentrate when they were occupied with quiet activities and airplanes passed over the building. From this survey, it can be suggested the lower age range students have a higher risk to lose their concentration due to the high level of aircraft noise in comparison with the students from the higher age range.

- **Part 2:** This part of the study concerns the number of students who believed that they were used to and would not show any reactions to the high level of aircraft noise.

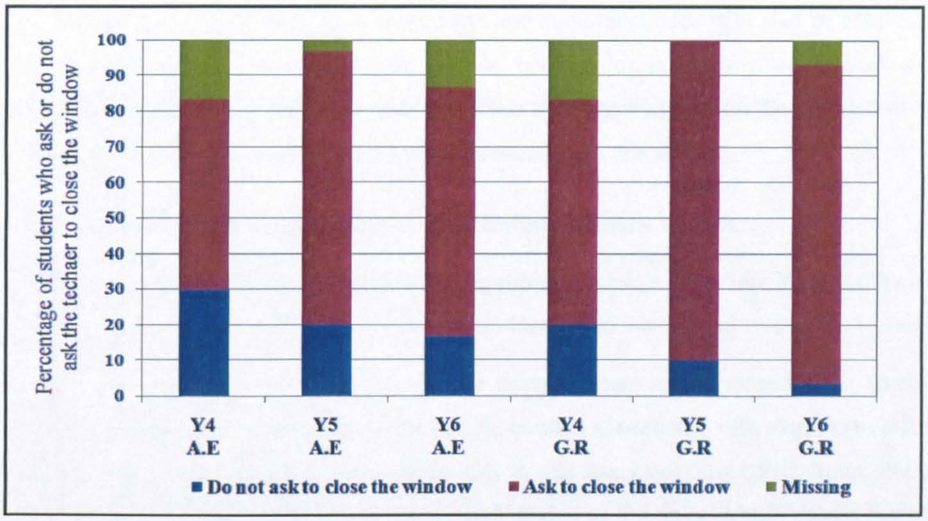
According to interviews carried out with Year 4 to Year 6 students, some of them believed that they were used to the aircraft noise. The following table shows the percentage of people in each classroom who believed that they were used to aircraft noise, and consequently would not show any reactions towards the high levels of background noises.



Graph 4-2.18: Percentage of students' adaptability towards the high level of background noise

As can be seen from the above graph (Graph 4-2.18), only a minority of the students believed that they were used to and not affected by the aircraft noise. However, the majority said otherwise and they are the ones who may show reaction towards the high level of background noise and ask the teacher to close the windows.

- **Part 3:** The number of students who showed reaction to the high level aircraft noise and asked the teacher to close the window is studied in this section.



Graph 4-2.19: Percentage of students who requested window closure in reaction towards high level of background noises

The above graph (Graph 4-2.19) shows the percentage of students in each classroom who were not used to the noise and asked the teachers to close the windows. As can be seen, over 50% of the students in each classroom asked the teachers to close the windows when they were annoyed by aircraft noise. This would consequently decrease the level of ventilation.

4.2.1.3. Conclusion

In this part of study, it is objectively & subjectively proven, that one of the main reasons for closing windows in the schools located within a close distance to Heathrow airport is the high level of aircraft noise.

4.2.2. Part Two: Analysis of the impact poor layout on opening status

Overview

The aim of this part is to show that aircraft noise is not the only source of distracting noises for students and teachers. Noise from other classrooms and communal halls may also be considered as distracting. This is usually caused due to the schools' poor layout. Poor layout of a school not only may result in low acoustic comfort but also may have a negative impact on the ventilation rate in naturally ventilated schools. This is the subject of discussion in this section.

4.2.2.1. Poor layout in Grove Road and Andrew Ewing Primary schools

The map review of Grove Road and Andrew Ewing primary schools show that in each school there is a communal hall (in which IT activities take place) located on the internal side of the classrooms.

According to the interview with the teachers, the internal doors stayed closed while there were noisy activities taking place in the communal hall, or in other classrooms with their doors left open. It should be noted that noise from other classrooms in this study not only refers to the noise that travels from shared walls between two classrooms but also to the noise which travels from other classrooms to the communal hall and from the communal hall to the classroom. If there is a possibility to leave the internal door open, the classroom will have a chance to provide fresh air from the communal hall. In addition, classrooms could have the benefit of cross ventilation as there is an opening on the roof of the communal hall in both schools.

Figure 4-2.3: Plan, communal hall and façade view in Grove Road Primary School

Figure 4-2.4: Plans and communal hall and façade views in Andrew Ewing Primary School

(Top- left: ground floor plan), (Bottom-Left -first floor plan)

In order to study how the poor layout causes lack of ventilation in Grove Road primary school, this study is objectively & subjectively carried out.

a) Objective survey in Grove Road primary school

To find out that how the noises heard from the communal hall is distracting, the level of background noise was measured in Y2 on 9th July 2008 when the classroom was un-occupied and the window was closed. The background noise measurements was carried out in two situations, i.e. the internal 'door' was OPEN and CLOSED, in order to find out that how closing the door would decrease the distracting noises.

Background noise level inside the classroom when door was closed

The noise from the adjacent classrooms not only transferred through the walls but also from the communal hall due to the layout of Grove Road primary school.

The communal hall is used for IT activities, and therefore it could be a source of distracting noise for all of the classrooms. Consequently, the teachers and students tend to keep the classrooms doors closed while they are occupied with silent and lecturing activities (based on the author observation and communication with teachers).

The noise measurement carried out in Y2 classroom (when it was un-occupied) during the session one (the classrooms are run over four sessions on each day) of other classrooms. As can be seen in the table below (Table 4-2.19), while the internal door was CLOSED the level of background noise was recorded at 37.9 (dB) which roughly meets the recommended background noise level inside a classroom [35 (dB)].

Periods	5m
Start	09/07/08 09:25:00:000
End	09/07/08 10:15:00:000
Location	Classroom
Weighting	A
Data type	Leq
Unit	dB
Period start	L90
09/07/08 09:25:00:000	35.1
09/07/08 09:30:00:000	37.6
09/07/08 09:35:00:000	37.7
09/07/08 09:40:00:000	35.4
09/07/08 09:45:00:000	39.1
09/07/08 09:50:00:000	39.8
09/07/08 09:55:00:000	41.6
09/07/08 10:00:00:000	41.6
09/07/08 10:05:00:000	41.9
09/07/08 10:10:00:000	36.1
Overall	37.9

Table 4-2.19: Noise level from adjacent classrooms transferred in to year 2 when door was closed

Background noise level inside the classroom when door was open

The noise measurement was carried out in Y2 classroom (when it was un-occupied) during the session two and three of other classrooms. As can be seen in the table below (Table 4-2.21), the levels of background noise during sessions two and three, while the internal door was OPEN, were recorded at 42.4 dB and 40.8dB respectively.

Periods	5m
Start	09/07/08 13:15:00:000
End	09/07/08 14:30:00:000
Location	Classroom
Weighting	A
Data type	Leq
Unit	dB
Period start	L90
09/07/08 13:15:00:000	41.7
09/07/08 13:20:00:000	38.7
09/07/08 13:25:00:000	41.7
09/07/08 13:30:00:000	41.7
09/07/08 13:35:00:000	41.4
09/07/08 13:40:00:000	40.9
09/07/08 13:45:00:000	41.9
09/07/08 13:50:00:000	46.8
09/07/08 13:55:00:000	47.3
09/07/08 14:00:00:000	46.9
09/07/08 14:05:00:000	47.3
09/07/08 14:10:00:000	47.0
09/07/08 14:15:00:000	47.1
09/07/08 14:20:00:000	48.7
09/07/08 14:25:00:000	49.3
Overall	42.4

Periods	5m
Start	09/07/08 14:45:00:000
End	09/07/08 15:25:00:000
Location	Classroom
Weighting	A
Data type	Leq
Unit	dB
Period start	L90
09/07/08 14:45:00:000	44.3
09/07/08 14:50:00:000	41.1
09/07/08 14:55:00:000	41.5
09/07/08 15:00:00:000	38.8
09/07/08 15:05:00:000	40.6
09/07/08 15:10:00:000	40.5
09/07/08 15:15:00:000	40.6
09/07/08 15:20:00:000	41.7
Overall	40.8

Table 4-2.20: Noise level from adjacent classrooms transferred in to year 2 when door was open

As it has been mentioned earlier, the standard level of background noise is 35dB. The result of the above survey shows that the level of background noise at Y2 was higher than the standard background noise when the door was OPEN.

As a result, occupants may close the internal door to reduce the background noise from 42.8 dB & 40.8 dB to 35 dB, therefore it can be said that the school's interior noise could be another cause of discomfort leading to closing internal doors in the classrooms of Grove Road primary school as a result of its layout.

b) Subjective survey in Grove Road and Andrew Ewing primary schools

The subjective study in Grove Road and Andrew Ewing primary schools are carried out in two separate parts. The first part is allocated to the students of Year 4 to Year 6 and the second part is allocated to the students of Year 1 to Year 3. As mentioned earlier, noise from other classrooms in this study not only refers to the noise that travels from the shared walls between two classrooms but also to the noise travelling from other classrooms to the communal hall, and then to a classroom. For the purpose of this study, the sources of noise are divided into: noises from school, and noises from aircrafts.

Subjective survey in Year 4 to Year 6 :

In order to assess how often the noise from aircrafts, hall and other classrooms distracts students, questionnaires were given to the students of Year 4 to Year 6 to rate their frequency of distraction. Table 4-2.21 shows the codes of distraction level from different noise sources.

Rating	Always	Often	Sometimes	Never
Coding	4	3	2	1

Table 4-2.21: Codes of distraction level from different noise sources in Year 4 to Year 6

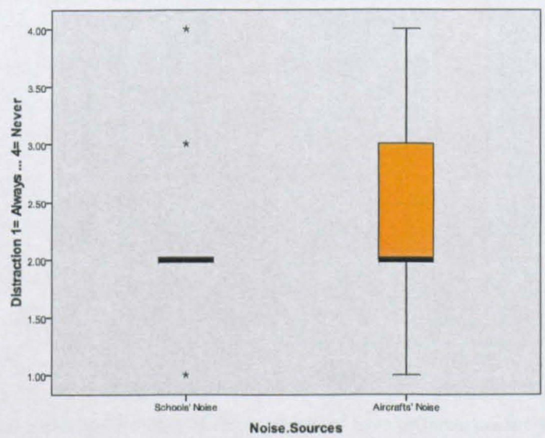
As can be seen, the mean distraction level from school is 2.02. This is 2.2 for aircraft noise.

Group Statistics

	Noise. Sources	N	Mean	Std. Deviation	Std. Error Mean
Distraction	School Noise	324	2.0185	.66279	.03682
	Aircraft Noise	162	2.2037	.93343	.07334

Table 4-2.22: Mean and variance distraction level from different noise sources in Year 4 to Year 6

The following graph shows the mean and variance of distraction from the school and aircraft:



Graph 4-2.20: Mean and variance it distraction from different noise sources in Year 4 to Year 6

An Independent Sample T test is carried out between the results of questionnaires to assess whether the noises from aircraft and layout are significantly different from each other. The result shows that the distraction levels from aircraft and school noises are not significantly different ($P>0.05$) [Appendix 10.20].

Based on this analysis, it is possible to justify that noises from school are as distracting as those of aircrafts. This also shows why the teachers claim that they tend to close classroom doors in order to prevent distraction.

<u>Subjective survey in Year 1 to Year 3:</u>

In addition to evaluating the distraction and concentration levels of students of Year 4 to Year 6, the distraction levels of students of Year 1 to Year 3 are evaluated with a simpler questionnaire. Table 4-2.24 shows the coding of distraction when noise is coming from different sources.

Rating	Always	Never
Coding	2	1

Table 4-2.23: Codes of distraction level from different noise sources in Year 1 to ear 3

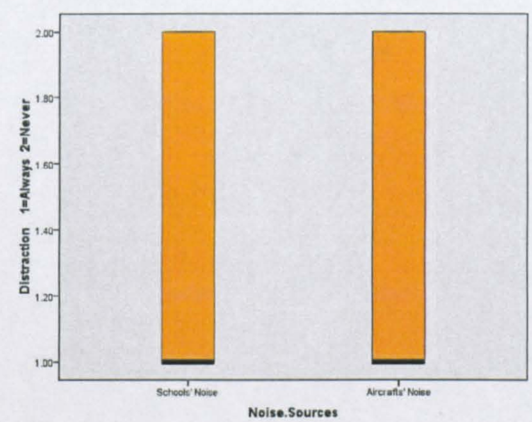
As can be seen, the mean distraction level from aircraft noise (1.33) is higher than the mean distraction level from school noises (1.26).

Group Statistics

	Noise.Sources	N	Mean	Std. Deviation	Std. Error Mean
Distraction	Schools' Noise	133	1.2632	.44201	.03833
	Aircrafts' Noise	106	1.3302	.47252	.04589

Table 4-2.24: Mean and variance distraction level from different noise sources in Year 1 to Year 3

The following graph shows the mean and variance of distraction from aircrafts and schools.



Graph 4-2.21: Mean and variance of distraction level from different noise sources in Year 4 to Year 6

An Independent Sample T test is carried out between the results of questionnaires to assess whether the noises from aircraft and layouts are significantly different from each other. The result shows that the distraction levels from aircraft and school noises are not significantly different ($P > 0.05$) [Appendix 10.20].

Based on this analysis, it is possible to justify that noises from school are as distracting as those of aircrafts. This also shows why the teachers' claim they tend to close classroom doors in order to prevent distraction.

c) Conclusion

From the above discussion, it can be concluded that on an average, the noises from inside an school are as distracting as aircraft noise. This is the noise from activities that occur in communal halls (e.g. IT activity) or other classrooms (when occupied with noisy activities and their doors are open) which transfer noise to the communal hall (due to poor layout). For this reason, teachers at Grove Road and Andrew Ewing primary schools prefer to keep the classrooms' doors shut to maintain a suitable background noise level for their classrooms when it is needed. As a consequence, classrooms lose their ability to have stack ventilation through the large opening on the roof of the communal hall of Grove Road primary school, and various openings on the roof in Andrew Ewing primary school. Therefore, it can be concluded that not only environmental noises such as aircraft noise cause lack of ventilation inside a classroom, but poor layout could also be a source of lack of ventilation.

Chapter 5: Air quality

Chapter 5.1: Air quality literature review

Chapter overview

As mentioned in chapter Three, apart from maintaining thermal comfort natural, ventilation plays a role in maintaining indoor air quality. The ventilation rate which is required for providing good indoor air quality is lower than that required for thermal comfort purposes. The aim of this part of the research is to study the reasons of poor air quality followed by studying a method to evaluate indoor air quality. Maintaining indoor air quality in schools' classrooms is extremely important as poor air quality has a negative impact on students' health and performance. Different guidelines are presented in this regard which are compared in this chapter. Different factors (i.e. the CO_2 which is produced by occupants, the existing CO_2 in the air and also room volume) which have impacts on ventilation rate are discussed. As mentioned earlier in chapter 3, there are different barriers to utilising natural ventilation which consequently cause poor air quality. The negative impact of poor air quality on students' performance and health are explained in detail in this chapter.

5.1.1. Air quality principles

The main requirement for having a good air quality is to have a sufficient ventilation rate to remove pollutants. Measuring indoor CO_2 level is one of the methods to estimate the ventilation rate in a space, which is explained later in this chapter.

The concern for the poor air quality issue became greater after the oil crisis in the 1970s and the report of sick building syndrome. The sick building syndrome was the result of buildings which were being built more air-tight than before which led to the reduction of fresh air flow and also the utilisation of the air conditioning systems (Bougdah and Sharples, 2010).

'Sick Building Syndrome' is a term that describes symptoms in a majority of the people, who work in buildings with an adverse indoor environment. The symptoms can be irritation of the eyes, blocked nose and throat, headache, dizziness etc. These symptoms are usually work related, that is, they begin a short time after a person enters a building and disappear after he leaves it (Rostron, 1997).

As people spend 90% of their time indoor, so studying the air quality is highly valuable. For this reason, the world concern has transferred from environment to a new terminology which is 'Invironment'. This new terminology focuses on Indoor Air Quality (IAQ) and its effect on human health. Indoor air pollutants are a combination of the indoor pollutants (produced by the occupants etc.) and outdoor pollutants which are the air contaminants (Pahwa D., n.d.).

The air contaminants are categorised into three groups:

- Gases and vapour such as CO_2, Carbon monoxide, Nitrogen dioxide, VOCs and Butyric Acid

- Inert Particles
- Micro organism such as Fungus, Bacteria-virus and Mold

5.1.2. Air quality evaluation

In order to evaluate indoor air in a space the type of pollutants which are present in that space as well as their level should be identified. Monitors are available to measure particulates and a few gases such as radon, formaldehyde, nitrogen dioxide, sulphur dioxide and carbon monoxide. Since working with such monitors can be complicated, costly and time consuming, ASHRAE (2001) recognises CO_2 as the simplest variable that can be measured to determine the ventilation rate and evaluate indoor air quality. In the other words, CO_2 level can be used as a surrogate index for ventilation rate.

5.1.3. Air quality guidelines

As mentioned earlier in Chapter Two of this research, poor air quality has a negative impact on children's health and academic performance. Several guidelines are proposed by different organisations in order to maintain indoor air quality at schools. Guidelines generally, propose thresholds for either CO_2 level or ventilation rate in order to control air quality.

Some of these guidelines are more relaxed compared to the others. The guideline, which is currently used for refurbishment and redesign of schools, is proposed by Building Bulletin 101. As per the discussion in Chapter Two of this research, it has been found that this guideline is the most relaxed guideline and in the author's belief should be revised.

5.1.4. Ventilation rate

The ventilation rate in a space is calculated from the CO_2 which exists in its indoor air space. In naturally ventilated buildings, the CO_2 produced by occupants in a space, are removed by the outdoor air (fresh air) which enters the building by different means of natural ventilation. It should be considered that outdoor air quality may not be fresh. Therefore, replacing indoor air with air from outdoors may not always be a suitable solution. In a situation where outdoor air is fresh, the required ventilation rate generally depends on three main factors. These are internal CO_2 level which is produced by occupants, the outdoor CO_2 level (existing in the atmosphere) and room volume.

5.1.5. CO_2 level which is produced by occupants:

The amount of CO_2 produced by an occupant is related to the occupant's respiration rate. Each occupant 'breathes in' a distinctive amount of air and 'breathes out' a percentage of the air inhaled as CO_2. The number of breathes inhaled in out in a minute depends on the occupant's activity (measured by metabolic rate), age, sex and also room temperature.

Metabolism refers to the amount of energy which is released in a human body as a result of the occupant's muscular activity by oxidation processes. Metabolism is measured in Met. Each Met is equal to 58 W/m² of body surface (ISO 7730, 2005). Figure 5-1.1 and Table 5-1.1 show the approximate rate of metabolism for different activities. In order to evaluate the metabolic rate, the average of the person's activity during the last hour (of the activity) is considered.

Typical Metabolic rate for various Activities	
Different type of activities	w/m2
Resting	
Sleeping	40
Reclining	45
Seated,quiet	60
Standing, relaxed	70
Walking (on the level)	
0.89 m/s	115
1.34m/s	150
1.79m/s	220
Office Activities	
Reading, seated	55
Writing	60
Typing	65
Filing,seated	70
Filing,standing	80
Walking about	100
Lifting/packing	120

Table 5-1.1: Typical metabolic rates for various activities extracted from ASHRAE (2001)

Figure 5-1.1: Typical metabolism for different activities extracted from lumasenseinc website

A higher metabolism rate causes a higher level of inhale/exhale rate. This consequently leads to a higher level CO_2 being produced which has a negative impact on air quality in a space that does not have adequate ventilation.

5.1.6. CO_2 level which exists in the outside air

The amount of CO_2 which is produced by occupants in a space is removed by the air which enters from the outside to the inside. It is not possible to decrease the internal CO_2 level to zero as the outside air (atmosphere) itself contains CO_2. The CO_2 concentration was 280 ppm before industrial periods and increased to 387 ppm in 2009 and then to 390 ppm in 2010 which is considered to be the highest level in comparison with the previous 800 thousand years (Amos , 2006). Industrial emissions (e.g. from fossil fuel consumption) could be named as the main reason for this increase. The main sources of CO_2 emissions are from burning coal utilised to generate electricity and petroleum utilised for transportation.

5.1.7. Room volume

Ventilation rate is the rate of air which is exchanged from inside to the outside. The amount of air which enters to the space is related to the room's volume.

5.1.8. Ventilation rate formula

There are two methods for estimating the ventilation rate: Formula and Plotting methods.

a) Formula method:

The formula method is based on the following formula. This method is applicable when the tracer gas is CO_2 and the amount of CO_2 which is produced by occupants (G) are available based on their activities. This method is proposed by Coley and Beisteiner (2000).

$V (d C_{(t)}/ d_t) = G + QC_{ex} - QC_{(t)}$

Solving the above equation by integration leads to the following equation:

$C_{(t)} = C_{ex} + (G/Q) + [C_{in} - C_{ex} - (G/Q)] \wedge [e \wedge ((-Q/V)\ t)]$

- $C_{(t)}$ = internal concentration of the tracer gas at the time t (ppm)
- C_{ex} = external concentration of the tracer gas (ppm)
- G = generation rate of tracer gas in the space (Cm^3/s)
- Q= internal-external exchange rate (m^3/s)
- Cin= initial concentration of the tracer gas (ppm)
- V= room volume (m^3/s)
- Q/V= air supply rate (ac/s)
- t = time (s)

b) Plotting method:

The plotting method which is used in this study to estimate the classrooms' ventilation rate is explained in the analysis part of this chapter. This method is based on the recorded CO_2 level. The recorded CO_2 is the difference between the CO_2 generated by the occupants and the amount of CO_2 which is removed by ventilation or infiltration.

5.1.9. Conclusion

Maintaining indoor air quality in school classrooms is very important as poor air quality has a negative impact on student's health and academic performance (explained in Chapter Two). The main requirement of good air quality is to have a sufficient ventilation rate. To achieve the required ventilation rate, the building's site should be free from any ventilation barriers such as noise, air pollution, etc, and the building itself, should have the potential to use natural ventilation (explained in Chapter Three). There are various guidelines in place in order to maintain indoor air quality in various buildings and specially schools' classrooms. As discussed in Chapter Two, the main guideline which is commonly used for refurbishment and re-design of schools (i.e. BB101) is the most relaxed one, and therefore should be revised.

Chapter 5.2: Air quality analysis

Chapter Overview

The aim of this part of the research is to evaluate whether schools which are located in noisy regions have a higher likelihood of experiencing poor air quality, as they may have a lower potential for having natural ventilation due the high level of background noise. To obtain a clearer understanding, this study is carried objectively and subjectively.

5.2.1. Objective analysis

The objective study is carried in the following steps:

-Collecting data

-Study the reasons for CO_2 fluctuation

-Study the windows closure

-Air quality guidelines per defined in BB101 & BSRIA

-Compare the CO_2 level inside classrooms with the benchmarks defined in BB101.

-Conclusion

5.2.2. Collecting data

In order to study the air quality of the classrooms which are located under flight paths, the CO_2 levels of various classrooms of two primary schools were measured at 1 to 2 minute intervals, for 11 days when they were occupied, and for 13 days when they were unoccupied, using a device called Tailer. BAA operates a runway alteration plan to reduce the impact of high level of aircraft noise on the residents of the regions around Heathrow Airport. Based on this initiative, one runway is used by landing aircrafts from 06:00 until 15:00 after which it is switched to the other runway. Departing aircrafts use the alternative run-way. However, on Sunday each week the runway used the day before continues to be used for landings. This means early morning arrivals use a different runway on successive weeks and the runways used by landing aircrafts before and after 15:00 also alternate on a weekly basis. This alteration does not mean that the aircraft noise is wholly mitigated, but it can be said that the noise is lowered every other week. The following table shows the CO_2 and internal noise measurements on the days when students and teachers were present in the classrooms (e.g. were not on a day travel). The days are tabulated according to the level of aircraft noise.

Week	Class	School	Date	Day	CO2 measuremnet	Activity noise measurmnet	Aircarft noise level (9:00 - 3:00)	Aircarft noise level (3:00 - 3:30)
Week.1	Y2	GR	24-Jun-08	Tue	x	x	Low	High
	Y4	GR	25-Jun-08	Wed	x	x	Low	High
	Y3	GR	26-Jun-08	Thu	x	x	Low	High
	Y6	GR	27-Jun-08	Fri	x	x	Low	High
Week.2	Y4	GR	30-Jun-08	Mon	x	0	High	Low
	Y4	GR	01-Jul-08	Tue	x	x	High	Low
	Y4	GR	02-Jul-08	Wed	x	x	High	Low
Week.3	Y4	AE	07-Jul-08	Mon	x	x	High	Low
	Y2	GR	10-Jul-08	Thu	x	0	Low	High
	Y3	GR	11-Jul-08	Fri	x	0	Low	High
Week.4	Y6	AE	14-Jul-08	Mon	x	x	Low	High
	Y3	AE	15-Jul-08	Tue	x	x	Low	High
Measurement carried out					x			
Measurement not carried out					0			

Table 5-2.1: The CO_2 and internal noise measurements

5.2.3. Study the reasons of CO_2 fluctuation

In this section of the study, the reasons of CO_2 fluctuation are discussed in order to show how the status of openings (doors and windows) and occupancy have an impact on CO_2 fluctuation. As it obvious from the Graphs 5-2.1, 5-2.2 & 5-2.3 which show the classrooms' CO_2 levels, the CO_2 levels fluctuate over time. The CO_2 levels mainly increase as a result of occupants' perspiration (which is related to the occupants' metabolic rate) and decrease by the ventilation level which is provided by openings (windows and doors when open). In the following section, the occupancy various classrooms (i.e. occupied/ unoccupied) and windows / doors statuses (i.e. open or closed) are recorded and overlapped with the CO_2 fluctuation graph.

The relationship of the CO_2 level with occupancy, and status of doors & windows (i.e. open & closed) are shown in the Graphs 5-2.1, 5-2.2 & 5-2.3 for Y3, Y4 & Y6 classrooms on 25th, 26th & 27th of June 2008 respectively. In order to have a better understating of how each of the above factors has an effect on the level of CO_2, the CO_2 levels are shown from 1 hour before and 1 hour after the schools hours (i.e. 8:00-16:30).

Table 5-2.2 represents the codes used for the status of occupancy, and positions of the doors and windows for each of the classrooms and shown on Graphs 5-2.15, 5-2.16 and 5-2.17.

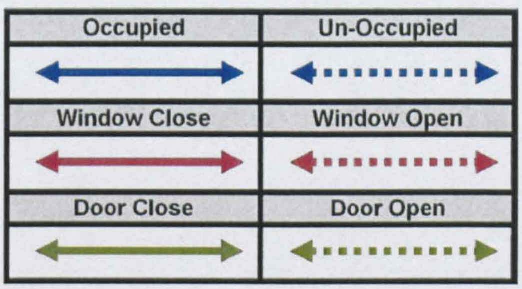
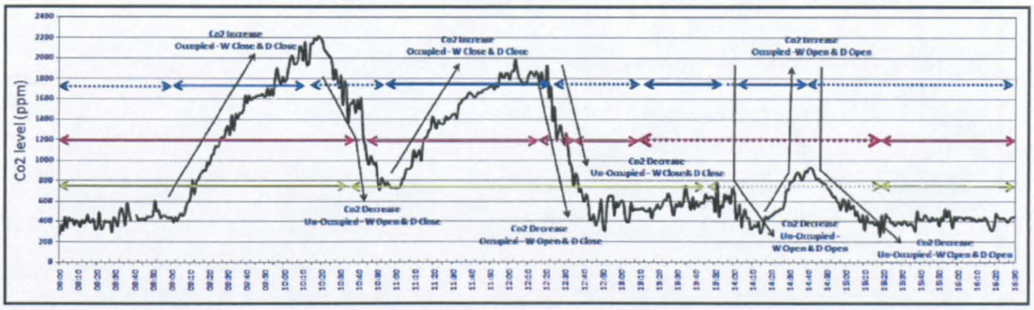


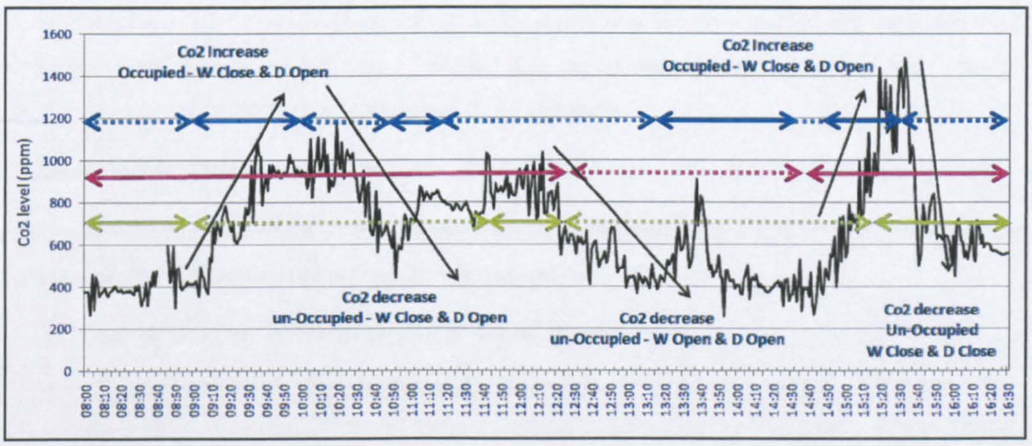
Table 5-2.2: Codes representing the status of occupancy, and positions of doors and windows

- **CO_2 fluctuation at Y4:** The following graph (Graph 5-2.1) shows the fluctuation of CO_2 levels on Wednesday, 25th of June 2008 in the Y4 classroom of Grove Road primary school.



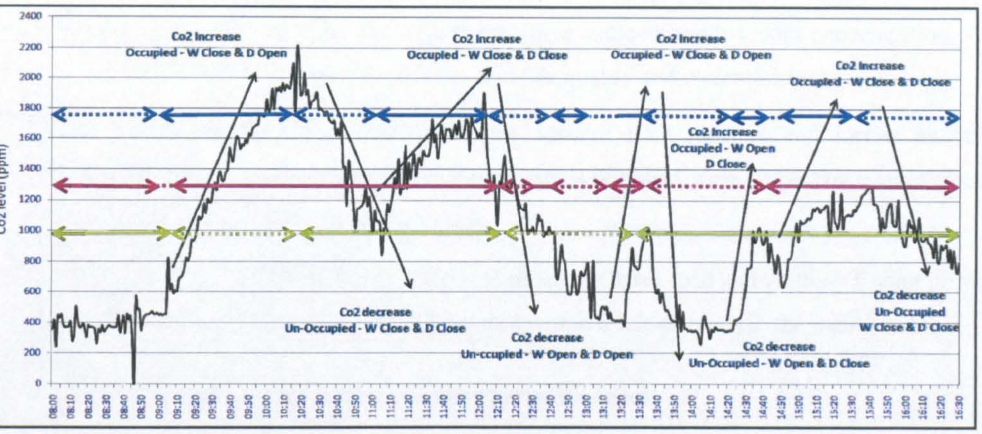
Graph 5-2.1: CO_2 level in relation to the occupancy level and opening status in Year 4 on 25th of June

- **CO_2 fluctuation at Y3:** The following graph (Graph 5-2.2) shows the fluctuation of CO_2 levels on Thursday, 26th of June 2008 in the Y3 classroom of Grove Road primary school.



Graph 5-2.2: CO_2 level in relation to the occupancy level and opening status in Year 3 on 26th of June

- **CO_2 fluctuation at Y6:** The following graph (Graph 5-2.3) shows the fluctuation of CO_2 level on Friday, 27th of June 2008 in the Y6 classroom of Grove Road primary school.



Graph 5-2.3: CO_2 level in relation to the occupancy level and opening status in Year 6 on 27th of June

As can be observed from the above three graphs (Graph 5-2.1, Graph 5-2.2 and Graph 5-2.3), CO_2 levels increase mainly when the classrooms are occupied and the doors and windows are closed. On the contrary, CO_2 levels decrease mainly when classrooms are un-occupied and the windows & doors are open. Therefore, it can be concluded that the occupancy and status of windows have a significant impact on the level of CO_2 inside the classrooms.

5.2.4. Study the window closure

The main reason of window closure is aircraft noise, disregarding the actual level of noise and can be explained under the following the following subjects.

- Nature of the study being taught and aircraft noise (a)
- Classroom's activity type and aircraft noise (b)

a) Nature of the study being taught and aircraft noise level

As mentioned earlier, the study is conducted under two scenarios, one when there is a high level of aircraft noise (present) and the other when the level of aircraft noise is low (absent).

This study shows that the presence of aircraft noise in some sessions did not have any impact on the status of windows. The classroom, windows were kept closed irrespective of the outside noise level conditions e.g. the 1st session of the 25 & 27 of June in Y4 & Y6 (noise absent) or the 1st session of the 30th of June in Y6 (noise present).

Teachers of the Y4 & Y6 classrooms were questioned about this situation. They believed that the aircraft noise is still heard inside the classrooms even on the days that aircrafts would have changed their direction. *As the aircraft noise contains distinct impulses, it is distracting for students when they are occupied with activities that need extra concentration such as math, science and literacy.*

They believed that they preferred to keep the windows shut during such activities, even in the weeks when aircraft noise was low as the nature of these subjects needed extra concentration. As a consequence, the classrooms would experience poor air quality and overheating.

They also mentioned other environmental noise sources such as cars and lorries as being distracting. But since their perception was that these kinds of noises were not as frequent as aircraft noise, they are not considered to be as disturbing.

In addition, noises from cars and lorries which are heard in Grove road and Andrew Ewing primary schools is of a low level as these schools are located within a fair distance to the main road.

b) Classrooms' activity type and aircraft noise level

As it was mentioned in the noise analysis chapter, the high level of aircraft noise is the main reason for window closure in the schools which are located under flight paths. For this reason, the windows' status and its impact on the internal CO_2 levels are studied in different weeks, with a high and low level of aircraft noise, respectively.

It should be noted that in this part of the study, the sessions allocated to the subjects that need extra concentration (e.g. maths) have been excluded. This is due to the fact that windows are closed at all the times during these sessions, due the nature of these subjects and also because the aircraft noise is distracting irrespective of its noise level (high or low).

This part of the study is carried out in following parts:

- Windows' status and CO_2 fluctuation during 'Activity1: Silent' in the weeks with high and low levels of aircraft noise (b1).
- Windows' status and CO_2 fluctuation during 'Activity 2: One person speaking' in the weeks with high and low levels of aircraft noise (b2).
- Windows' status and CO_2 fluctuation during 'Activity 3: individual' in the weeks with high and low levels of aircraft noise (b3).
- Windows' status and CO_2 fluctuation during 'Activity 4: Group' in the weeks with high and low levels of aircraft noise (b4).
- Summary of windows' status and CO_2 fluctuation according to the presence of aircraft noise (b5).

b1) Windows' status and CO_2 fluctuations during 'Activity1: Silent' in the weeks with high and low levels of aircraft noise

The following table (Table 5-2.3) shows the windows' status and CO_2 fluctuations during 'Activity1: Silent' in the weeks with high and low levels of aircraft noise.

Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act1.Silent											
				Duration Minutes	Window status	Co2 fluctuation (ppm)				Duration Minutes	Window status	Co2 fluctuation (ppm)			
					Open	Start	End	Differences	Trend		Close	Start	End	Differences	Trend
Y2	GR	24-Jun-08	Low Aircraft noise (Absent)	17	Open	746	467	279	Decresed	-	-	-	-	-	-
Y4	GR	25-Jun-08		20	Open	518	514	4	Decresed	-	-	-	-	-	-
				-	-	-	-	-		-	-	-	-	-	-
Y3	GR	26-Jun-08		-	-	-	-	-		-	-	-	-	-	-
Y6	GR	27-Jun-08		-	-	-	-	-		-	-	-	-	-	-
Y6	AE	14-Jul-08		28	Open	897	649	248	Decresed	-	-	-	-	-	-
Y3	AE	15-Jul-08		22	Open	928	765	163	Decresed	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
Avrage				4 occasions windows were open						0 occasion windows was closed					

Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act1.Silent											
				Duration Minutes	Window status	Co2 fluctuation (ppm)				Duration Minutes	Window status	Co2 fluctuation (ppm)			
					Open	Start	End	Differences	Trend		Close	Start	End	Differences	Trend
Y4	GR	01-Jul-08	High Aircarft noise (Present)	-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
Y4	GR	02-Jul-08		-	-	-	-	-	-	36	Close	672	716	-44	Increased
				-	-	-	-	-	-	20	Close	460	742	-282	Increased
				-	-	-	-	-	-	-	-	-	-	-	-
Y4	AE	07-Jul-08		-	-	-	-	-	-	18	Close	669	1092	-423	Increased
Avrage				0 occasion window was open						4 occasions windows were closed					

Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act1.Silent											
				Duration Minutes	Window status	Co2 fluctuation (ppm)			Trend	Duration Minutes	Window status	Co2 fluctuation (ppm)			Trend
					Open	Start	End	Differences			Close	Start	End	Differences	
Y2	GR	24-Jun-08	High Aircarft noise (Present)	-	-	-	-	-	-	30	Closed	526	882	-356	Increased
Y4	GR	25-Jun-08		Unoccupied											
Y3	GR	26-Jun-08		-	-	-	-	-	-	-	-	-	-	-	-
Y6	GR	27-Jun-08		-	-	-	-	-	-	-	-	-	-	-	-
Y6	AE	14-Jul-08		Unoccupied											
Y3	AE	15-Jul-08		Unoccupied											
Avrage				0 occasion window was open						1 occasion windowswas closed					

Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act1.Silent											
				Duration Minutes	Window status	Co2 fluctuation (ppm)			Trend	Duration Minutes	Window status	Co2 fluctuation (ppm)			Trend
					Open	Start	End	Differences			Close	Start	End	Differences	
Y4	GR	01-Jul-08	Low Aircraft noise (Absent)	Unoccupied											
Y4	GR	02-Jul-08		Unoccupied											
Y4	AE	07-Jul-08		-	-	-	-	-	-	-	-	-	-	-	-
Avrage				0 occasion window was open						0 occasion window was open					

Activity type: 'Activity1: Silent'	
Windows status when aircraft noise is high (Present)	
Window status when aircraft noise is low (absent)	

Table 5-2.3: Windows' status and CO_2 fluctuations during 'Activity1: Silent' in the weeks with high and low levels of aircraft noise

b2) Windows' status and CO_2 fluctuations during 'Activity 2: One person speaking' in the weeks with high and low levels of aircraft noise

The following table (Table 5-2.4) shows the windows' status and CO_2 fluctuations during 'Activity 2: One person speaking' in the weeks with high and low levels of aircraft noise.

Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act2.1 Person Speaks											
				Duration Minutes	Window status	CO2 fluctuation (ppm)				Duration Minutes	Window status	CO2 fluctuation (ppm)			
					Open	Start	End	Difference	Trend		Close	Start	End	Difference	Trend
Y2	GR	24-Jun-08	Low Aircraft noise (Absent)	31	Open	746	467	279	Decreased	31	Close	428	690	-262	Increased
Y4	GR	25-Jun-08		10	Open	878	818	60	Decreased	-	-	-	-	-	-
				12	Open	637	632	5	Decreased	-	-	-	-	-	-
Y3	GR	26-Jun-08		31	Open	682	434	248	Decreased	-	-	-	-	-	-
Y6	GR	27-Jun-08		-	-	-	-	-	-	-	-	-	-	-	-
Y6	AE	14-Jul-08		20	Open	556	404	152	Decreased	-	-	-	-	-	-
Y3	AE	15-Jul-08		-	-	-	-	-	-	20	Close	713	957	-244	Increased
				-	-	-	-	-	-	20	Close	412	634	-222	Increased
Avrage				5 ocassions windows were open						2 occasions windows were closed					

Class	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act2.1 Person Speaks											
				Duration Minutes	Window status	CO2 fluctuation (ppm)				Duration Minutes	Window status	CO2 fluctuation (ppm)			
					Open	Start	End	Difference	Trend		Close	Start	End	Difference	Trend
Y4	GR	01-Jul-08	High Aircarft noise (Present)	-	-	-	-	-	-	26	Close	954	1144	-190	Increased
				-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
Y4	GR	02-Jul-08		-	-	-	-	-	-	28	Close	380	878	-498	Increased
				-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
Y4	AE	07-Jul-08		10	Open	1053	892	161	Decreased	49	Close	2483	3187	-704	Increased
Avrage				1 occasion window was open						3 occasions windows were closed					

Class	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act2.1 Person Speaks											
				Duration Minutes	Window status	CO2 fluctuation (ppm)			Trend	Duration Minutes	Window status	CO2 fluctuation (ppm)			Trend
					Open	Start	End	Difference			Close	Start	End	Difference	
Y2	GR	24-Jun-08	High Aircarft noise (Present)	-	-	-	-	-	-	-	-	-	-	-	-
Y4	GR	25-Jun-08		Unoccupied											
Y3	GR	26-Jun-08		-	-	-	-	-	-	12	Close	846	1169	-323	Increased
Y6	GR	27-Jun-08		-	-	-	-	-	-	25	Close	931	1102	-171	Increased
Y6	AE	14-Jul-08		Un occupied											
Y3	AE	15-Jul-08		Un occupied											
Avrage				0 occasion window was opened						2 occasions windows were closed					

Class	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act2.1 Person Speaks											
				Duration Minutes	Window status	CO2 fluctuation (ppm)			Trend	Duration Minutes	Window status	CO2 fluctuation (ppm)			Trend
					Open	Start	End	Difference			Close	Start	End	Difference	
Y4	GR	01-Jul-08	Low Aircraft noise (Absent)	Un occupied											
Y4	GR	02-Jul-08		Un occupied											
Y4	AE	07-Jul-08		10	Open	897	871	26	Decresead	-	-	-	-	-	-
Avrage				1 occasion window was opened						0 occasion window was closed					

Activity type: 'Activity 2: One person speaking'	
Windows status when aircraft noise is high (Present)	
Window status when aircraft noise is low (absent)	

Table 5-2.4: Window status and CO_2 fluctuations during 'Activity 2: One person speaking' in the weeks with high and low level of aircraft noise

b3) Windows' status and CO_2 fluctuations during 'Activity 3: individual' in the weeks with high and low levels of aircraft noise

The following table (Table 5-2.5) shows the windows' status and CO_2 fluctuations during 'Activity 3: Individual' in the weeks with high and low levels of aircraft noise.

Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act3.Individual											
				Duration Minutes	Window status	Co2 fluctuation (ppm)				Duration Minutes	Window status	Co2 fluctuation (ppm)			
					Open	Start	End	Differences	Trend		Close	Start	End	Difference	Trend
Y2	GR	24-Jun-08	Low Aircraft noise (Absent)	-	-	-	-	-	-	-	-	-	-	-	-
Y4	GR	25-Jun-08		-	-	-	-	-		-	-	-	-	-	-
				-	-	-	-	-		-	-	-	-	-	-
Y3	GR	26-Jun-08		26	Open	409	309	100	Decreased	-	-	-	-	-	-
Y6	GR	27-Jun-08		-	-	-	-	-	-	-	-	-	-	-	-
Y6	AE	14-Jul-08		90	Open	453	432	21	Decreased	-	-	-	-	-	-
Y3	AE	15-Jul-08		-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
Avrage				2 occasions windows were open						0 occasion window was closed					

Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act3.Individual											
				Duration Minutes	Window status	Co2 fluctuation (ppm)				Duration Minutes	Window status	Co2 fluctuation (ppm)			
					Open	Start	End	Differences	Trend		Close	Start	End	Difference	Trend
Y4	GR	01-Jul-08	High Aircarft noise (Present)	40	Open	1175	639	536	Decreased	-	-	-	-	-	-
				50	Open	832	721	111	Decreased	-	-	-	-	-	-
				57	Open	600	510	90	Decreased	-	-	-	-	-	-
Y4	GR	02-Jul-08		38	Open	991	493	498	Decreased	28	Close	716	863	-147	Increased
				-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
Y4	AE	07-Jul-08		-	-	-	-	-	-	-	-	-	-	-	-
Avrage				4 ocasions windows were opened						1 occasion window was open					

Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act3.Individual											
				Duration Minutes	Window status	Co2 fluctuation (ppm)			Trend	Duration Minutes	Window status	Co2 fluctuation (ppm)			Trend
					Open	Start	End	Differences			Close	Start	End	Differences	
Y2	GR	24-Jun-08	High Aircarft noise (Present)	-	-	-	-	-	-	-	-	-	-	-	-
Y4	GR	25-Jun-08		Unoccupied											
Y3	GR	26-Jun-08		-	-	-	-	-	-	-	-	-	-	-	-
Y6	GR	27-Jun-08		-	-	-	-	-	-	-	-	-	-	-	-
Y6	AE	14-Jul-08		Un occupied											
Y3	AE	15-Jul-08		Un occupied											
Avrage															

Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act3.Individual											
				Duration Minutes	Window status	Co2 fluctuation (ppm)			Trend	Duration Minutes	Window status	Co2 fluctuation (ppm)			Trend
					Open	Start	End	Differences			Close	Start	End	Differences	
Y4	GR	01-Jul-08	Low Aircraft noise (Absent)	Un occupied											
Y4	GR	02-Jul-08		Un occupied											
Y4	AE	07-Jul-08		-	-	-	-	-	-	-	-	-	-	-	-
Avrage				0 occasion window was open						0 occasion window was open					
Activity type: 'Activity 3: Individual'															
Windows status when aircraft noise is high (Present)															
Window status when aircraft noise is low (absent)															

Table 5-2.5: Windows status and CO_2 fluctuations during 'Activity 3: individual' in the weeks with high and low levels of aircraft noise

b4) Windows' status and CO_2 fluctuations during 'Activity 4: Group' in the weeks with high and low levels of aircraft noise

The following table (Table 5-2.6) shows the windows' status and CO_2 fluctuations during 'Activity 3: Group' in the weeks with high and low levels of aircraft noise.

Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act4.Group											
				Duration Minutes	Window statues	Co2 fluctuation (ppm)				Duration Minutes	Window statues	Co2 fluctuation (ppm)			
					Open	Start	End	Differences	Trend		Close	Start	End	Differences	Trend
Y2	GR	24-Jun-08	Low Aircraft noise (Absent)	17	Open	439	377	61	Decreased	-	-	-	-	-	-
Y4	GR	25-Jun-08		-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
Y3	GR	26-Jun-08		-	-	-	-	-	-	-	-	-	-	-	-
Y6	GR	27-Jun-08		-	-	-	-	-	-	-	-	-	-	-	-
Y6	AE	14-Jul-08		17	Open	532	503	29	Decreased	-	-	-	-	-	-
Y3	AE	15-Jul-08		58	Open	718	612	106	Decreased	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
Avrage				3 occasions windows were closed						0 occasion window were open					
Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act4.Group											
				Duration Minutes	Window statues	Co2 fluctuation (ppm)				Duration Minutes	Window statues	Co2 fluctuation (ppm)			
					Open	Start	End	Differences	Trend		Close	Start	End	Differences	Trend
Y4	GR	01-Jul-08	High Aircarft noise (Present)	-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
Y4	GR	02-Jul-08		-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
				-	-	-	-	-	-	-	-	-	-	-	-
Y4	AE	07-Jul-08		-	-	-	-	-	-	-	-	-	-	-	-
Avrage				0 occasion windows was closed						0 occasion window was opened					
Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act4.Group											
				Duration Minutes	Window statues	Co2 fluctuation (ppm)			Trend	Duration Minutes	Window statues	Co2 fluctuation (ppm)			Trend
					Open	Start	End	Differences			Close	Start	End	Differences	
Y2	GR	24-Jun-08	High Aircarft noise (Present)	-	-	-	-	-	-	-	-	-	-	-	-
Y4	GR	25-Jun-08		Unoccupied											
Y3	GR	26-Jun-08		-	-	-	-	-	-	-	-	-	-	-	-
Y6	GR	27-Jun-08		-	-	-	-	-	-	-	-	-	-	-	-
Y6	AE	14-Jul-08		Un occupied											
Y3	AE	15-Jul-08		Un occupied											
Avrage															
Classroom	School	Date	Aircraft 9:00 (am) 3:00 (pm)	Act4.Group											
				Duration Minutes	Window statues	Co2 fluctuation (ppm)			Trend	Duration Minutes	Window statues	Co2 fluctuation (ppm)			Trend
					Open	Start	End	Differences			Close	Start	End	Differences	
Y4	GR	01-Jul-08	Low Aircraft noise (Absent)	Un occupied											
Y4	GR	02-Jul-08		Un occupied											
Y4	AE	07-Jul-08		-	-	-	-	-	-	-	-	-	-	-	-
Avrage				0 occasion window was open						0 occasion window was open					
Activity type: 'Activity 4: Group'															
Windows status when aircraft noise is high (Present)															
Window status when aircraft noise is low (absent)															

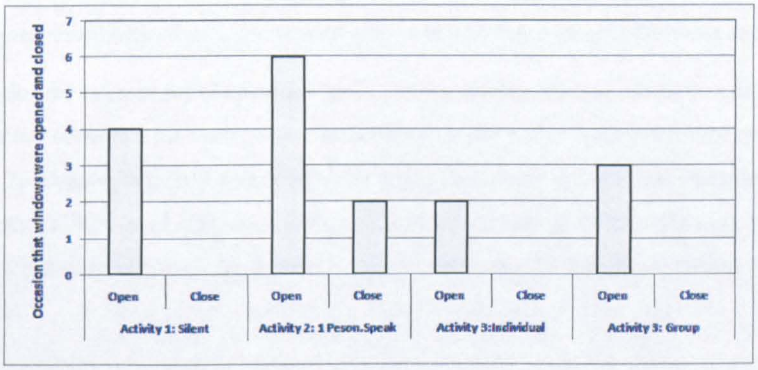
Table 5-2.6: Windows' status and CO_2 fluctuations during 'Activity 4: Group' in the weeks with high and low levels of aircraft noise

b5) Summary of windows' status and CO_2 fluctuation according to the presence of aircraft noise

The above tables (Tables 5-2.3, 5-2.4, 5-2.5 and 5-2.6) provide the basis for studying the impact of aircraft noise on windows' status.

- **Number of occasions that windows were open and closed in relation to the occupants' activity when the aircraft noise was low (absent)**

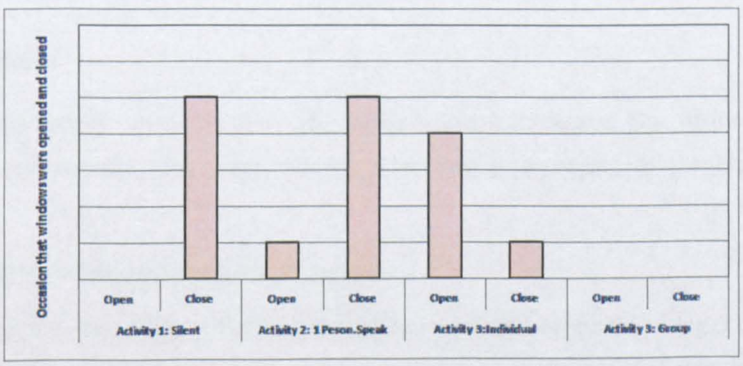
The following graph (Graph 5-2.4) shows the occasions when windows were open and aircraft noise was low (absent). As can be seen, the numbers of occasions that the windows were open are higher than the occasions when the windows were closed during all activities.



Graph 5-2.4: Occasions when windows were open and closed
when the aircraft noise was low (absent)

- **Number of occasions that windows were open and closed in relation to the occupants' activity when aircraft noise was high (present)**

The following graph (Graph 5-2.5) shows the occasions when windows were kept closed and aircraft noise was high (present). As can be seen, the numbers of occasions that the windows were kept closed are significantly higher than the occasions when the windows were open during 'Activity1: Silent' and 'Activity 2: One person speaking'.



Graph 5-2.5: Occasions when windows were open and closed
when the aircraft noise was high (present)

The results confirm the previous assumption regarding window closure when aircraft noise is high, and occupants are occupied with the 'Activity1: Silent' and 'Activity 2: One person speaking'.

A Chi-Square Test is carried out between the occasions that windows were open and closed in relation to the aircraft noise (present/ absent) and types of activities (silent, 1 person speak, individual and group) [Appendix 10.21]. The result shows that the presence of aircraft noise has a significant impact on the status of windows (n=33 $P<0.005$), however there is no relation observed between window status and types of activities carried out inside classrooms (this may be due to the lack of sufficient data as it was proven otherwise in the previous chapter).

As a result, the presence of aircraft has an impact on the window status. The result shows that there is a higher possibility of window closure due to the presence of aircraft noise and vice versa.

As window closure reduces the classrooms' potential for having natural ventilation, it can be assumed that the schools which are located under flight paths suffer from poorer air quality and overheating. In Chapter Three, it was objectively and subjectively proven that classrooms located under the flight path have a higher risk of experiencing overheating. In the following pages, the classrooms' air quality for two schools which are located under the Heathrow airport flight path are assessed.

5.2.5. Air quality guidelines as defined in BB101 & BSRIA

CO_2 is produced by the exhalation of occupants. The amount of occupants' exhalation is related to the number of occupants, their weight and activity level. The rooms' volume also has an impact on CO_2 concentration. Ventilation has a role in removing the CO_2 by providing fresh air. In other words, the higher the level of CO_2, the lower the air quality and ventilation.

According to BB101, CO_2 concentration is chosen as the key performance indicator for assessment of indoor are quality.

a) BB101 criteria

BB101 propose two sets of criteria to assess air quality inside a classroom. One of these sets is according to the classrooms' CO_2 level and the other one is according to the classrooms' ventilation rate.

The BB101 criteria according to classrooms' CO_2 level:

Based on these criteria, classrooms' CO_2 level should be tested against the following 3 criteria in order to determine the indoor air quality. Classrooms should meet all the criteria below in order to be identified as classrooms having good air quality.

1. The average concentration of CO_2 should not exceed 1500 ppm during occupied hours.

2. The maximum concentration of CO_2 should not exceed 5000 ppm during the teaching day.

3. At any occupied time, the occupants should be able to reduce the concentration of CO_2 to 1000 ppm.

The BB101 criteria according to the classrooms' ventilation rate:

Based on these criteria, classrooms' ventilation rate should be tested against the following 3 criteria in order to determine the indoor air quality. Naturally ventilated classrooms should meet all the criteria below in order to be identified as good air quality classrooms.

1. A minimum ventilation rate of 3 l/s per person

2. A minimum daily average ventilation rate of 5 l/s per person

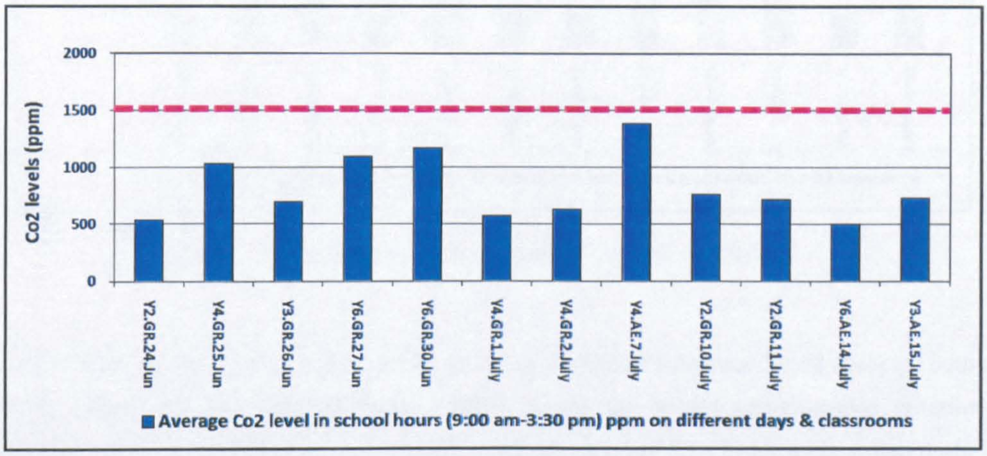
3. A capability of achieving a minimum ventilation rate of 8 l/s per person

b) BSRIA criteria

Building Services Research and Information Association (BSRIA) consider that a concentration of 800ppm or lower, the ventilation rate of 8 l/s/person will provide acceptable air quality.

5.2.5.1 The comparison of the classrooms' CO_2 level with the 'BB101 air quality guideline based on CO_2 level'

a) **Study the first criterion**



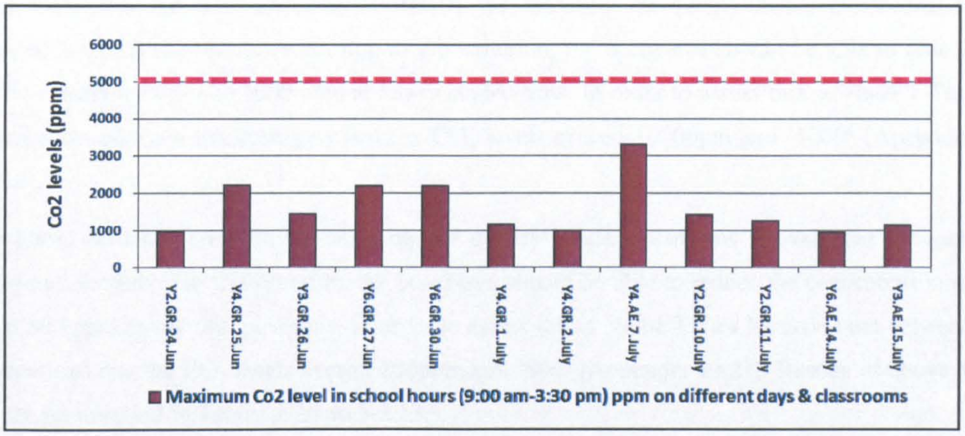
Graph 5-2.6: The comparison of the averages of CO_2 level with 1500ppm

Graph 5-2.6 shows that the averages of CO_2 levels in all of the classrooms during occupied hours (9:00am-3:30pm) are less than 1500ppm. This is as per the first recommended criterion. According to BB101, 1500ppm is an acceptable average level of CO_2 inside a classroom during teaching days.

A Value T test is carried out between the averages of CO_2 levels in all the classrooms during occupied hours (9:00am-3:30pm) and the value of 1500ppm. The result shows that the averages of CO_2 levels in these classrooms during occupied hours (9:00am-3:30pm) are significantly different to 1500ppm ($n= 12$, $p<0.05$) [Appendix 10.22.a].

As a result of above discussion, the indoor CO_2 levels of the classrooms under study meet the first air quality criterion.

b) Study the second criterion



Graph 5-2.7: The comparison of the maximum of CO_2 level with 5000ppm

Graph 5-2.7 shows that the maximums of CO_2 levels in all of the classrooms during occupied hours (9:00am-3:30pm) are less than 5000ppm. This is as per the second recommended criterion. According to BB101, 5000ppm is an acceptable maximum level of CO_2 inside a classroom during the teaching days. In order words, the indoor air quality meets the second criterion.

A Value T test is carried out between the maximums of CO_2 levels in all the classrooms during occupied hours (9:00am-3:30pm) and the value of 5,000ppm. The result shows that the maximum of CO_2 levels in these classrooms during occupied hours (9:00am-3:30pm) are significantly different to 5000ppm ($n= 12$, $p<0.05$) [Appendix 10.22.b].

As a result of above discussion, the indoor CO_2 levels of the classrooms under study meet the second air quality criterion.

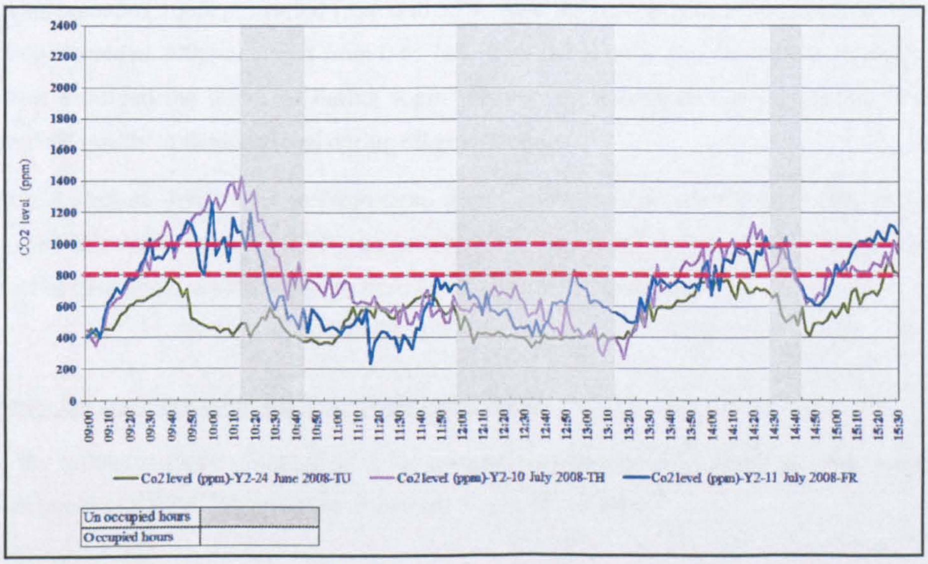
c) Study the third criterion

In the following, the third criterion of BB101 for assessing air quality inside classrooms is evaluated for each classroom. According to this criterion, the occupants should be able to reduce the concentration of CO_2 to 1000 ppm at any occupied time. In order to assess this, a Value T Test is carried out between the occasions that the CO_2 levels exceed 1000ppm and '1000' [Appendix 10.22.c].

In addition, BSRRIA criterion for assessing air quality inside classrooms is evaluated for each classroom. According to this criterion, the occupants should be able to reduce the concentration of CO_2 to 800 ppm at any occupied time. In order to assess this, a Value T Test is carried out between the occasions that the CO_2 levels exceed 800ppm and '800' [Appendix 10.23]. Results of above T tests are summarised in Tables 5-2.7 to 5-2.13.

__Study the third criterion for Year 2 of Grove Road__

In the following graph (Graph 5-2.8), the comparisons between CO_2 levels and the recommended benchmarks (800 & 1000ppm) are shown for Year 2 on three different days (24th June, 10th & 11th of July).



Graph 5-2.8: The comparisons between CO_2 levels and the recommended benchmarks in Y2 on three different days

The following table (Table 5-2.7) shows the percentage of the occasions when the level of CO_2 exceeded 800ppm & 1000ppm in Y2 on different days during classrooms sessions.

School	Classroom	Date	Day	Session	Proportion of time exceeding 1000ppm (%) during occupied hours	Proportion of time exceeding 800 ppm (%) during occupied hours	CO2 level above 1000 ppm significantly different from 1000 ppm	CO2 level above 800ppm significantly different from 800 ppm	3rd criterion of BB101	Air quality based on BSRIA
Grove. Road	Y2	24-Jun-08	Tuesday	1st	0	0	N.A	X $p > 0.05$	√	X
				2nd	0	0				
				3rd	0	0				
				4th	0	17				
		10-Jul-08	Thursday	1st	55	68	√ $p < 0.05$	√ $p < 0.05$	X	X
				2nd	0	3				
				3rd	16	61				
				4th	3	74				
		11-Jul-08	Friday	1st	34	66	√ $p < 0.05$	√ $p < 0.05$	X	X
				2nd	0	3				
				3rd	3	42				
				4th	43	70				

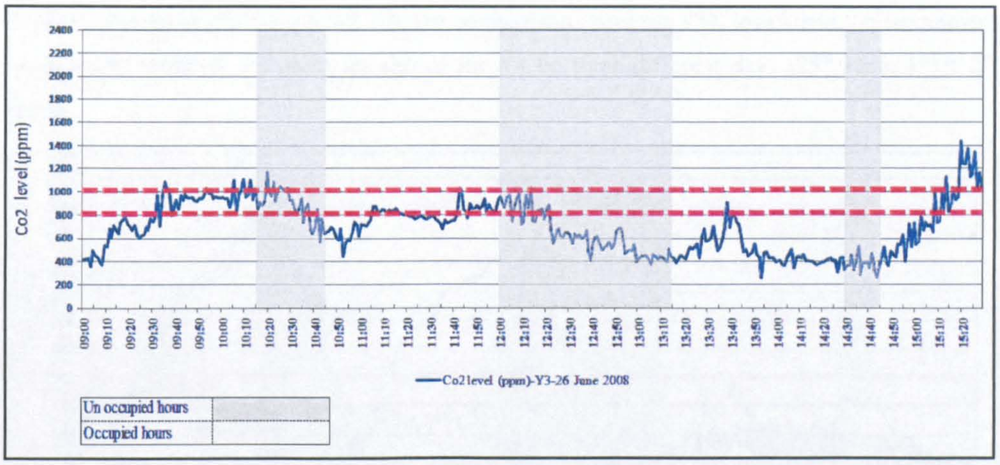
Table 5-2.7: The percentages of occasions that CO_2 exceeded 1000 and 800ppm in Y2 on three different days

As can be seen from the above table (Table 5-2.7), the percentage of the occasions that the CO_2 levels exceeded 1000ppm varied from 0 to 55%. Also the percentage of the occasions that the CO_2 levels exceeded 800ppm varied from 0 to 74%. The above table also shows that although the CO_2 levels exceeded the threshold during some sessions, the classroom has the potential for having good air quality as demonstrated during other sessions.

Year 2 students sometimes suffered from poor air quality (but not always). This is due to the classroom's environmental conditions in which the occupants choose to close the windows, and this does not allow the classroom to have a sufficient ventilation rate.

Study the third criterion for Year 3 of Grove Road

In the following graph (Graph 5-2.9), the comparisons between CO_2 levels and the recommended benchmarks (1000 & 800ppm) are shown for Y3 on 26th of June.



Graph 5-2.9: The comparisons between CO_2 levels and the recommended benchmarks in Y3 on one day

The following table (Table 5-2.8) shows the percentage of the occasions when the level of CO_2 exceeded 800ppm & 1000ppm in Y3 during classrooms sessions on one day.

School	Classroom	Date	Day	Session	Proportion of time exceeding 1000ppm (%) during occupied hours	Proportion of time exceeding 800 ppm (%) during occupied hours	Significantly different from 1000 ppm during occupied hours	Significantly different from 800 ppm during occupied hours	3rd criterion of BB101	Air quality based on BSRIA
Grove. Road	Y3	26-Jun-08	Thursday	1st	13	62	√	√	X	X
				2nd	3	49				
				3rd	0	4	$p < 0.05$	$p < 0.05$		
				4th	29	40				

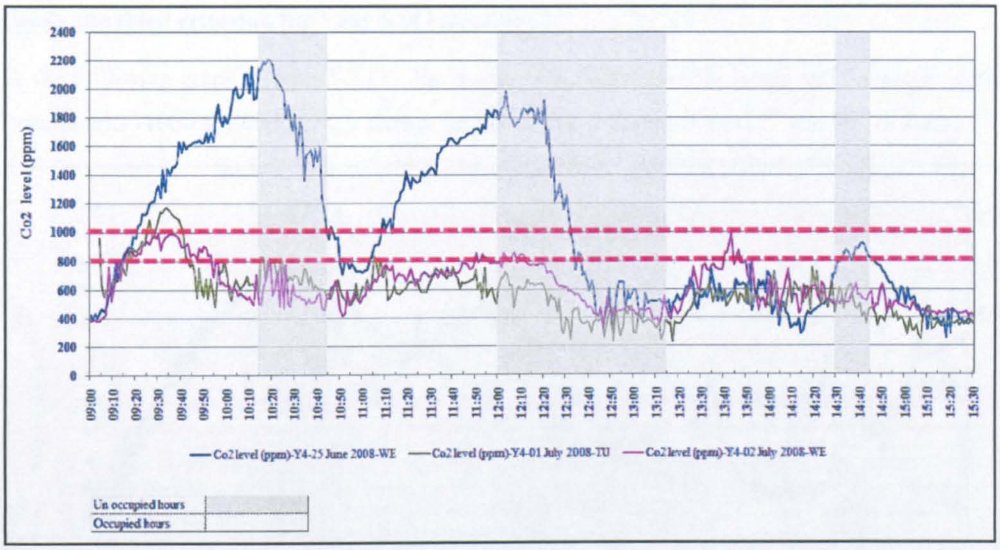
Table 5-2.8: The percentages of occasions that CO_2 exceeded 1000 and 800ppm in Y3 on one day

As can be seen from the above table (Table 5-2.8), the percentage of the occasions that the CO_2 levels exceeded 1000ppm varied from 0 to 29%. Also the percentage of the occasions that the CO_2 levels exceeded 800ppm varied from 4 to 62%. The above table also illustrates that although the CO_2 levels exceeded the threshold during some sessions, the classroom has the potential for having good air quality as demonstrated during other sessions.

Year 3 students sometimes suffered from poor air quality (but not always). This is due to the classrooms environmental conditions in which the occupants choose to close the windows, and this does not allow the classroom to have a sufficient ventilation rate.

Study the third criterion for Year 4 of Grove Road

In the following graph (Graph 5-2.10), the comparisons between CO_2 levels and the recommended benchmarks (1000 & 800ppm) are shown for Y4 on three different days (25[th] June, 1[st] & 2[nd] of July).



Graph 5-2.10: The comparisons between CO_2 levels and the recommended benchmarks in Y4 on three different days

The following table (Table 5-2.9) shows the percentage of the occasions when the level of CO_2 exceeded 800ppm & 1000ppm in Y4 during classroom sessions on different days.

School	Classroom	Date	Day	Session	Proportion of time exceeding 1000ppm (%) during occupied hours	Proportion of time exceeding 800 ppm (%) during occupied hours	Significantly different from 1000 ppm during occupied hours	Significantly different from 800 ppm during occupied hours	3rd criterion of BB101	Air quality based on BSRIA
Grove. Road	Y4	25-Jun-08	Wednesday	1st	72	83	√ $p < 0.05$	√ $p < 0.05$	X	X
				2nd	69	84				
				3rd	0	0				
				4th	0	0				
		01-Jul-08	Thursday	1st	17	39	√ $p < 0.05$	√ $p < 0.05$	X	X
				2nd	0	3				
				3rd	0	0				
				4th	0	0				
		02-Jul-08	Wednesday	1st	0	51	N.A	√ $p < 0.05$	√	X
				2nd	0	7				
				3rd	0	9				
				4th	0	0				

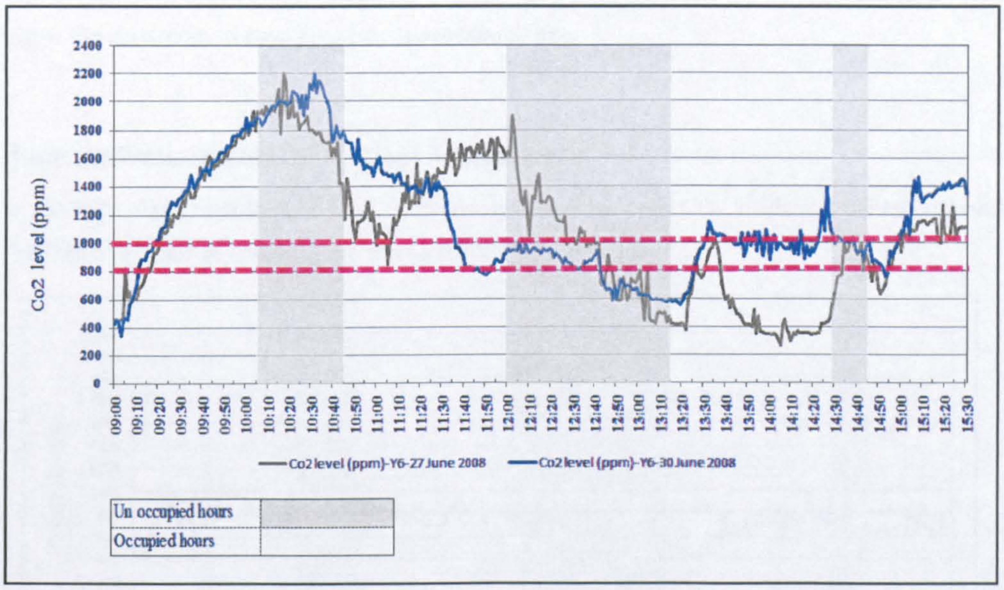
Table 5-2.9: The percentages of occasions that CO_2 exceeded 1000 and 800ppm in Y4 on three different days

As it can be seen from the above table (Table 5-2.4), the percentage of the occasions that the CO_2 levels exceeded 1000ppm varied from 0 to 72%. Also, the percentage of the occasions that the CO_2 levels exceeded 800ppm varied from 0 to 84%. This table also illustrates that although the CO_2 levels exceeded the threshold during some sessions, the classroom has the potential for having good air quality as demonstrated during other sessions.

Year 4 students sometimes suffered from poor air quality (but not always), this is due to classrooms' environmental conditions in which the occupants choose to close the windows, and this does not allow the classroom to have a sufficient ventilation rate.

Study the third criterion for Year 6 of Grove road

In the following graph (Graph 5-2.11), the comparisons between CO_2 levels and the recommended benchmarks (1000 & 800ppm) are shown for Y6 on two different days (27th and 30th of June).



Graph 5-2.11: The comparisons between CO_2 levels and the recommended benchmarks in Y6 on two different days

The following table (Table 5-2.10) shows the percentage of occasions that CO_2 went above 800 & 1000ppm during the classroom sessions on different days.

School	Classroom	Date	Day	Session	Proportion of time exceeding 1000ppm (%) during occupied hours	Proportion of time exceeding 800 ppm (%) during occupied hours	Significantly different from 1000 ppm during occupied hours	Significantly different from 800 ppm during occupied hours	3rd criterion of BB101	Air quality based on BSRIA
Grove. Road	Y6	27-Jun-08	Friday	1st	72	82	√	√	X	X
				2nd	97	100				
				3rd	1	11	$p < 0.05$	$p < 0.05$		
				4th	69	84				
		30-Jun-08	Monday	1st	75	86	√	√	X	X
				2nd	67	92				
				3rd	47	88	$p < 0.05$	$p < 0.05$		
				4th	71	96				

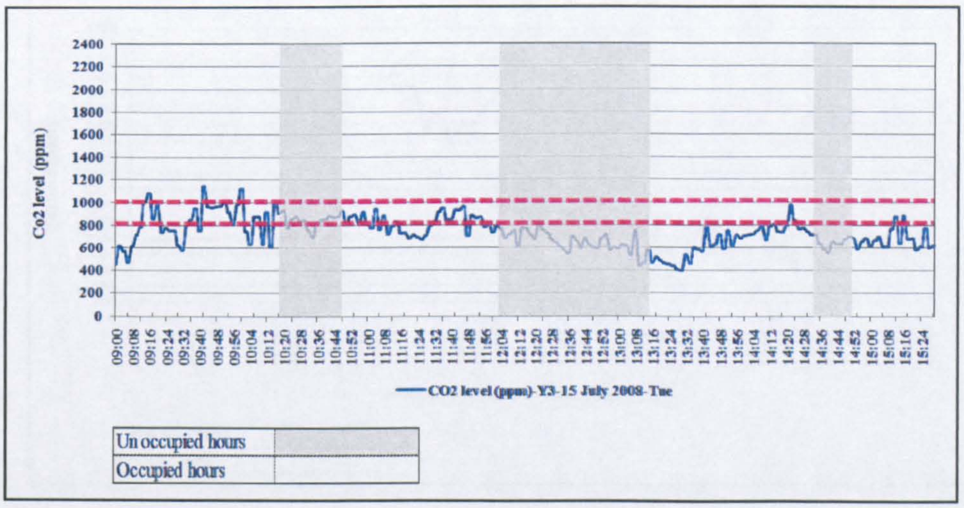
Table 5-2.10: The percentage of occasions that CO_2 exceeded 1000 and 800ppm in Y6 on two different days

As can be seen from the above table (Table 5-2.5), the percentage of the occasions that the CO_2 levels exceeded 1000ppm varied from 1 to 97%. Also, the percentage of the occasions that the CO_2 levels exceeded 800ppm varied from 1 to 100%. This table also illustrates although the CO_2 levels exceeded the threshold during some sessions, the classrooms have the potential for having good air quality as demonstrated during other sessions.

Year 6 students sometimes suffered from poor air quality (but not always), this is due to classrooms' environmental conditions the occupants choose to close the windows, and this do not allow the classroom to have a sufficient ventilation rate.

Study the third criterion for Year 3 of Andrew Ewing

In the following graph (Graph 5-2.12), the comparisons between CO_2 levels and the recommended benchmarks (1000 & 800ppm) are shown for Y3 on 15th of July.



Graph 5-2.12: The comparisons between CO_2 levels and the recommended benchmarks in Y3 on a day

The following table (Table 5-2.11) shows the percentage of occasions that CO_2 exceeded 800 & 1000ppm during the classroom sessions on different days.

School	Classroom	Date	Day	Session	Proportion of time exceeding 1000ppm (%) during occupied hours	Proportion of time exceeding 800 ppm (%) during occupied hours	Significantly different from 1000 ppm during occupied hours	Significantly different from 800 ppm during occupied hours	3rd criterion of BB101	Air quality based on BSRIA
Andrew. Ewing	Y3	15-Jul-08	Tuseday	1st	14	57	√	√	X	X
				2nd	0	59				
				3rd	0	11	$p < 0.05$	$p < 0.05$		
				4th	0	9				

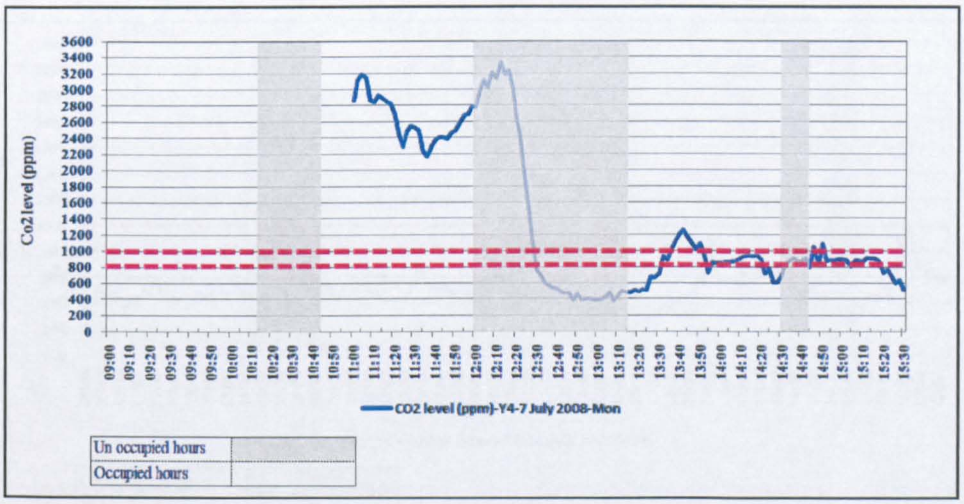
Table 5-2.11: The percentage of occasions that CO_2 exceeded 1000 and 800ppm in Y6 on a day

As can be seen from the above table (Table 5-2.6), the percentage of the occasions that the CO_2 levels exceeded 1000ppm varied from 0 to14%. Also, the percentage of the occasions that the CO_2 levels exceeded 800ppm varied from 9 to 59%.This table also illustrates that although the CO_2 level exceeded the threshold during some sessions, the classroom has the potential for having good air quality as demonstrated during other sessions.

The reason that Year 3 students sometimes suffered from poor air quality (but not always), this is due to classrooms' environmental conditions in which occupants choose to close the windows, and this does not allow the classroom to have a sufficient ventilation rate.

Study the third criterion for Year 4 of Andrew Ewing

In the following graph (Graph 5-2.13), the comparisons between CO_2 levels and the recommended benchmarks (1000 & 800ppm) are shown for Y4 on 7th of July. In this classroom, the CO_2 monitoring started from 11:00.



Graph 5-2.13: The comparisons between CO_2 levels with the recommended benchmark in Y4 on a day

The following table (Table 5-2.12) shows the percentage of occasions when the levels of CO_2 exceeded 800 & 1000ppm during the classroom sessions on different days.

School	Classroom	Date	Day	Session	Proportion of time exceeding 1000ppm (%) during occupied hours	Proportion of time exceeding 800 ppm (%) during occupied hours	Significantly different from 1000 ppm during occupied hours	Significantly different from 800 ppm during occupied hours	3rd criterion of BB101	Air quality based on BSRIA
Andrew. Ewing	Y4	07-Jul-08	Tuseday	1st	-	-	√	√	X	X
				2nd	100	100				
				3rd	22	65	$p < 0.05$	$p < 0.05$		
				4th	9	74				

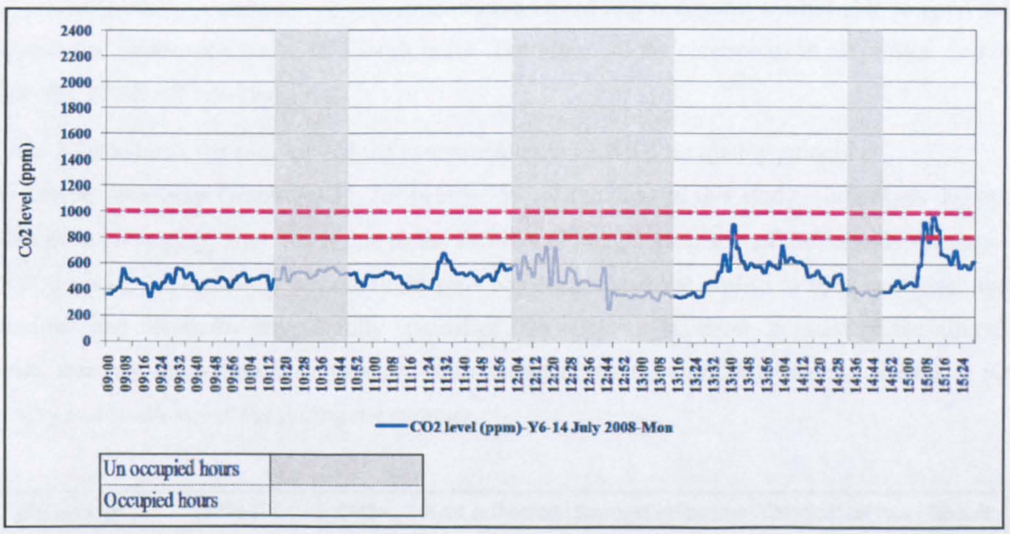
Table 5-2.12: The percentages of occasions that CO_2 exceeded 1000 and 800ppm in Y4 on a day

As can be seen from the above table (Table 5-2.12), the percentage of occasions that the CO_2 levels went above 1000ppm varied from 9 to100%. Also, the percentage of the occasions that the CO_2 levels exceeded 800ppm varied from 65 to 74%.This table also illustrates that although the CO_2 level exceeded the threshold during some sessions, the classroom has the potential for having good air quality as demonstrated during other sessions.

Year 3 students sometimes suffered from bad air quality (but not always) this is due to classroom's environmental conditions in which the occupants choose to close the windows, and this does not allow the classroom to have a sufficient ventilation rate.

<u>Study the third criterion for Year 6 of Andrew Ewing</u>

In the following graph (Graph 5-2.14), the comparisons between CO_2 levels and the recommended benchmarks (1000 & 800ppm) and shown for Y6 on 14th of July.



Graph 5-2.14: The comparisons between CO_2 levels with the recommended benchmarks in Y6 on a day

The following table (Table 5-2.13) shows the percentage of occasions that CO_2 exceeded 800 & 1000ppm during the classroom sessions on different days.

School	Classroom	Date	Day	Session	Proportion of time exceeding 1000ppm (%) during occupied hours	Proportion of time exceeding 800 ppm (%) during occupied hours	Significantly different from 1000 ppm during occupied hours	Significantly different from 800 ppm during occupied hours	3rd criterion of BB101	Air quality based on BSRIA
Andrew. Ewing	Y6	14-Jul-08	Monday	1st	0	0	N.A	x $p > 0.05$	√	X
				2nd	0	0				
				3rd	0	3				
				4th	0	13				

Table 5-2.13: The percentage of occasions that CO_2 exceeded 1000 and 800ppm in Y4 on a day

As can be seen from the above table (Table 5-2.13), the CO_2 levels did not exceed 1000ppm while the percentage of occasions that exceeded 800ppm varied from 0 to 13%. The table also illustrates that although the CO_2 levels exceeded the threshold during some sessions, it has the potential of having good air quality (based on BSRIA criterion) as demonstrated during other sessions.

Year 3 students sometimes suffered from poor air quality (based on BSRIA but not always). This is due to the classroom's environmental conditions in which the occupants choose to close the windows, and this does not allow the classroom to have sufficient ventilation rate. Students of this classroom had a privilege of good air quality based on BB101 criteria.

d) Result of assessment of indoor air quality as per BB101 guideline based on CO_2 level

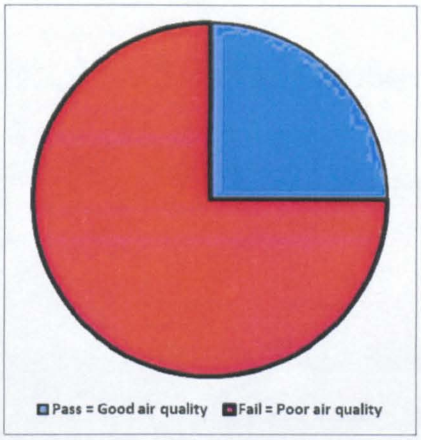
As a result of the indoor CO_2 levels in different classrooms against the third BB101 criterion, it can be concluded that, in some situations, windows are closed and occupants are not able to open the classrooms' windows because of aircraft noise. Therefore, all the classrooms in all session do not meet the 3^{rd} BB101 criterion.

Table 5-2.14 shows the summary of the assessment as per BB101 air quality guideline.

As can be seen from Graph 5-2.15, for nearly 75% of the days in this study, classrooms did not have good air quality. And this is due to the fact that although occupants of the schools which are located under the Heathrow airport flight path physically have the ability to open and close the windows and nominally have a fully control of the windows, however, because of the aircraft noise, there are some limitations to maintaining access to natural ventilation which caused poor air quality and stuffy situations during the summer.

Classroom	School	Date	First criterion	Second criterion	Third criterion	Result
Y2	Grove Road	24.June	√	√	√	Pass
Y4	Grove Road	25.June	√	√	x	Fail
Y3	Grove Road	26.June	√	√	x	Fail
Y6	Grove Road	27.June	√	√	x	Fail
Y6	Grove Road	30.June	√	√	x	Fail
Y4	Grove Road	1.July	√	√	x	Fail
Y4	Grove Road	2.July	√	√	√	Pass
Y4	Andrew Ewing	7.July	√	√	x	Fail
Y2	Grove Road	10.July	√	√	x	Fail
Y2	Grove Road	11.July	√	√	x	Fail
Y6	Andrew Ewing	14.July	√	√	√	Pass
Y3	Andrew Ewing	15.July	√	√	x	Fail

Table 5-2.14: Summary of classrooms indoor air quality against BB101 air quality guideline based on CO_2



Graph 5-2.15: Share of the days according to classrooms' air quality

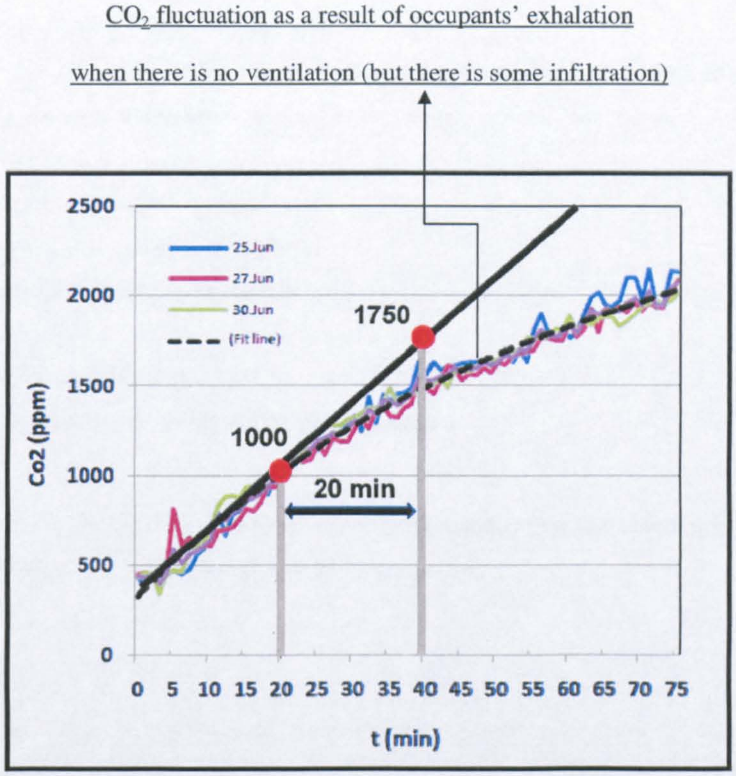
5.2.5.2. Comparison of the classrooms' ventilation rate as per the BB101 air quality guideline based on ventilation rate

In the previous section, it has been proven that classrooms located under the flight path suffer from poor air quality as per the BB101 air quality guideline based on CO_2 level. In this section some classrooms of Grove Road primary school are assessed against the BB101 air quality guideline based on ventilation rate to show how aircraft noise can have a negative impact on ventilation rate as well as on classrooms' CO_2 level. According to these criteria, the minimum ventilation should be 3 l/s per person with a minimum daily average of 5 l/s per person and a capability of achieving a minimum of 8 l/s per person at any time.

In this part, the classrooms' ventilation rate is calculated when windows are fully open and fully closed. As mentioned in the literature review, there are two methods for calculating ventilation rate (there are also methods available to physically measure ventilation rate e.g. pressure test, which are not viable for this study). These two methods are 'formula method' which is explained in the literature review and 'plotting method' which is explained in this section, and are used to calculate ventilation rate in this study. In the 'plotting method', ventilation rate is calculated based on the CO_2 fluctuation that is recorded inside the classrooms. This method requires less data to be input in comparison with the formula method. As shown in the previous graphs, in the worst condition, the windows are closed for 75min (entire duration), and in the best condition windows are open for this entire duration. The ventilation rates for these two scenarios are calculated as follows:

a) Calculating the ventilation rate when windows are fully closed

The following graph (Graph 5-2.16) shows the CO_2 fluctuations when windows were closed during first session of the morning (9:00 -10:15 for 75 minutes) on 3 different days in Grove Road primary school's classrooms. The graph enables the determination of the ventilation level.



Graph 5-2.16: CO_2 levels on different days when windows are fully closed

In order to estimate the ventilation rate, the following four steps should be followed:

- First: The tangent line of the CO_2 fluctuation curve should be drawn. This line represents the CO_2 level if the classroom does not have any ventilation or infiltration.
- Second: The equation of the tangent line is Y=a x + b
  - 'a' is calculated by calculating the tangent of this line which is ((1750-1000)/(20x60))=0.6ppm per second
  - 'b' is the CO_2 inside and outside at the time of t=0 and is equal to 400ppm So the formula of the tangent line is Y=0.6 x +400
- Third: change in CO_2 concentration (dc) is obtained by the following formula

dc =[emission – exhaust (note exhaust is inside concentration – outside concentration)] x dt

dc= 0.6 dt – VR x (C – 400) x dt/V

dc/dt=0.6 – VR x (C – 400) / V

VR = ventilation rate

V = room volume

C= CO_2 level at the time of t

- Forth: the infiltration rate at t= 2400 is calculated as follows:

The CO_2 level at the time when t is 1500 ppm

dc/dt at the time when 't=2400' from the CO_2 fluctuation curve is [(1500-1300)/(10x60)] = 0.3t

0.3 = 0.6 – VR x (1500 – 400) / V

VR x 1100/V = 0.3

Room volume (V) is 180 cubic metres

VR= (0.3 x 180) /1100= 0.049 m3/s = 49 l/s

Number of children inside the classroom is 30

Number of teacher is 1

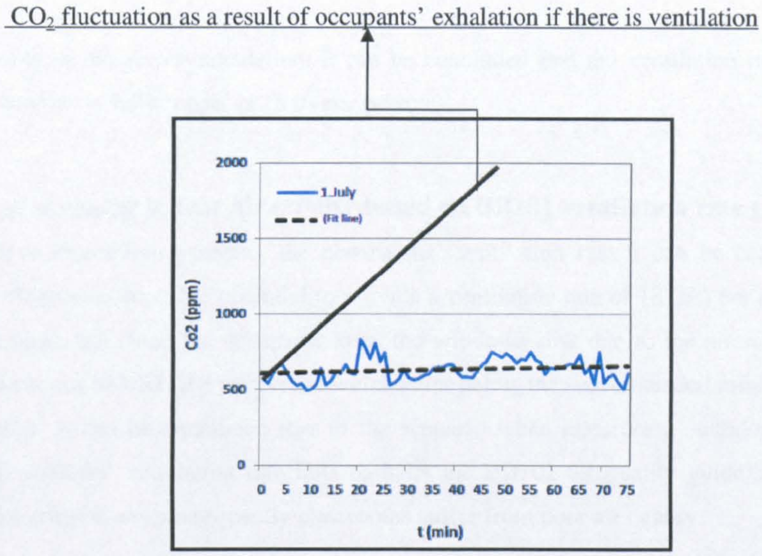
Number of teacher assistant is 1

Ventilation rate per person= 49 /32 = 1.53 l/s per person

From the results of the above calculation, it can be concluded that the ventilation rate when the classrooms' windows are fully 'closed' is 1.53 l/s per person.

b) Calculating the ventilation rate when windows are fully open

The following graph (Graph 5-2.17) shows the CO_2 fluctuations when windows were open during the first session of the morning (10:45 -12:00) on one day. The graph enables the determination of the ventilation level.



Graph 5-2.17: CO_2 level on one day when windows are fully open

In order to estimate the ventilation rate the following four steps should be carried out:

First: From the previous discussion, it is estimated that the formula for CO_2 fluctuation line when the window is closed is Y=0.6 x +400

Second: Concentration (dc) is obtained by the following formula:

dc =[emission – exhaust (note exhaust is inside concentration – outside concentration)] x dt

dc= 0.6 dt – VR x (C – 400) x dt/V

dc/dt=0.6 – VR x (C – 400) / V

VR = ventilation rate

V = room volume

C= CO_2 level at the time of t

Third: The ventilation rate at t= 2400 is calculated as follows:

The CO_2 level at the time when t is 600 ppm

dc/dt at the time when 't=2400' from the CO_2 fluctuation curve is [(600-6001300)/(10x60)]= 0

0 = 0.6 – VR x (600 – 400) / V

VR x 1100/V = 0.6

Room volume (V) is 180 cubic metres

VR= (0.6 x 180) /1100= 0.54 m3/s =540 l/s

Number of children inside the classroom is 30

Number of teacher is 1

Number of teacher assistant is 1

Ventilation rate per person= 540 /32 = 18 (l/s) per person

From the results of the above calculation, it can be concluded that the ventilation rate when the classroom's window is fully 'open' is 18 l/s per person.

c) Result of assessing indoor air quality based on BB101 ventilation rate guideline

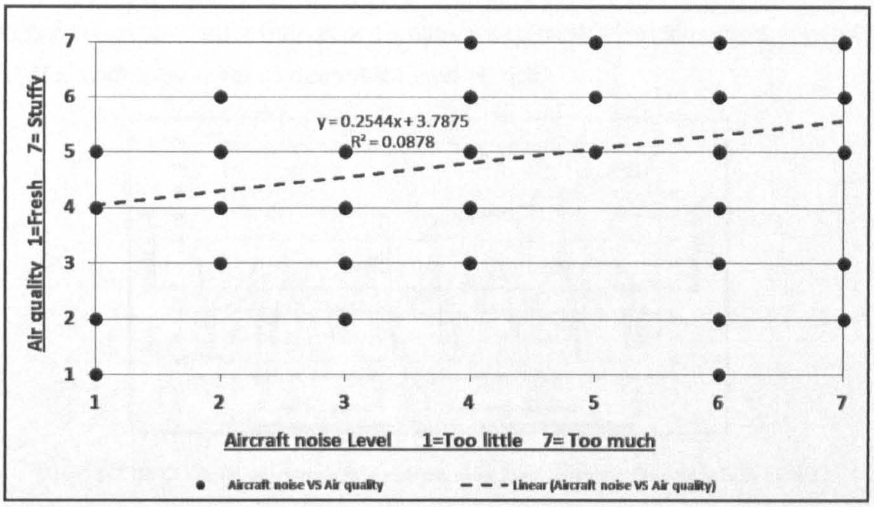
From the above discussion regarding the classrooms' ventilation rate it can be concluded that although the classrooms have the potential to provide a ventilation rate of 18 (l/s) per person when windows are open, but since the occupants keep the windows shut due to the aircraft noise, the ventilation rate drops to 1.53 (l/s) per person which is far below the recommended minimum rate of 3 l/s per person. It can be concluded that in the scenario when classrooms' windows are fully closed, the classrooms' ventilation rate fails to meet the BB101 air quality guideline based on ventilation rate criteria, and consequently classrooms suffer from poor air quality.

5.2.2. Subjective study

The subjective result also confirms the result from objective study.

In the questionnaires, the teachers were requested to rate the air quality and aircraft noise levels from one to seven. A regression analysis is carried out between teachers' perception of air quality and aircraft noise (Appendix 10.24). The result of this regression shows that aircraft noise is a predictor for air quality ($P<0.05$, $r=0.296$).

The following graph (Graph 5-2.18) demonstrates that, the higher the level of aircraft noise, the lower the air quality level.



Graph 5-2.18: Air quality VS Aircraft noise level

As can be seen from the above graph (Graph 5-2.18), the teachers who scored a higher level of aircraft noise, also scored for stuffier situations and vice versa. Therefore, it can be concluded the buildings' distances of the schools from airports has an impact on ventilation level which plays an important role on air quality.

5.2.3. Conclusion

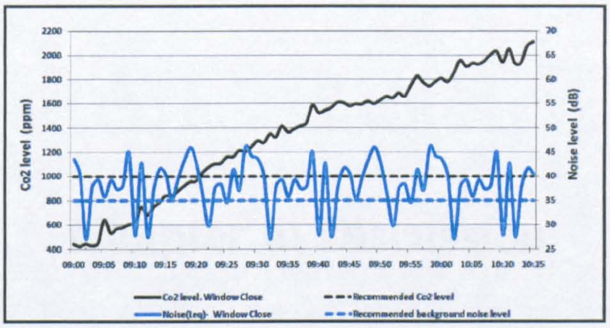
It is objectively and subjectively has proven that the schools which are located within a short distance to the Heathrow airport have a higher risk of experiencing poor air quality.

Although occupants of the schools, which are located under the Heathrow airport flight path physically, have the ability to open and close the windows and nominally have the full control of the windows, however because of the aircraft noise, there are limitations in maintaining access to natural ventilation. This can lead to overheating and stuffy situations during summer.

The occupants in these regions would fall under one of the following critical situations:

Poor air quality with suitable background noise

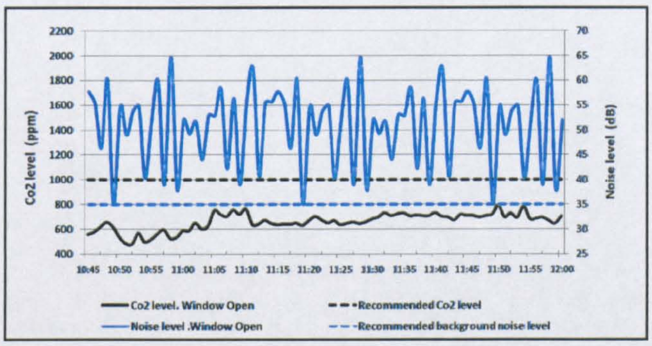
The following graph (Graph 5-2.19) shows a critical situation where the CO_2 levels exceed 1000ppm and classrooms suffer from poor air quality as a result of window closure to reduce the high level of aircraft noise to the recommended level of 35dB.



Graph 5-2.19: CO_2 level vs. classroom's ambient noise level when the window is fully closed

A high level of background noise but with good air quality

The following graph (Graph 5-2.20) shows a critical situation where aircraft noise level exceeds 35 (dB) and the classroom suffers from a poor background noise level. This is due to keeping windows open to maintain indoor air quality and reduce the CO_2 level to the recommended level of 1000ppm.



Graph 5-2.20: CO_2 level vs. classroom's ambient noise level when the window is fully open

Chapter 6: Discussion

Overview:

This part of the research summarises the reasons that why a classroom fails to provide good environmental conditions as a result of conflict between comfort factors and also use of relaxed benchmarks. The type of conflict that is studied in this research is the conflict between acoustic comfort and 'thermal and air quality' in the classrooms located under the flight path, which causes overheating and poor air quality. The seven findings of the research are summarised. These findings focus on the impact of high level aircraft noise and poor layout on ventilation and consequently experiencing overheating and poor air quality inside classrooms. In addition, the impact of climate condition (i.e. solar irradiance & outside temperature) and building factors (i.e. thermal mass level and solar gain potential) on overheating are reviewed. This is followed by the explanation of the use of relaxed thermal and air quality benchmarks in design of classrooms which causes the classrooms to experience overheating and poor air quality. Finally, the limitations that the author faced during this study and suggestions for further research are discussed.

6.1. Problems

According to the extensive research available it can be seen that there is a significant relation between academic performance of students and the level of noise (Shield & Dockrell, 2003), temperature (Limb, 1997), air quality (Coley et al, 2007) & light (BB90, 1999).

In particular, concern has been shown for students in the age range of 5 to 11 years old (Dudek, 2000). Academic performance can be increased if classrooms have good acoustics without any external noise, as well as comfortable temperatures, good air quality and good lighting design, especially for natural light.

Not only poor environmental conditions could have negative impacts on students' performance but also on their health in critical situations. Providing good environmental condition has been a fundamental factor that has always been paid attention to, through the history of school design in the UK. By reviewing the schools' construction in the UK in Chapter Two of this study, the causes of poor environmental conditions can be summarised as follows:

- Poor environmental conditions as a result of conflict between comfort factors
- Poor environmental conditions as a result of using relaxed benchmarks

Providing a balance between all the environmental factors is critical as they may conflict and interact with each other for the following reasons:

1. Conflict between comfort factors because they are considered separately. It should be noted that these are usually not independent factors but interrelate with each other.
2. Conflict between comfort factors due to change of conditions over the life of the building.

This research focuses on one type of conflict in the classrooms located under flight paths. The hypothesis of this research is that the schools located under flight paths suffer from overheating and poor air quality compared to the ones that are located in quite regions. The reasoning is that the main role of ventilation is to provide thermal comfort and good air quality. The lack of ventilation (window closure) because of the high level of air craft noise causes overheating and poor air quality in the schools located under flight paths. This is illustrated in this study and the summary of finding is reviewed below.

6.2. Summary of Findings

This research has seven findings which are discussed as follows:

6.2.1. First finding: Window closure as a result of the high level of aircraft noise

The first finding of this research is that the occupants of the school located under the Heathrow Airport flight path complain about the high level of aircraft noise and tend to keep windows shut for a considerable amount of time.

BAA operates a runway alteration plan to reduce the impact of high level of aircraft noise on the residents of the regions around Heathrow Airport. Based on this initiative, one runway is used by landing aircrafts from 06:00 until 15:00 and then they switch to the other runway. Departing aircrafts use the alternative run-way. However, on Sunday each week the runway used the day before continues to be used for landings. This means early morning arrivals use a different runway on successive weeks and the runways used by landing aircrafts before and after 15:00 also alternate on a weekly basis. This alteration does not mean that the aircraft noise is wholly mitigated, but it can be said that the noise is lowered every other week.

In order to show that windows are shut for a considerable amount of time in primary school classrooms located under Heathrow Airport flight path, the following assessments are carried out:

6.2.1.1. Assessment 1: Aircraft noise and possibility of window closure based on detailed study

Generally aircraft noise has a negative impact on occupants' speech intelligibility as it impairs communications. It also annoys and causes them to lose their ability to concentrate. The detailed study is carried in two parts in order to evaluate the impact of aircraft noise on occupants' speech intelligibility and occupants' complaint level.

a) Aircraft noise, speech intelligibility and window closure

Various guidelines are proposed regarding the impact of aircraft noise on speech intelligibility. The aircraft noises heard in classrooms against the criteria set for speech intelligibility in two situations (window closed and open) are evaluated in order to demonstrate that how acoustic difficulties arise in the schools located under the Heathrow flight path. According to these guidelines, speech intelligibility is significantly improved if windows are closed. The extent of the improvement varies depending on what guideline is referred to. This assessment confirms the possibilities of window closure due to the aircraft noise based on the evaluation of speech intelligibility when windows are open and closed.

It should be noted that both the level of disturbing noise (e.g. aircraft noise) and the distance between speaker and listener have a significant impact on speech intelligibility.

In every 90 seconds, an aircrafts passes over the schools which are within a close distance to Heathrow airport.

The maximum suitable distances between speaker and listener based on BS 8233 (which is adapted for L5 and L10) and the percentage of occasions that communications would be failed are calculated. Based on this calculation, it is shown that if the distance between the speaker (with normal voice) and listener exceeds 0.7m, 4.5 out of 90 seconds of the communication is missed out when an aircraft is passing over the school building and window is open. In other words, if pronouncing each word lasts for 1 second, it can be concluded that nearly 5 out of 90 words will be missed out which causes a negative impact on speech intelligibility.

Furthermore, if the distance between speaker (with the normal voice) and listener becomes higher than 1.32m, then 9 out of 90 seconds is missed out when an aircraft is passing over the school building and window is open. This creates a more critical situation as 9 out of 90 words will be missed out.

In the situation that the window is closed, these distances are 2.7 and 4.7 respectively.

The best condition in which the speech intelligibility is provided (while the windows are open and aircrafts are flying over the school) is when the teacher sits on a chair at the centre, students sit around him/her and the teacher raises his/her voice. In this condition, teacher speech intelligibility is provided even for the students who sit in the second and third rows. As it was observed several times in the classrooms of Grove Road and Andrew Ewing primary schools teachers invited students to sit on the floor and they themselves sat on the chair during most of the lecturing activities in order to improve speech intelligibility. It should be noted that if the teacher wants to stand up or students want to sit at their desks, the speech intelligibility will be impaired. In this situation, in order to improve speech intelligibility, classrooms' windows should be kept closed. *This assessment confirms the possibility of window closure due* *to the aircraft noise based on the evaluation of suitable distance between speaker and listener in order to provide speech intelligibility when windows are open and closed.*

b) Aircraft noise, occupants' annoyance level and window closure

In terms of annoyance level, both BS 4142 and the Guides on Noise from Pubs and Clubs (I.O.A, 2003) use a criterion which looks at the difference between the specific noise (e.g. disco, aircraft) and background noise (e.g. students' activity). If this difference exceeds 10 dB, complains are likely. Based on this criterion, the likelihood that occupants complain about the high level of aircraft noise inside classrooms when windows are open and closed and occupants are occupied with different activities are calculated for each classroom. Four types of activities which are carried of inside a classroom are 'Activity 1: Silent', 'Activity 2: one person speaking', 'Activity 3: individual' & 'Activity 4: Group'. Based on these calculations for the classrooms located under the flight path, it is found that for activities 1 and 2, the disturbance is more likely when the windows are open, and unlikely when the windows are closed, whilst for activities 3 and 4, the noise through open windows causes disturbance in only one or two classrooms out of six.

The average duration of each type of activity inside classrooms ('Activity 1: Silent', 'Activity 2: one person speaking', 'Activity 3: individual' and 'Activity 4: Group') are 11%, 42%, 18% & 30% respectively.

The result shows the share of 'Activity 1: Silent' and 'Activity 2: one person speaking' are around 55% of all activities. However the share of 'Activity 2' is significantly higher than other activities. Therefore, it can be concluded that there is a possibility that classrooms located under the flight paths will need to keep their windows shut for more than half of the duration of their activities, and this would lead to lack of ventilation in the classrooms. In addition, based on the Assessment 3, which is explained later, it is discovered that not only do the occupants close the classrooms' windows during 'Activity 1: Silent' and 'Activity 2: one person speaking', but also they are kept shut during the subjects that need extra concentration such as maths, science and literacy, even in a week where aircraft noise is low. Based on Assessment 1 and Assessment 3 which is explained later, it can be concluded that the percentage of the occasion that windows are closed is more that 55%. *This assessment confirms the possibility of window closure due to the aircraft noise based on the calculation of the likelihood of occupants complaining about the high level of aircraft noise inside classrooms when windows are open and closed.*

6.2.1.2. Assessment 2: Aircraft noise and the possibility of window closure based on Random Study

A random survey was carried out on a day that aircraft noise was high. In the survey, the status of windows (i.e. open or closed) and type of the activities for all range of classrooms (Y1-Y6) were recorded while they were being affected by aircraft noise (Table 6.1). The result suggests that only the windows of noisy classrooms stayed OPEN in contrast to those of quiet activities which were kept CLOSED. In this study, the 'quiet activities' mainly refers to 'Activity 1: Silent' and 'Activity 2: one person speaking' and the 'noisy activities' mainly refers to 'Activity 3: individual' & 'Activity 4: Group'.

Classrooms	Window situation	Activities
Y1	Close	Quiet
Y2	Open	Noisy
Y3	Open	Noisy
Y4	Open	Noisy
Y5	Close	Empty
Y6	Close	Quiet

Table 6.1: Windows status VS the level of noise in different classrooms

This assessment confirms the possibilities of window closure due to the aircraft noise based on Random Study.

6.2.1.3. Assessment 3: Nature of the class subject and window closure

As mentioned earlier, the study was conducted on two types of days – one where there was a high level of aircraft noise (present) and the other where there was a low level of aircraft noise (absent).

This study shows that the presence of aircraft noise in some sessions did not have any impact on the status of windows. The classroom windows were kept closed irrespective of the level of outside noise.

Teachers of the classrooms in which the windows were kept shut during the weeks that aircraft noise was low were questioned about this. They believed that the aircraft noise could still be heard inside the classrooms even on the days that aircrafts would have changed their direction. On these days, the level of aircraft noise which is heard inside the classrooms is 45dB, which is still above the recommended benchmark that a classroom is allowed during purge ventilation.

As aircraft noise contains distinct impulses, it is distracting for students when they are occupied with the subjects that need extra concentration such as math, science and literacy. They considered that they preferred to keep the window shut during such subjects even in the weeks that aircraft noise was low, as the nature of these subjects needed extra concentration, and consequently they experienced poor air quality and overheating.

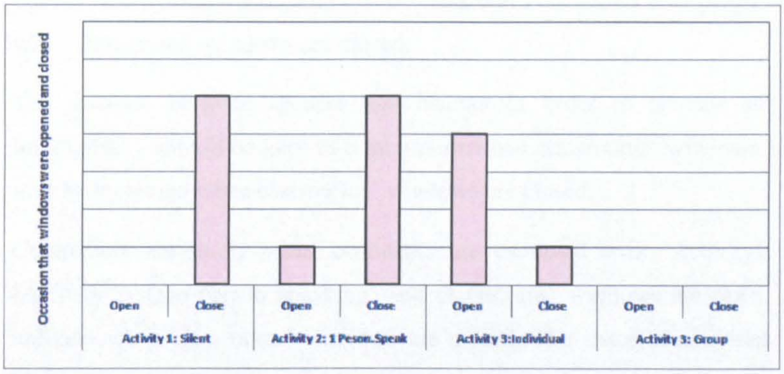
It should be noted that in this study the schools which have been chosen are relatively free from other environmental noises such as cars and lorries so that the impact of aircraft noise on window closure can be studied more accurately. *This assessment confirms the possibilities of window closure due to the aircraft noise based on observations and interviews with teachers.*

6.2.1.4. Assessment 4: Occasions that windows were kept closed and open

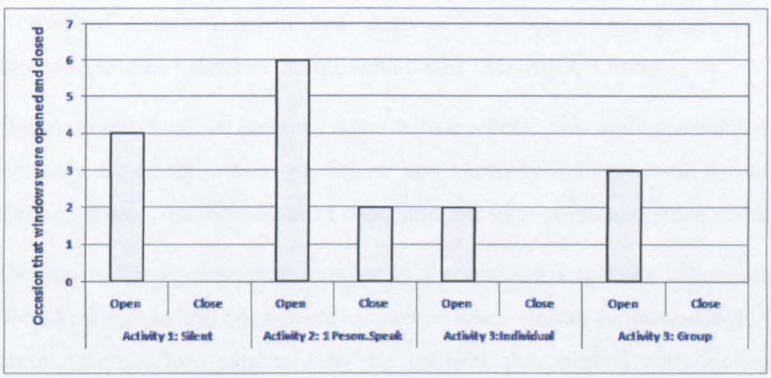
As mentioned in Assessment 1, the occupants complaints are 'likely' from the high level of aircraft noise when windows are open and they are occupied with 'Activity 1: Silent' and 'Activity 2: one person speaking' but it is 'unlikely' when windows are closed. Due to this assessment, there is a possibility that the classrooms located under flight paths will need to keep their windows shut for the duration that the occupants are occupied with 'Activity 1: Silent' and 'Activity 2: one person speaking'. Assessment 2 which is a random assessment and was carried out in a week when aircraft noise was present, confirms that the windows were kept shut while the occupants were occupied with silent activities (i.e. 'Activity 1: Silent' and 'Activity 2: one person speaking') and they were open when occupants were occupied with noisy activities ('Activity 3: individual' & 'Activity 4: Group'). In this assessment, the relation between the number of occasions that the windows were kept closed and open (status of windows) with activities that were carried out inside the classrooms is studied.

It should be noted that in this part of the study, the sessions allocated to the subjects that needed extra concentration (e.g. math) have been excluded. This is due to the fact that windows are closed at all times in these sessions, due the nature of the subject and also the nature of aircraft noise irrespective of its noise level (high or low).

Based on this assessment, it is found out that the number of the occasions that windows were kept closed are significantly higher than the occasions they were kept open during 'Activity1: Silent' and 'Activity 2: One person speaking' during the weeks that aircraft noise was high (Graph 6.1). Also, *the numbers of* the occasions that windows were kept open are significantly higher than the occasions they were closed during 'Activity1: Silent' and 'Activity 2: One person speaking' during the week that aircraft noise was low (Graph 6.2).



Graph 6.1: Occasions that windows were open and closed when the aircraft noise was high (present)



Graph 6.2: Occasions that windows were open and closed when the aircraft noise was low (absent)

This assessment confirms the possibility of window closure due to the aircraft noise based on observation.

6.2.1.5. Assessment 5: Subjective analysis

The regression analysis that is carried out between the perceived ventilation control level and aircraft noise confirms that there is a low significant negative relationship between ventilation control level and aircraft noise level.

6.2.1.6. Results of the above five assessments

The summery of the above five assessments which are carried out on classrooms located under the Heathrow flight paths are as follows:

- Speech intelligibility is impaired when classrooms' windows are opened and improved when classrooms' windows are closed.
- The distance between speaker and listener in order to provide suitable speech intelligibility should be kept to a minimum when classrooms' windows are open, and may be increased when classrooms' windows are closed.
- Complaints are likely when occupants are occupied with 'Activity1: Silent' and 'Activity 2: One person speaking' and classrooms' windows are open, and become unlikely when classrooms' windows are closed. The share of activities 1 and 2 are higher than the share of activities 3 and 4 and the share of activity 2 is significantly higher than all the others. For this reason, it can be concluded that the percentage of the occasions that windows are closed is higher.
- Based on Random Study, classrooms' windows were kept closed during Quiet Activities ['Activity1: Silent' and 'Activity 2: One person speaking'] and open during Noisy Activities ['Activity 3: Individual' and 'Activity 4: Group'].
- Based on observations and interviews with teachers, classrooms' windows were closed not only during the 'Activity1: Silent' and 'Activity 2: One person speaking' but also during subjects that needed extra concentration such as math, science and literacy.
- During the observation, the number of the occasions that the classrooms' windows were kept closed and open, were monitored when aircraft noise was high and low. The result (the sessions allocated to the subjects that needed extra concentration are excluded) shows that the number of occasions that windows were closed during 'Activity 1' and 'Activity 2' are significantly higher during the weeks that aircraft noise was high.
- The subjective analysis also confirms the impact of aircraft noise on occupants' behaviour regarding window closure.

From the results of the above assessments, it is proven that the classrooms located under the Heathrow flight path keep the windows shut for a considerable amount of time. The only available ventilation system in the classrooms which are studied, is through windows as they are all naturally ventilated buildings. Although the occupants of these buildings physically have the ability to open and close windows, access to natural ventilation is limited due to the aircraft noise. This suggests they will lack sufficient ventilation, and therefore overheating and poor indoor air quality will occur.

6.2.2. The second finding: Door closure as a result of poor layout

The second finding of this research is with regards to the negative impact of poor layout on the lack of ventilation. A review of the layouts of some schools (e.g. Grove Road, Andrew Ewing) shows that there is a communal hall (in which IT activities take place) located on the internal side of the classrooms. According to the interview with the teachers, the internal doors stayed closed while there were activities taking place in the communal hall, or when other classrooms carried out noisy activities and would have left their doors open. It should be noted that if there is a possibility to leave the internal doors open, the classrooms will have a chance to provide fresh air through stack ventilation from the communal hall as there are openings on its roof. So it can be concluded that poor layout could decrease the ventilation level.

6.2.3. Third finding: Overheating as a result of the high level of aircraft noise

The third finding of this research is roughly the impact of the high level of aircraft noise on the risk of schools' overheating.

In order to assess the likelihood of classrooms which are located under the flight path suffering from overheating more than the ones located in quiet regions, the indoor temperatures of 70 classrooms from 18 free running primary schools in London were recorded every half an hour, by placing two 'I Buttons' with the accuracy of (±0.5 ° C) in each classroom in June & July of the years 2005, 2007 & 2008.

The schools are simply caregorised as noisy or quiet schools. Noisy schools are defined as those lying in the Heathrow map of above 57 dBA and Quiet schools are defined as those lying outside noise map.

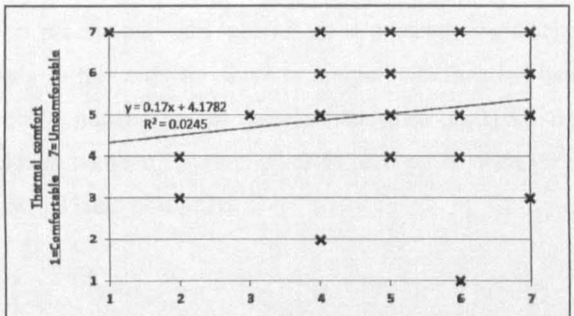
Dimensional measurements, solar gain calculation, thermal mass & classroom elevation evaluations were carried out for each classroom.

Indoor temperature is affected by climate and building characteristics. According to CIBSE TM36 (2006), the key characteristics to prevent overheating are ventilation rate, solar gain, thermal mass, building design and internal gain.

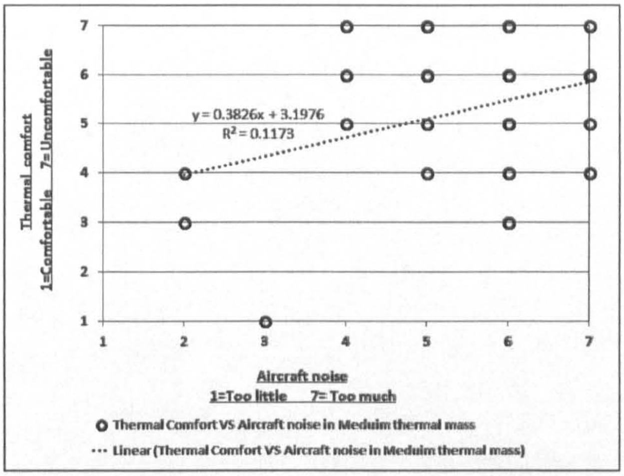
Climate condition is different for each classroom on each day, each of which creates a unique 'Classroom-Day' scenario. To study the impact of ventilation on indoor temperature, comparisons are carried out between the percentages of dissatisfaction from overheating (based on fixed and adaptive model) and the percentage of the occasion that indoor occupied temperatures exceed the maximum allowable difference from adaptive thermal comfort, in classrooms located in noisy schools with those in quiet schools. To do this, the groups of classrooms with similar properties (i.e. thermal mass, risk of receiving solar gain) with the same climate conditions (i.e. the days which have similar solar irradiance and outside temperature) are compared. Classrooms in this study are divided into two groups according to their maximum risk for receiving solar gain on a clear day in June & July (i.e. above and below 50 W/m²). The impact of internal gain is considered constant as the number of students and their activities, classrooms' areas and also the number and types of equipments in use are almost the same.

After equalising the factors that have a significant impact on indoor temperature such as thermal mass, maximum risk for receiving solar gain in classrooms (which is related to the direction of classroom windows, window area etc.), outside daily temperature and daily irradiance (i.e. actual daily solar irradiance), it is concluded that the percentage of dissatisfaction from overheating, and the percentage of occasions that indoor occupied temperatures exceed the maximum allowable difference from adaptive thermal comfort, are mainly higher in the noisy classrooms as compared to those in quiet regions. Therefore, it can be concluded that the noisy classrooms with a high level of aircraft noise have a lower potential for using natural ventilation.

The subjective results confirmed this analysis. A regression analysis is carried out between teachers' perceptions towards environmental noise and thermal comfort in low and medium thermal mass schools. The result of this regression shows that aircraft noise is the only predictor for thermal comfort in both low thermal mass schools ($p<0.05$, $r=0.323$) and medium thermal mass schools ($p<0.05$, $r=0.343$). The following two graphs (Graph 6.3 and Graph 6.4) show this relationship as thermal mass level is one of the factors that has an impact on the indoor temperature. The teachers' perceptions were elicited through a questionnaire.



Graph 6.3: Relationship between teachers' perception toward aircraft noise and thermal comfort (in low thermal mass school)

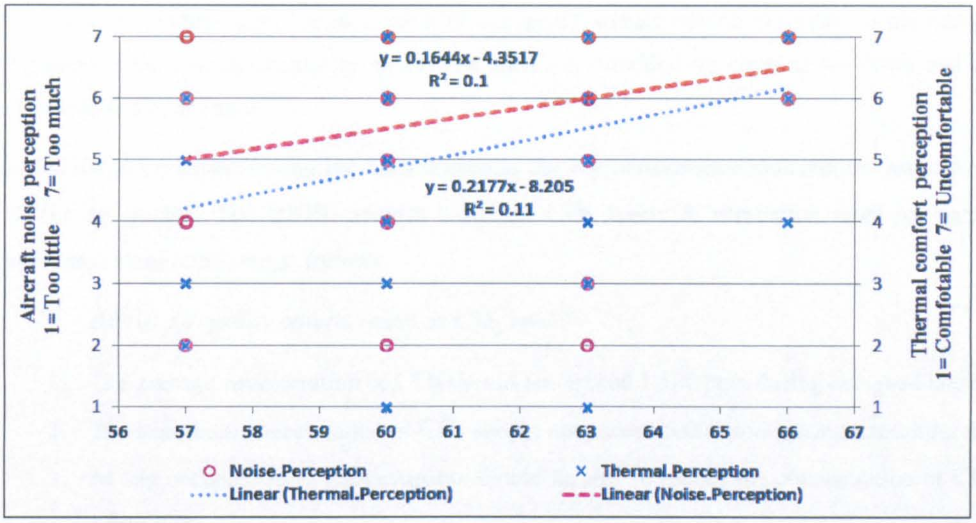


Graph 6.4: Relationship between teachers' perception toward aircraft noise and thermal comfort (in medium thermal mass school)

As can be seen from Graphs 6.3 and 6.4, the teachers who rated higher levels of aircraft noise, also rated lower levels of thermal comfort and vice versa. This subjective study confirms the objective survey that claims aircraft noise is a predictor for thermal comfort.

6.2.4. Fourth finding: The relation between schools' location on noise counter map and teachers' perceptions regarding aircraft noise and thermal comfort

In order to have a better understanding of how the level of aircraft noise has an impact on thermal comfort, the teachers' perceptions toward thermal comfort and aircraft noise are compared with the schools location on the noise contour map of above 57 dBA. A regression analysis is carried out between 'thermal comfort perception' with 'aircraft noise perception and schools' location on the noise contour'. According to this analysis, there is a significant relation between 'aircraft noise perception' with the schools' location on the noise counter map ($p<0.05$ and $r = 0.316$), and also there is a significant relation between 'thermal comfort perception' with the schools' location on the noise counter map ($p< 0.05$ and $r= 0.337$).



Graph 6.5: The relation between schools' location on aircraft noise with teachers' perception regarding aircraft noise and thermal comfort

Graph 6.5 shows the relation between the schools' location on the aircraft noise contour map with the teachers' perceptions toward aircraft noise and thermal comfort. As can be seen from this graph, the schools located on the higher aircraft noise contour experience lower thermal comfort and vice versa.

As a result, it can be suggested that not only do the schools located in noisy regions have a higher risk of experiencing overheating in comparison to those located in the quiet regions due to the aircraft noise, but also the schools located in the noisy regions suffer from different levels of overheating according to their location on the noise contour map. In other words, distance of the schools' building from Heathrow airport and the impact of aircraft noise on classrooms' background noise level have an impact on the level of thermal comfort. The high level of aircraft noise plays an important role in dissatisfaction from overheating as it reduces the buildings' potential for having natural ventilation.

6.2.5. Fifth finding: Poor air quality as a result of the high level of aircraft noise

The fifth finding of this research is the impact of the high level of aircraft noise on classrooms' poor air quality.

CO_2 is produced by occupants' breathing and the amount of CO_2 produced depends on the number of occupants, their weight and activity level. The volume of the room also has an impact on CO_2 concentration. Ventilation helps removing the CO_2 by providing fresh air. In general, the higher the CO_2 level, the lower the air quality.

CO_2 level is mainly increased as a result of occupants' exhale (which is related to the occupants metabolic rate) and decreased by ventilation which is provided by opening windows and doors (window and door status).

In BB101, CO_2 concentration has been chosen as the key performance indicator for assessment of indoor air quality. The BB101 criteria based on CO_2 levels & ventilation rates for naturally ventilated classrooms, are as follows:

- BB101 air quality criteria based on CO_2 level:

1. The average concentration of CO_2 should not exceed 1,500 ppm during occupied hours.
2. The maximum concentration of CO_2 should not exceed 5,000 ppm during a teaching day.
3. At any occupied time, the occupants should be able to reduce the concentration of CO_2 to 1,000 ppm.

- BB101 air quality criteria based on ventilation rate:

1. The minimum ventilation rate should be 3 l/s per person
2. The minimum daily average ventilation rate should be 5 l/s per person
4. Occupants should be capable of achieving a minimum of 8 l/s per person at any time.

In order to assess the likelihood of the classrooms which are located under the flight path, suffering from poor air quality more than the ones located in quiet regions, the CO_2 level of different classrooms of two primary schools were measured for 12 days at 1 to 2 minutes intervals using a device called Telaire.

The results of the air quality study carried out are as follows:

6.2.5.1. Study the classrooms' air quality according to BB101 air quality guidelines based on CO_2 level

The average CO_2 levels in all classrooms on different days were significantly less than 1,500ppm, which means that the classrooms meet the1st criterion for having good air quality. The maximum CO_2 levels in all classrooms on different days were significantly less than 5,000ppm, which means that classrooms meet the 2nd criterion for having good air quality. The fluctuations of CO_2 levels in all classrooms on different days are compared with 1,000ppm as the 3rd criterion for having good air quality, and it was found out that the percentage of occasions that the CO_2 levels went above 1,000ppm varied. Although occupants of the buildings located under flight paths physically had the ability to open windows and reduce the CO_2 level to below 1000ppm, due the aircraft noise, access to natural ventilation was limited. As per the result of the calculations, classrooms which are located under flight paths did not satisfy the 3rd criterion on 75% of the occasions, and therefore experienced poor air quality.

6.2.5.2. Study the classrooms' air quality according to BB101 air quality guidelines based on ventilation rate

The ventilation rates in classrooms located under flight paths are calculated when windows were open and closed in order to find out how window closure impacts the ventilation rate.

When classrooms' windows were open, the average ventilation rate was 8 l/s per person and when windows were closed, the average ventilation rate was 1.53l/s per person. This means that when windows were closed due to the high level of aircraft noise, ventilation rate dropped from 8 to 1.53 l/s per person. This amount is far below the recommended minimum rate which is 3 l/s per person.

It can be concluded that on occasions when classrooms' windows are fully closed, the classrooms' ventilation rate fails to meet the BB101 criteria based on ventilation rate criteria, and consequently classrooms suffer from poor air quality.

6.2.5.3. Subjective study

The subjective results also confirm the relationship between aircraft noise and air quality. The regression analysis between teachers' perceptions regarding air quality and aircraft noise confirms that there is a significant relationship between them. In this study, the teachers who rated a higher level of aircraft noise, also rated a stuffier situation and vice versa. Therefore, it can be concluded that aircraft noise has an impact on classrooms' indoor air quality. Also it can be concluded the distance of a school buildings from an airport has a major impact on ventilation level which plays an important role in achieving air quality.

6.2.6. Sixth finding: The impacts of climate and building factors on classrooms' indoor temperature

A regression analysis is carried out between (a) indoor temperatures and (b) outside temperature, solar irradiance (climate's factors) and classroom thermal mass levels (building factors). The result shows that in the majority of occasions, climate and building factors have significant impacts on indoor temperature. The impacts of these factors are individually studied as follows:

6.2.6.1. Climate factors

In general, climate factors are wind, rain, outside temperature, solar gain etc. In this study, the impacts of the most important climate factors (i.e. outside temperature and solar irradiance) are assessed:

a) Impact of outside temperature

The indoor temperatures of 58 classrooms from 16 primary schools are studied on two different weekend days. These classrooms have nearly the same actual daily solar irradiances but different outside temperatures. The results confirm that the outside temperature has an impact on classrooms' indoor temperature. They also show that the classrooms' indoor temperatures on the weekend day with the higher outside temperature, is found to be higher in comparison with the classrooms' indoor temperature on the weekend day with the lower outside temperature.

b) Impact of solar irradiance

The indoor temperatures of 58 classrooms from 16 primary schools with similar outside temperatures but different actual daily solar irradiances are studied on two different days at weekend. The results illustrate that in general, the indoor temperatures of the classrooms on the day with the higher actual daily solar irradiance are higher than that with the lower one. There are some exceptions to this which may be explained by the differences in the properties of any particular classroom for receiving solar gain.

6.2.6.2. Building factors

The building factors are thermal mass, solar gain potential, building layout and ventilation. The impact of ventilation on indoor temperature was confirmed earlier. The impact of solar gain and thermal mass are assessed as follows:

a) Impact of classrooms' potential for receiving solar gain

Classrooms' potential to receive solar gain is related to their direction, window size, shading, premier zone etc. Each of these factors has a significant impact on the amount of solar gain that classrooms could receive and consequently on indoor temperature. The indoor temperatures of the classroom of three primary schools were recorded one a weekend day that had the highest solar irradiation and outside temperature. The results confirm that there is a significant relationship between the classrooms' indoor temperature and their window direction. In this assessment, all other factors such as window size, shading, and premier zone are kept constant.

b) Impact of thermal mass

The indoor temperatures of 58 classrooms from 16 primary schools are studied on a weekend day. The results confirm that the classrooms with a lower level of thermal mass experience a higher level of indoor temperature and the classrooms with a higher level of thermal mass experience a lower level of indoor temperature during the cooling season (summer).

6.2.7. Seventh finding: Conflict between environmental benchmarks

In chapter 2 of this study, it was concluded that not only the conflict between comfort factors (i.e. as a result of them being considered separately and/or change of conditions over the life of the building) means that UK classrooms fail to provide a good environmental condition, but also designing school classrooms based on the benchmarks which are proposed by BB 87 & BB101 (updated revision of BB 87) may cause failure in providing good environmental conditions, as they are relaxed benchmarks in comparison to the others. In this research, it is demonstrated that BB101 which is currently being used as a design guideline, sets the most relaxed thresholds for air quality and thermal comfort factors, which are required to be revised (similar to the acoustic section of this guideline which was revised to the stringent benchmarks for background noise level and reverberation time and included in BB93).

Based on this research, it is discovered that the adaptive model, proposed by Nicol et al. (2009) on overheating, is the best criteria for assessing thermal comfort inside a classroom because not only it has been designed based on the adaptive model which has a better relation with occupants' feelings, but also provides detailed information regarding overheating by predicting the percentage of people that may feel overheated.

6.2.8. Eight finding: Applying a method for calculating solar gain

In the following formula which is proposed by CIBSE TM 37 regarding the calculation of solar gain, only the impact of solar shading effect is considered. The formula does not take overshadowing into account:

Solar gain inside building=
[(Window Area x External solar radiation x Shading Coefficient)] / Perimeter zone.

The external solar radiation can be found in CIBSE external irradiation table for each orientation (Appendix 3).

In this study, a new method is suggested in order to consider the overshadowing effect. A building is overshadowed either by other buildings (or part of the main building) or trees. In the case that a building is overshadowed by other buildings, the solar irradiance could be completely masked. Trees planted near a building could patricianly overshadow. In order to consider the overshadowing effect on solar gain, the following steps are to be carried out:

- Firstly, the probability of sunshine diagram is drawn using a method which is proposed by British Standards (BS no. 8206-Lighting for Building) in order to assess the period that other building and trees are masking solar irradiance.

- Secondly, if solar irradiance is masked by other buildings or part of the main building itself, the amount of solar irradiance over the overshadowed period is considered zero. If solar irradiance is masked by trees, the amount of solar irradiance over the overshadowed period depends on the type of trees. Trees transmit different amount of solar irradiance according to their density which is represented as shading coefficient. Therefore, solar irradiance over the overshadowed periods should be multiplied by shading coefficient of the trees which obscures the main building. MacPherson (1984) proposes the shading coefficients (percentage of transmission) of different types of trees.

Thus, in order to calculate the solar gain, the 'external solar radiation' should be adjusted. An example of this adjustment can be seen in 'Scenario 1, 2 and 3 in chapter three '. Thus a modified solar gain formula is suggested as follow:

Solar gain =

[(Window Area x External solar radiation (considering the overshadowing effect) x Shading Coefficient)] / Perimeter zone.

6.3. Limitations

There were two limitations in this study that are explained as follows:

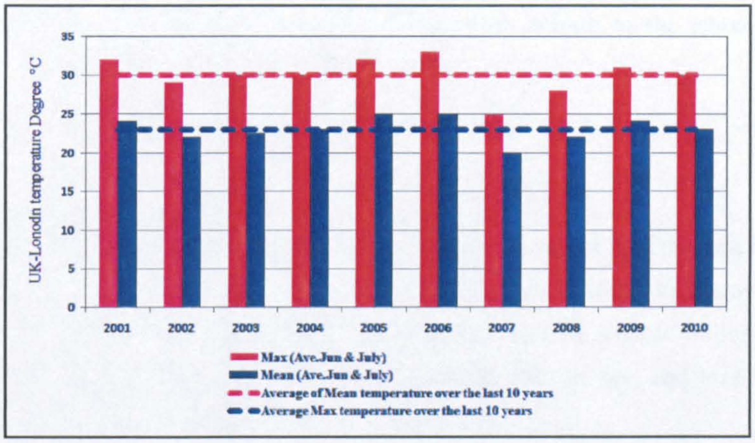
6.3.1 First limitation

One of the main focuses of this study is on overheating in primary school classrooms which are located under the Heathrow Airport flight path in the summer duration of an academic year (June and July). As explained in chapter 3 of this research, indoor temperature is mainly affected by building and climate factors. The building factors refer to solar gain, thermal mass level, ventilation and internal gain. The climate factors are mainly related to the outside temperature and solar irradiance.

Carrying out such a research in a warm summer provides an opportunity to more clearly study the impact of building factors on indoor temperature. The summers in which this research was mainly carried out (i.e. June & July 2007 & 2008) were not warm summers. In fact they could be categorised as the coldest summers during the last 10 years.

The following graph (Graph 6.6) shows the mean and maximum London temperatures for the last 10 years. As can be seen, the temperatures in June & July of the years of 2007 & 2008 are the least, and far less than average.

It can therefore be concluded that one of the limitations of this study is related to the cold summers in the years of 2007& 2008, as the majority of this study was carried out in these two years as opposed to 2005. However, it should be noted that despite the coldest summers (2007 & 2008) in the last 10 years, the classrooms still experienced overheating during these months.



Graph 6.6: June and July London temperatures during last 10 years

6.3.2. Second limitation

One of the main factors that control overheating in buildings is the usage of heavy thermal mass material. It would have been useful to study Victorian buildings (which are of a heavy thermal mass), but there were none located under the flight path. A study on such buildings would have shown how heavy thermal mass building may compensate the lack of ventilation in removing excessive heat.

6.4. Further research

Further research could be divided in two parts:

6.4.1. Part 1

Further research could be carried out in order to spot any other current conflicts between comfort factors inside classrooms (which reduce environmental comfort conditions), and also to assess schools and classrooms in terms of their potential to experience any conflicts between comfort issues in the future.

It is suggested that a further section is incorporated to the comfort sections of the existing design assessment tools, to evaluate the **current and future** potential conflicts between comfort issues in buildings.

In order to assess the potential future conflicts in the design stage many questions such as the followings are required to be answered:

- What will be the future road development around the schools that may have impacts on schools' background noise?
- What will be the future buildings developments around the schools (specifically their possible height should be considered) that may have impacts on the schools' potential to have both natural ventilation and natural light?

6.4.2. Part 2

The overheating control techniques which were mentioned in chapter 3 of this research should be assessed for the schools under study by simulation software in order to discover how these techniques can decrease the overheating risks in the future life of the schools' buildings, especially for the ones located under the flight path. It is beneficial that the cost and feasibility of these techniques are assessed.

Chapter 7: Conclusion

Conclusion:

As per the results of literature review, it can be concluded that providing good environmental condition has a significant impact on children's performance and also their health.

Good environmental condition in this study refers to providing thermal comfort, lighting comfort, acoustic comfort and air quality. Providing all of them together is critical as they are interrelated with each other and could conflict if they are considered separately, if the conditions over the life of the building change or the relaxed benchmarks are used to design in the first stage.

As a result of this study, it can be suggested that the two main reasons for poor environmental conditions are, firstly, the conflict between comfort factors (thermal, lighting, acoustic comfort and air quality) as they are interrelated and secondly, the use of the relaxed thermal, air quality, acoustic and lighting benchmarks.

One kind of conflict that is mentioned in this study is the conflict between acoustic comfort with thermal comfort and air quality. It was objectively and subjectively proven that occupants of the schools which are located under the Heathrow Airport flight path keep their windows closed (to prevent external noise from entering classrooms) during subjects that need extra concentration such as maths, science & literacy and also silent and lecturing activities. Due to this fact, schools located under the flight path have a lower potential to have natural ventilation through windows and consequently have a higher risk to experience overheating and poor air quality.

The overriding conclusion of this study is that window is not a sufficient means of natural ventilation for schools which are located under flight paths, to keep indoor temperature at a comfortable level and provide fresh air. Due to global warming, according to the current set of UK climate scenarios, it is predicted that average temperature during summers will increase by 7°C by the end of this century. This will have a significant impact on overheating in naturally ventilated schools. In addition, the lack of ventilation due to aircraft noise will be added to this problem and causes the classrooms to be overheated more significantly in the future.

One of the techniques to control the impact of global warming on overheating in London primary schools is to produce the cool island effect on a small scale by planting vegetation, trees and usage of water. Wind also boosts the benefits of Cool Island effect (due to the fact that wind speed is considerably high in London). As natural ventilation through windows is not possible in the schools which are located under the flights, it is possible to reduce the overheating risk by controlling solar gain, internal gain, design lay-out and by use of heavy thermal mass material instead of low and medium ones. Each of the mentioned factors can be controlled as follows:

- Solar gain should be controlled by introducing shading strategies during summer (but not winter). It should be noted that the direction and shading should be designed in such a way so as not to cause glare or reduce daylight factor. The solar radiation which enters the space from the east and west window causes higher glare and overheating than the north and south, if the windows are not controlled.

- The heavy thermal mass surfaces should be used in summer to store the excessive heat and covered up (e.g. carpet) during winter.
- Internal gain could be controlled by selecting the equipment and lighting systems which produce lower levels of heat.

As mentioned earlier, the ventilation rate which is needed to remove heat is higher than that required to remove CO_2. For this reason, it is beneficial to use different techniques of natural ventilation to remove excessive heat. Night time ventilation could be a solution for thermal comfort purposes for overheating risk reduction to provide thermal comfort for classrooms which are located under the flight paths. As control of ventilation is one of the methods of controlling overheating, it is possible to reduce the overheating risk by controlling solar gain, internal gain, design layout and by the use of heavy thermal mass material instead of low and medium ones.

Ventilation shafts may be adapted as a suitable means of ventilation for both purposes of thermal comfort and fresh air. The ventilation shafts which are proposed by different companies can be a suitable solution to provide air quality for schools located under flight paths, as they have the ability to attenuate the noise level by up to 30dB. For this reason, they can be adapted for such classrooms within the noise counter of less than 65dB to meet the recommended background noise level of 35dB (Table 7.1).

Figure 7.1: Noise contours map of Hounslow Borough

Aircarft nosie	Attentiation level	Noise level inside
57 Leq	30 Leq	27 Leq
60 Leq	30 Leq	30 Leq
63 Leq	30 Leq	33 Leq
69 Leq	30 Leq	39 Leq
72 Leq	30 Leq	42 Leq

Table 7.1: Internal aircraft noise after attenuation by ventilation shaft

For schools which are located on the noise counter of higher than 65dB, mechanical ventilation systems need to be adapted for providing good air quality. It should be noted that excessive care should be taken into account to ensure that the level of noise produced by mechanical ventilation is lower than the recommended benchmarks for the background noise level, and also the system do not make high drafts that make the occupants uncomfortable in situations where classrooms require the purge ventilation of 8 l/s per person.

In addition, in this study it has been shown that the school overheating benchmarks which are proposed by Building Bulletin are the most relaxed ones (among the fixed benchmarks) in comparison to the benchmarks proposed by other organisations. This may be one of the reasons that the UK classrooms designed based on BB101 criteria suffer from overheating.

Furthermore, it has been suggested in this study, that the occupants' satisfaction from indoor temperature is more correlated to the adaptive rather than the fixed thermal comfort. Therefore, there is a gap between predicting thermal comfort (based on the fixed model) and actual occupants' feeling inside a classroom.

It may therefore be beneficial to replace the fixed models with the adaptive model (considering Nicol overheating criteria) as it better represents the occupants feeling regarding thermal comfort. Nicol's criterion is not only designed based on adaptive model which has a better relation with occupants' feeling, but also provides detailed information regarding overheating by predicting the percentage of people who may feel overheated and considers the type of occupants inside classrooms, while overheating criteria based on the fixed model only determine whether the classrooms are overheated or not.

It is suggested that the current building design thermal benchmark (i.e. BB101) for the UK primary schools to be revised considering Nicol's formula.

Appendices

Appendix 1: Selecting samples:

- **Appendix 1.A:**

Corresponding with Hounslow Council:

Request

FROM: Azadeh

TO: rob.gibson@hounslow.gov.uk +

Dear Mr. Gibson

It was nice to speak with you on the phone yesterday afternoon. As I mentioned, I am a PhD student of London metropolitan university and I would be delighted if you answer my question as soon as you can,

For my Master research I was looking at the reasons of overheating in London primary school, especially the ones which suffer from aircraft noise.
In this research it was found that schools which are located in noisy areas such as near Heathrow Airport suffer from overheating more than those in quiet areas. The reason is partly due to the student's preference to keep the windows closed most of the time to get rid of air craft noises.

Currently for my PhD thesis I want to look at the level of ventilation and conflict between aircraft noise and comfort internal temperature, therefore I must concentrate on the environmental condition of Hounslow primary schools in depth.

I read an article with the title of "Multilevel modeling of aircraft noise on performance test in schools around Heathrow Airport London" which was written with M M Haines, S A Stansfeld, J Head, R F S Job.
In the 2nd table of this research, Hounslow primary schools classified in two categories: 29 of them located in area with moderate level of noise & 16 of them located in area with high level of noise.

It would be extremely helpful if you let me know the name of the primary schools that face high levels and moderate level of aircraft noise.

I would be happy to give a copy of my research to the council after it's finished, if it will be of any interest.

Many thanks,

Azadeh

RE: Request 1 Hide Details

FROM: Rob Gibson Tuesday, 27 February 2007, 11:52

TO: Azadeh

CC: John Mundy

http://www.hounslow.gov.uk/index/education_and_learning/schools_and_colleges

Dear Azedeh

Further to your e-mail below.

The link above takes you to a webpage with the contact details of all Hounslow schools.

The particular schools I think you may be interested in are as follows

Primary Schools

Beavers Community School
Bedfont Junior School
Chatsworth Infants and Nursery School
Cranford Junior School
Grove Park Primary School
Hounslow Heath Junior School
Norwood Green Junior School
Orchard Infants and Nursery School
Springwell Infants and Nursery School
St Michael's and St Martin's Primary School
Wellington Primary School

Secondary Schools

Cranford Community School
Lampton at Secondary School

Marjory Kinnon School
the Cedars Primary School

These are the schools that we consider to be the noisiest in the borough.

In relation to your project generally, this is of great interest to the Council as we are continually striving to improve the facilities we offer to children and demonstrate the effect Heathrow has on the borough. You should be aware that the council successfully lobbied for improvements to our schools in relation to noise insulation through the Air Transport White Paper December 2003, paragraph 3.21.

In response to this the airports operator, BAA, has set up a community noise insulation programme and I have included the websites address below. I believe this group will be considering ventilation issues.

http://www.heathrowairport.com/portal/controller/dispatcher.jsp?
CiID=30ca6e9c812fc010VgnVCM10000036821c0a____&CtID=448c6a4c7f1b0010VgnVCM200000357e120a____&Ct=B2C_CT_GENERAL&R
ootCh=About%20BAA%
20Heathrow&Ch=Community+insulation+board&ChID=fe486e9c812fc010VgnVCM10000036821c0a____&ChPath=LHR%
5EAbout+BAA+Heathrow%5ECommunity+insulation+board&ChIDPath=bde597dc2eb12010VgnVCM100000147e120a____%
5E815797dc2eb12010VgnVCM100000147e120a____%5Efe486e9c812fc010VgnVCM10000036821c0a____

It may be worth contacting them, at the very least to establish what their programme of work is, so that you can programme your work around this, if appropriate.

Whilst we are all quite busy here at the council I am more than happy to offer further assistance with your project, mainly in terms of contacts within our education department and/or BAA if this would be of any help.

I would also be very interested to see the results of your work.

Finally I have copied in my colleague, Mr John Mundy, part of his role is to look at school buildings a with respect to noise etc so he may go to offer more assistance.

Please do not hesitate to contact me again if you think I can assist further in any way.

Regards

Rob Gibson -- Head of Environmental Strategy, London Borough of Hounslow

- **Appendix 1.B:**

List of quiet schools from Shield study:

Borough	School	LAeq @ 4m	Lmax @ 4m	minL @ 4m	L99 @ 4m	L90 @ 4m	L10 @ 4m	subjective impression	Occupied teaching space LAeq	Unoccupied teaching space LAeq	Corridor or foyer LAeq
Haringey	Coleraine Park Primary	50.1	64.7	42.5	44.5	46	52.5	quiet	74.6	47.5	
Haringey	Ferry Lane Primary	54	65.1	48.2	49.5	48.5	56.5	quiet	70.7	53.4	48.1
Haringey	Lordship Lane Infants & Juniors	48.7	55.9	46.7	47	47.5	49.5	quiet	71.9	50.5	
Haringey	St Gildas' RC Juniors	56.6	71.7	42.1	42.5	44	60.5	quiet	65.2		47
Haringey	St Ignatius' RC Primary	75	92.8	53.7	54	59.5	77	noisy	68.7	41.2	50.1
Haringey	St Paul & All Hallows CE Infants & Juniors	50.5	61.3	40.4	42.5	45	53.5	quiet	76.9	60.6	55.1
Haringey	Stamford Hill Primary	59.5	74.9	51.1	52	54	61	quiet	72.9	47.4	53.7
Haringey	The Green CE Primary	56.7	67.9	51.2	52	53.5	58.5	quiet	73.7	52.2	50.5
Islington	Ambler Primary	67.8	80.9	47.5	49	52	71.5	quiet	70.4	46.4	66.2
Islington	Ashmount Primary	59.9	73.9	37	37.5	43	64	quiet	65.8	50.2	48.1
Islington	Blessed Sacrament RC Primary	67.5	59.7	47.4	52.3	54.8	70.5	quiet	70.7	54.1	61.8
Islington	Hungerford Primary	51	60.1	47.2	47.3	48.3	52.8	quiet	69.5	37.8	61.2
Islington	Pooles Park Primary	57.9	75.1	44.4	45.5	46.5	58.5	quiet	70.2		59.6
Islington	St John's CE Primary, N19	66.2	79.9	54.7	56	58.3	68.6	quiet	65.2	44.7	79.7
Islington	St John's CE Primary, N5	62.9	83.9	47.3	47.8	49.3	61.3	quiet	67.7	37	51
Islington	St Luke's CE Primary	59.8	74.2	51.4	51.5	52.5	61.5	quiet	70.4	61.7	50.3

Table 8-1: List of quiet schools from shield study

- **Appendix.2: Questionnaires**
  - Appendix 2.1: Teachers' questionnaires

Classroom Evaluation

This survey is being conducted to help with future planning and design of classroom and primary School. The information collected will be treated as completely confidential by the survey team . Surveys report will use summaries of information and not reveal the identities is individuals .
Please answer for this classroom. Please fill as many questions as you can. Write any future comments is the space provided or on a separate sheet. Thank you for your help .

Queries :
If you have any queries please contact : Azadeh Montazami
Email: azadeh_mo79@yahoo.co.uk

Background

We ask the name of schools and classrooms so that we can follow up any matters that arise

- Please give the name of your school ☐
- Please give the name of your classroom ☐
- How long have you worked in this school ? Less than a year ☐ A year or more ☐
- How long have you worked in classroom? Less than a year ☐ A year or more ☐
- How many days do you spend in classroom in a normal working week ? ☐
- How many hours per day do you spend in school in a normal working week ? ☐
- How many hours per day do you spend in classroom in a normal working week ? ☐
- How many hours per day do you normally spend working with a computer screen (VDU)? ☐
- Does your classroom have cooling system for summer ? Yes ☐ No ☐
- Do you sit next to a window at your classroom ? Yes ☐ No ☐

Comfort : Acoustic Comfort

- How would you describe noise from inside your school in your classroom in summer term?

		1	2	3	4	5	6	7	
Noise overall in your classroom	Too little								Too much
Noise from students (inside classroom)	Too little								Too much
Other noise from inside classroom	Too little								Too much
Noise from outside classroom	Too little								Too much

- How would you describe the noise from outside school in your classroom in summer term?

		1	2	3	4	5	6	7	
Noise overall from outside school	Too little								Too much
Noise from Cars	Too little								Too much
Noise from Aircraft	Too little								Too much
Noise from Lorries	Too little								Too much
Noise from Buses	Too little								Too much
Noise from Railway	Too little								Too much
Noise from Other	Too little								Too much

- Please estimate how you are affected by unwanted interruptions ...

Not at all 1 2 3 4 5 6 7 Very frequently

- How well can your students hear you ?

1	2	3	4	5
not at all	not very well	okay	quite well	very well

- How well can you hear your students ?

1	2	3	4	5
not at all	not very well	okay	quite well	very well

Comfort : Thermal Comfort

- How would you describe thermal comfort in your classroom in summer term ?

Temperature in Summer

	1	2	3	4	5	6	7	
Comfortable								Uncomfortable
Too cold								Too hot
Varies during the day								Stable

Air in summer

	1	2	3	4	5	6	7	
Still								Draughty
Dry								Humid
Fresh								Stuffy
Odourless								Smelly

Condition in Summer

	1	2	3	4	5	6	7	
Satisfactory Overall								Unsatisfactory Overall

Comfort : Lighting Comfort

- How would you describe the quality of lighting in your classroom in summer term?

		1	2	3	4	5	6	7	
Lighting overall	Unsatisfactory								Satisfactory
Natural light	Too little								Too much
Glare from sun and sky	None								Too much
Artificial light	Too little								Too much
Glare from lights	None								Too much

Do you have blinds on your widow ? Yes ☐ No ☐

How often do you put the blinds down ?

Never 1 2 3 4 5 6 7 Always

What is the main reason for putting the blind down ?

☐ A : Prevent inisde from direct solar gain which cause over heating
☐ B : Prevent inisde from direct solar gain which cause glare
☐ C : Both A & B

Overall comfort

• All things considered, how do you rate the overall comfort of the classroom

Please tick one point on the scale

Unsatisfactory	1	2	3	4	5	6	7	Satisfactory

Productivity at classroom

• Please estimate how you think **your** productivity at classroom is decreased or increased by the environmental conditions in the classroom ?

Please tick one point on the scale

	-40% or less	-30%	-20%	-10%	0	+10%	+20%	+30%	+40% or less	
Productivity Decreased by...	1	2	3	4	5	6	7	8	9	Productivity Increased by ...

• Please estimate how you think **students** productivity at classroom is decreased or increased by the environmental conditions in the classroom ?

Please tick one point on the scale

	-40% or less	-30%	-20%	-10%	0	+10%	+20%	+30%	+40% or less	
Productivity Decreased by...	1	2	3	4	5	6	7	8	9	Productivity Increased by ...

Health

• Do you feel less or more healthy when you are in the classroom ?

Less healthy	1	2	3	4	5	6	7	More healthy

Personal control

• How much control do you personally have over the followind aspect of your working environment ... ?

Please tick one point on the scale

										Importance of control (Please tick if important to you)
Cooling	No Control	1	2	3	4	5	6	7	Full Control	1
Ventilation	No Control	1	2	3	4	5	6	7	Full Control	1
Lighting	No Control	1	2	3	4	5	6	7	Full Control	1
Noise	No Control	1	2	3	4	5	6	7	Full Control	1

Thank you for your help

If you have future comments on the topics raised, please add them on a separate sheet .

• Please write any future comments is this space.

- **Appendix 2.2 : Students' Y1 to Y3 questionnaires**

Dear Miss ……

Please ask your student to voting the following question by raising their hand.

- **How well can you concentrate when airplane passes over the school?**
- **Are you distracted when airplane passes over the school?**
- **Are you distracted when noise coming from other classroom?**
- **Are you distracted when noise coming from hall and play ground?**
- **Are you distracted when classroom become warm?**

Imagine you must choose to go one of the following classrooms, which one would you pick?

A. **A quiet classrooms , No aircraft noise but warm and stuffy**
B. **A cool (Pleasant) classroom but hears the aircraft noise time to time.**

Thank you for helping me with my project!

- **Appendix 2.3 : Students' Y4 to Y6 questionnaires**

Noise and Temperature Project

My Project is about noise and temperature inside your classroom. I would like to you help me by filling this worksheet for me.

Read the question and put a tick √ inside the box to show your answer.

1-Are you a boy or a girl? **A. Boy** ☐ **B. Girl** ☐

2-How often do you get distracted from your activities by noise coming from other classrooms?

A. Never ☐ **B. Sometimes** ☐ **C. Often** ☐ **D. Always** ☐

3-How well you can concentrate when you hear the noise from other classroom?

very well	well	ok	not very well	not at all

4-How often do you distracted from your activities when noise is coming from the hall or playground?

A. Never ☐ **B. Sometimes** ☐ **C. Often** ☐ **D. Always** ☐

5-How well you can concentrate when you hear the noise from the hall and the playground?

very well	well	ok	not very well	not at all

6. How often you distracted from your activities when an airplane passes over the school?

A. Never ☐ B. Sometimes ☐ C. Often ☐ D. Always ☐

7. You're in your classroom and you are listening to your teacher. An airplane passes over the school. How well can you hear your teacher?

very well	well	ok	not very well	not at all

8. You are doing a quiet activity and it needs concentration (e.g. reading a book, doing a math exercise). An airplane passes over the school. How well can you can concentrate?

very well	well	ok	not very well	not at all

9. Have you ever asked your teacher to close the window during summer terms because you were annoyed by aircraft noise?

A. Yes ☐ B. No ☐ If yes, how many times?

10. Which year were you in when you first started attending this school?

☐

12. Do you hear aircraft noise at home?

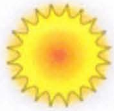
A. Yes ☐ B. No ☐

13. If you hear the aircraft noise at home, please write how many years have you been living at that address?

☐

14. Do you think you are used to the aircraft noise?

A. Yes ☐ B. No ☐



15. How often your classrooms become hot and stuffy during summer?

A. Never ☐ B. Sometimes ☐ C. Often ☐ D. Always ☐

16. How well you can concentrate when the classroom becomes hot and stuffy during summer ?

very well	well	ok	not very well	not at all

17. Have you ever asked your teacher to open the window during summer term because you were annoyed by overheating?

A. Yes ☐ B. No ☐ If yes, how many times?

18. Imagine you must choose to go one of the following classrooms, which one would you pick?

A. A quiet classrooms, No aircraft noise but warm and stuffy ☐

B. A cool classroom but hear the aircraft noise time to time ☐

Thank you for helping me with my project!

Appendix.3: Solar irradiance data

Maximum hourly beam, diffuse solar irradiances on different surfaces from Jan-Dec

Date and times of sunrise/sunset	Orient-ation	Type	Daily mean irradiance (/ W·m⁻²) and mean hourly irradiance (/ W·m⁻²) for stated solar time*																		
			Mean	0330	0430	0530	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830	1930	2030
Jan 29	Normal to beam		156		—	—	—	104	288	466	593	617	612	507	363	224	81	—	—	—	—
	N	Beam	0	—	—	—	—	0	0	0	0	0	0	0	0	0	0	—	—	—	—
Sunrise: 07:37		Diffuse	15	—	—	—	—	9	23	40	53	61	62	57	42	24	10	—	—	—	—
Sunset: 16:23	NE	Beam	1	—	—	—	—	23	22	0	0	0	0	0	0	0	0	—	—	—	
		Diffuse	16	—	—	—	—	25	29	45	53	61	62	57	42	24	10	—	—	—	—
	E	Beam	34	—	—	—	—	88	217	269	215	77	0	0	0	0	0	—	—	—	—
		Diffuse	23	—	—	—	—	34	80	99	94	72	71	57	42	24	10	—	—	—	—
	SE	Beam	98	—	—	—	—	101	285	449	521	460	349	186	53	0	0	—	—	—	—
		Diffuse	36	—	—	—	—	37	97	135	149	146	128	101	57	27	10	—	—	—	—
	S	Beam	130	—	—	—	—	55	186	365	522	574	569	447	285	145	43	—	—	—	—
		Diffuse	43	—	—	—	—	28	72	118	150	166	169	157	114	70	32	—	—	—	—
	SW	Beam	89	—	—	—	—	0	0	68	217	352	456	446	350	222	79	—	—	—	—
		Diffuse	35	—	—	—	—	9	26	54	95	126	148	157	129	92	42	—	—	—	—
	W	Beam	28	—	—	—	—	0	0	0	0	0	76	184	210	169	69	—	—	—	—
		Diffuse	23	—	—	—	—	9	23	40	53	70	73	101	97	77	39	—	—	—	—
	NW	Beam	1	—	—	—	—	0	0	0	0	0	0	0	0	17	18	—	—	—	—
		Diffuse	16	—	—	—	—	9	23	40	53	61	62	57	47	30	29	—	—	—	—
	Horiz.	Beam	42	—	—	—	—	3	34	106	180	213	211	154	82	26	2	—	—	—	—
	Horiz.	Diffuse	24	—	—	—	—	19	41	65	77	87	89	91	74	47	22	—	—	—	—
	Horiz.	Global	66	—	—	—	—	22	75	171	257	300	300	245	156	73	24	—	—	—	—
Feb 26	Normal to beam		201	—	—	—	67	210	375	503	605	647	636	608	552	426	238	77	—	—	—
	N	Beam	0	—	—	—	0	0	0	0	0	0	0	0	0	0	0	0	—	—	—
Sunrise: 06:46		Diffuse	26	—	—	—	9	23	44	68	82	92	90	82	66	44	22	9	—	—	—
Sunset: 17:14	NE	Beam	6	—	—	—	32	77	57	0	0	0	0	0	0	0	0	0	—	—	—
		Diffuse	28	—	—	—	26	49	59	79	82	92	90	82	66	44	22	8	—	—	—
	E	Beam	46	—	—	—	64	192	294	302	229	83	0	0	0	0	0	0	—	—	—
		Diffuse	37	—	—	—	34	81	115	138	130	103	102	82	66	44	22	8	—	—	—
	SE	Beam	106	—	—	—	59	194	358	466	509	454	330	185	42	0	0	0	—	—	—
		Diffuse	49	—	—	—	32	81	129	173	184	181	155	121	71	49	22	8	—	—	—
	S	Beam	145	—	—	—	18	83	213	358	491	558	549	489	392	242	94	21	—	—	—
		Diffuse	57	—	—	—	24	50	97	150	181	201	196	179	146	99	51	24	—	—	—
	SW	Beam	111	—	—	—	0	0	0	39	185	336	446	507	512	407	220	67	—	—	—
		Diffuse	49	—	—	—	8	23	49	74	121	158	177	183	170	133	85	32	—	—	—
	W	Beam	50	—	—	—	0	0	0	0	0	0	82	228	332	334	217	74	—	—	—
		Diffuse	37	—	—	—	8	23	44	68	82	104	101	129	135	118	84	34	—	—	—
	NW	Beam	7	—	—	—	0	0	0	0	0	0	0	0	0	65	87	37	—	—	—
		Diffuse	30	—	—	—	8	23	44	68	82	92	90	129	77	59	49	26	—	—	—
	Horiz.	Beam	75	—	—	—	1	24	95	184	270	336	311	269	202	108	27	1	—	—	—
	Horiz.	Diffuse	40	—	—	—	18	44	77	109	121	131	129	120	100	73	42	18	—	—	—
	Horiz.	Global	115	—	—	—	19	68	172	293	391	447	440	389	302	181	69	19	—	—	—
Mar 29	Normal to beam		263	—	—	70	221	385	524	610	649	696	683	663	631	552	415	238	76	—	—
	N	Beam	0	—	—	5	0	0	0	0	0	0	0	0	0	0	0	0	5	—	—
Sunrise: 05:43		Diffuse	41	—	—	27	30	53	77	96	112	119	120	112	96	75	51	28	24	—	—
Sunset: 18:17	NE	Beam	20	—	—	53	145	180	131	12	0	0	0	0	0	0	0	0	0	—	—
		Diffuse	45	—	—	35	72	97	107	90	118	119	120	112	96	75	49	24	9	—	—
	E	Beam	72	—	—	70	219	355	415	371	248	90	0	0	0	0	0	0	0	—	—
		Diffuse	57	—	—	41	93	136	167	169	160	128	135	112	96	75	49	24	9	—	—
	SE	Beam	117	—	—	46	165	322	455	513	489	426	293	141	0	0	0	0	0	—	—
		Diffuse	65	—	—	33	78	129	176	196	205	194	173	136	117	79	49	24	9	—	—
	S	Beam	139	—	—	0	14	100	229	354	443	512	503	453	367	241	108	15	0	—	—
		Diffuse	67	—	—	11	32	78	129	166	196	210	210	196	165	126	75	30	10	—	—
	SW	Beam	121	—	—	0	0	0	0	0	138	298	418	499	531	480	347	177	59	—	—
		Diffuse	65	—	—	9	26	51	80	118	137	172	195	204	195	172	126	75	39	—	—
	W	Beam	75	—	—	0	0	0	0	0	0	0	89	253	384	437	383	236	76	—	—
		Diffuse	56	—	—	9	26	51	77	96	112	134	129	159	168	164	134	91	37	—	—
	NW	Beam	22	—	—	0	0	0	0	0	0	0	0	0	12	138	194	156	57	—	—
		Diffuse	45	—	—	9	26	51	77	96	112	119	120	118	89	104	94	70	32	—	—
	Horiz.	Beam	131	—	—	2	28	110	223	330	404	462	454	413	341	235	118	30	2	—	—
	Horiz.	Diffuse	59	—	—	21	50	87	120	139	158	161	163	155	135	113	81	46	19	—	—
	Horiz.	Global	190	—	—	23	78	197	343	469	562	623	617	568	476	348	199	76	21	—	—

* Mean over hour centred at stated solar time

Table 8.2: Design 97.5 percentile of beam and diffuse irradiance on vertical and horizontal surfaces: London area (Bracknell) (1981–1992) (Jan-March) extracted from CIBSE Guide A (2006)

Date and times of sunrise/sunset	Orientation	Type	Daily mean irradiance (/ W·m⁻²) and mean hourly irradiance (/ W·m⁻²) for stated solar time*																	
			Mean	0330	0430	0530	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830	1930	2030
Apr 28	Normal to beam		343	—	74	235	440	555	674	707	744	765	761	740	724	655	568	408	218	69	—
	N	Beam	7	—	27	59	24	0	0	0	0	0	0	0	0	0	0	22	55	26	—
Sunrise: 04:46		Diffuse	56	—	25	43	53	87	101	117	130	139	141	131	120	100	88	52	41	25	—
Sunset: 19:14	NE	Beam	47	—	68	202	316	298	220	71	0	0	0	0	0	0	0	0	0	0	—
		Diffuse	64	—	33	86	123	142	142	119	145	139	141	131	120	100	77	47	22	8	—
	E	Beam	103	—	69	226	423	497	519	417	276	96	0	0	0	0	0	0	0	0	—
		Diffuse	74	—	34	93	146	183	196	185	171	143	155	131	120	100	77	47	22	8	—
	SE	Beam	128	—	29	118	282	405	513	519	483	392	253	92	0	0	0	0	0	0	—
		Diffuse	77	—	25	61	115	164	195	202	205	196	179	136	138	100	77	47	22	8	—
	S	Beam	122	—	0	0	0	76	207	317	407	458	465	404	324	202	78	0	0	0	—
		Diffuse	74	—	8	24	57	90	139	168	192	207	212	194	174	138	91	56	23	8	—
	SW	Beam	127	—	0	0	0	0	0	0	92	255	390	480	531	499	415	262	109	27	—
		Diffuse	77	—	8	23	48	77	101	134	135	175	201	207	210	192	165	110	58	25	—
	W	Beam	101	—	0	0	0	0	0	0	0	0	97	275	427	504	509	392	210	64	—
		Diffuse	74	—	8	23	48	77	101	117	130	152	146	173	192	193	184	139	86	34	—
	NW	Beam	45	—	0	0	0	0	0	0	0	0	0	0	73	214	305	293	187	63	—
		Diffuse	64	—	8	23	48	77	101	117	130	139	141	146	122	140	143	117	80	33	—
	Horiz.	Beam	199	—	1	26	119	235	377	475	558	605	602	555	486	367	240	110	25	1	—
	Horiz.	Diffuse	73	—	18	44	80	117	138	151	163	170	177	166	157	138	116	80	43	18	—
	Horiz.	Global	272	—	19	70	199	352	515	626	721	775	779	721	643	505	356	190	68	19	—
May 29	Normal to beam		386	—	145	350	482	580	685	753	787	794	793	787	758	693	623	511	371	154	—
	N	Beam	22	—	73	114	66	0	0	0	0	0	0	0	0	0	0	70	120	78	—
Sunrise: 04:01		Diffuse	68	—	49	72	77	108	116	126	137	143	142	134	125	113	104	73	68	43	—
Sunset: 19:59	NE	Beam	63	—	140	308	360	333	255	117	0	0	0	0	0	0	0	0	0	0	—
		Diffuse	74	—	64	121	144	159	154	136	159	143	142	134	125	108	87	60	36	15	—
	E	Beam	112	—	125	323	444	498	505	426	280	96	0	0	0	0	0	0	0	0	—
		Diffuse	81	—	59	124	162	191	197	188	170	145	153	134	125	108	87	60	36	14	—
	SE	Beam	117	—	36	148	268	372	460	486	443	343	207	47	0	0	0	0	0	0	—
		Diffuse	80	—	44	81	125	167	189	197	194	184	165	126	134	108	87	60	36	14	—
	S	Beam	98	—	0	0	0	28	145	261	347	389	388	347	262	147	30	0	0	0	—
		Diffuse	72	—	16	39	72	89	133	163	180	191	190	177	159	128	85	68	37	14	—
	SW	Beam	120	—	0	0	0	0	0	0	47	207	343	443	489	465	399	284	157	38	—
		Diffuse	79	—	16	39	64	90	111	137	128	165	184	190	193	183	160	118	76	39	—
	W	Beam	116	—	0	0	0	0	0	0	0	0	96	280	429	511	535	471	342	132	—
		Diffuse	80	—	16	39	64	90	111	126	137	153	145	168	184	191	184	153	117	53	—
	NW	Beam	66	—	0	0	0	0	0	0	0	0	0	0	118	258	357	382	327	149	—
		Diffuse	74	—	17	39	64	90	111	126	137	143	142	157	134	149	153	136	114	56	—
	Horiz.	Beam	243	—	10	74	175	296	439	564	649	685	685	649	567	444	318	186	79	10	—
	Horiz.	Diffuse	77	—	33	70	101	133	146	153	156	162	161	153	146	140	121	91	63	29	—
	Horiz.	Global	320	—	43	144	276	429	585	717	805	847	846	802	715	584	439	277	142	39	—
Jun 21	Normal to beam		414	64	191	387	554	683	747	797	826	837	840	809	771	705	639	531	390	192	65
	N	Beam	27	40	100	132	85	0	0	0	0	0	0	0	0	0	0	82	133	100	40
Sunrise: 03:49		Diffuse	71	25	55	76	85	111	117	125	134	139	140	135	127	121	114	85	77	58	25
Sunset: 20:11	NE	Beam	74	64	185	342	417	397	285	134	0	0	0	0	0	0	0	0	0	0	0
		Diffuse	77	32	72	124	157	158	150	134	158	139	140	135	127	113	94	69	42	21	9
	E	Beam	124	50	162	352	504	579	544	445	290	100	0	0	0	0	0	0	0	0	0
		Diffuse	83	27	66	126	175	189	189	180	163	140	149	135	127	113	94	69	42	20	8
	SE	Beam	122	7	44	155	296	422	484	496	447	345	204	36	0	0	0	0	0	0	0
		Diffuse	79	21	50	82	133	163	180	187	183	173	157	123	134	113	94	69	42	20	8
	S	Beam	94	0	0	0	0	18	141	256	342	387	389	335	247	133	17	0	0	0	0
		Diffuse	72	8	18	41	77	83	125	154	170	179	180	172	158	130	87	77	42	20	8
	SW	Beam	118	0	0	0	0	0	0	0	37	203	346	438	479	457	395	284	157	44	7
		Diffuse	80	8	18	41	69	91	110	132	122	156	175	185	193	188	169	133	83	52	21
	W	Beam	120	0	0	0	0	0	0	0	0	0	101	284	431	513	542	483	355	163	51
		Diffuse	83	8	18	41	69	91	110	125	134	148	140	165	185	197	196	175	128	69	27
	NW	Beam	71	0	0	0	0	0	0	0	0	0	0	0	130	269	371	399	345	186	65
		Diffuse	77	9	19	41	69	91	110	125	134	139	140	159	138	156	164	157	126	75	32
	Horiz.	Beam	264	1	17	91	214	362	493	610	694	735	738	679	590	465	339	205	92	18	1
	Horiz.	Diffuse	76	16	37	71	104	120	132	140	141	144	146	146	149	146	131	107	72	38	16
	Horiz.	Global	341	17	54	162	318	482	625	750	835	879	884	825	739	611	470	312	164	56	17

* Mean over hour centred at stated solar time

Table continues

Table 8.2 (continued): Design 97.5 percentile of beam and diffuse irradiance on vertical and horizontal surfaces: London area (Bracknell) (1981–1992) (Jan-March) extracted from CIBSE Guide A (2006)

Date and times of sunrise/sunset	Orient-ation	Type	Daily mean irradiance (/ W·m⁻²) and mean hourly irradiance (/ W·m⁻²) for stated solar time*																		
			Mean	0330	0430	0530	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830	1930	2030
Jul 4	Normal to beam		381	*57*	170	362	505	610	687	729	751	753	765	750	717	672	616	502	360	169	*57*
	N	Beam	24	*35*	88	122	75	0	0	0	0	0	0	0	0	0	0	74	121	87	*35*
Sunrise: 03:53		Diffuse	66	*20*	47	64	73	103	110	121	133	140	141	132	123	113	102	78	62	43	*18*
Sunset: 20:08	NE	Beam	67	*57*	165	320	379	353	260	119	0	0	0	0	0	0	0	0	0	0	*0*
		Diffuse	71	*25*	61	103	132	146	143	132	156	140	141	132	123	107	85	64	35	15	*6*
	E	Beam	114	*45*	145	331	461	519	502	409	265	90	0	0	0	0	0	0	0	0	*0*
		Diffuse	77	*22*	57	106	147	174	179	176	166	144	150	132	123	107	85	64	35	14	*5*
	SE	Beam	113	*7*	40	148	273	381	450	459	412	315	190	37	0	0	0	0	0	0	*0*
		Diffuse	76	*16*	43	69	113	151	171	183	186	179	162	124	131	107	85	64	35	14	*5*
	S	Beam	89	*0*	0	0	0	20	135	240	318	355	361	317	236	132	20	0	0	0	*0*
		Diffuse	70	*6*	16	35	67	81	121	152	173	185	186	172	156	124	80	71	35	14	*5*
	SW	Beam	112	*0*	0	0	0	0	0	0	37	187	320	411	451	440	385	272	147	40	*7*
		Diffuse	76	*6*	16	35	60	85	104	129	124	161	180	185	188	176	150	121	67	39	*15*
	W	Beam	113	*0*	0	0	0	0	0	0	0	0	92	264	402	491	524	459	329	144	*45*
		Diffuse	78	*6*	16	35	60	85	104	121	133	149	144	165	181	184	173	157	102	52	*20*
	NW	Beam	66	*0*	0	0	0	0	0	0	0	0	0	0	117	254	357	377	318	164	*57*
		Diffuse	72	*6*	17	35	60	85	104	121	133	140	141	155	135	147	145	141	100	56	*23*
	Horiz.	Beam	241	*0*	14	83	191	319	449	554	627	658	668	626	545	439	323	190	82	14	*0*
	Horiz.	Diffuse	75	*13*	31	60	90	116	130	143	154	162	162	153	150	137	114	97	58	29	*12*
	Horiz.	Global	315	*13*	45	143	281	435	579	697	781	820	830	779	695	576	437	287	140	43	*12*
Aug 4	Normal to beam		333	—	93	259	411	551	644	698	755	744	727	706	705	609	496	361	227	*82*	—
	N	Beam	10	—	*40*	73	36	0	0	0	0	0	0	0	0	0	0	32	64	*35*	—
Sunrise: 04:29		Diffuse	57	—	*33*	50	58	89	101	116	127	134	135	131	116	100	87	56	47	*32*	—
Sunset: 19:31	NE	Beam	49	—	*87*	225	301	305	222	86	0	0	0	0	0	0	0	0	0	*0*	—
		Diffuse	64	—	*44*	88	118	137	140	122	143	134	135	131	116	100	75	48	27	*11*	—
	E	Beam	101	—	*84*	245	389	486	488	406	276	93	0	0	0	0	0	0	0	*0*	—
		Diffuse	72	—	*43*	93	136	171	186	179	162	138	147	131	116	100	75	48	27	*11*	—
	SE	Beam	118	—	*31*	122	250	383	468	488	465	358	221	70	0	0	0	0	0	*0*	—
		Diffuse	74	—	*32*	62	107	152	182	192	189	182	166	133	130	100	75	48	27	*11*	—
	S	Beam	107	—	*0*	0	0	55	174	284	381	413	404	356	287	164	50	0	0	*0*	—
		Diffuse	70	—	*11*	28	59	84	131	160	177	190	198	187	159	131	83	55	28	*11*	—
	SW	Beam	113	—	*0*	0	0	0	0	0	74	226	350	434	493	442	345	219	107	*28*	—
		Diffuse	73	—	*11*	27	51	77	100	130	126	163	185	200	191	181	146	98	58	*31*	—
	W	Beam	94	—	*0*	0	0	0	0	0	0	0	91	258	410	461	438	342	215	*74*	—
		Diffuse	72	—	*11*	27	51	77	100	116	127	145	141	171	178	184	164	123	85	*41*	—
	NW	Beam	45	—	*0*	0	0	0	0	0	0	0	0	0	87	210	274	264	197	*77*	—
		Diffuse	64	—	*11*	27	51	77	100	116	127	134	135	149	121	140	133	107	80	*42*	—
	Horiz.	Beam	204	—	*4*	40	127	253	383	492	590	612	598	552	497	362	228	112	35	*3*	—
	Horiz.	Diffuse	72	—	*23*	51	84	113	136	147	148	159	166	167	146	140	116	82	50	*22*	—
	Horiz.	Global	276	—	*27*	91	211	366	519	639	738	771	764	719	643	502	344	194	85	*25*	—
Sep 4	Normal to beam		302	—	—	*139*	371	551	654	683	678	688	720	716	683	604	452	304	*114*	—	—
	N	Beam	1	—	—	*19*	0	0	0	0	0	0	0	0	0	0	0	0	*16*	—	—
Sunrise: 05:24		Diffuse	43	—	—	*30*	36	58	76	99	115	118	118	109	95	77	59	37	*33*	—	—
Sunset: 18:36	NE	Beam	34	—	—	*111*	252	272	182	32	0	0	0	0	0	0	0	0	*0*	—	—
		Diffuse	48	—	—	*40*	88	105	104	94	123	118	118	109	95	77	55	31	*12*	—	—
	E	Beam	93	—	—	*137*	365	505	515	412	257	89	0	0	0	0	0	0	*0*	—	—
		Diffuse	58	—	—	*45*	112	146	157	165	158	126	131	109	95	77	55	31	*12*	—	—
	SE	Beam	132	—	—	*84*	264	442	546	551	488	399	286	131	0	0	0	0	*0*	—	—
		Diffuse	64	—	—	*36*	90	135	162	188	197	182	159	123	113	79	55	31	*12*	—	—
	S	Beam	139	—	—	*0*	9	120	258	367	433	475	498	457	367	238	99	7	*0*	—	—
		Diffuse	64	—	—	*12*	32	76	117	158	187	194	190	175	150	119	77	34	*13*	—	—
	SW	Beam	125	—	—	*0*	0	0	0	0	124	273	418	515	551	505	363	217	*69*	—	—
		Diffuse	64	—	—	*11*	30	54	78	118	132	162	179	184	178	164	131	88	*39*	—	—
	W	Beam	85	—	—	*0*	0	0	0	0	0	0	93	272	412	475	414	299	*113*	—	—
		Diffuse	57	—	—	*11*	30	54	76	99	115	132	124	148	157	159	141	107	*49*	—	—
	NW	Beam	28	—	—	*0*	0	0	0	0	0	0	0	0	32	168	223	206	*91*	—	—
		Diffuse	48	—	—	*11*	30	54	76	99	115	118	118	116	90	107	104	85	*43*	—	—
	Horiz.	Beam	158	—	—	*7*	66	184	310	402	454	489	512	479	402	286	151	54	*6*	—	—
	Horiz.	Diffuse	56	—	—	*23*	51	79	99	128	150	153	145	134	120	107	88	57	*25*	—	—
	Horiz.	Global	214	—	—	*30*	117	263	409	530	605	642	657	613	522	393	239	111	*31*	—	—

* Mean over hour centred at stated solar time

Table continues

Table 8.2 (continued): Design 97.5 percentile of beam and diffuse irradiance on vertical and horizontal surfaces: London area (Bracknell) (1981–1992) (Jul-Sept) extracted from CIBSE Guide A (2006)

Date and times of sunrise/sunset	Orientation	Type	Daily mean irradiance (/ W·m⁻²) and mean hourly irradiance (/ W·m⁻²) for stated solar time*																		
			Mean	0330	0430	0530	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830	1930	2030
Oct 4	Normal to beam		237	—	—	—	148	381	551	679	700	644	632	605	568	451	312	121	—	—	—
	N	Beam	0	—	—	—	0	0	0	0	0	0	0	0	0	0	0	0	—	—	—
Sunrise: 06:22		Diffuse	29	—	—	—	12	30	52	71	84	94	94	90	76	53	31	13	—	—	—
Sunset: 17:38	NE	Beam	13	—	—	—	83	155	105	0	0	0	0	0	0	0	0	0	—	—	—
		Diffuse	32	—	—	—	36	66	71	85	86	94	94	90	76	53	31	12	—	—	—
	E	Beam	68	—	—	—	145	351	436	412	267	84	0	0	0	0	0	0	—	—	—
		Diffuse	41	—	—	—	47	107	132	135	124	104	106	90	76	53	31	12	—	—	—
	SE	Beam	127	—	—	—	122	341	512	611	569	433	308	165	23	0	0	0	—	—	—
		Diffuse	51	—	—	—	42	105	146	165	169	168	148	123	75	57	31	12	—	—	—
	S	Beam	153	—	—	—	28	132	287	452	537	528	518	465	378	235	108	23	—	—	—
		Diffuse	57	—	—	—	32	61	106	141	164	184	184	179	150	102	60	33	—	—	—
	SW	Beam	113	—	—	—	0	0	0	29	191	314	425	491	511	419	280	100	—	—	—
		Diffuse	51	—	—	—	12	30	57	69	112	148	168	184	175	137	98	44	—	—	—
	W	Beam	57	—	—	—	0	0	0	0	0	0	82	231	345	357	287	119	—	—	—
		Diffuse	41	—	—	—	12	30	52	71	84	106	104	136	144	125	100	49	—	—	—
	NW	Beam	11	—	—	—	0	0	0	0	0	0	0	0	0	86	127	68	—	—	—
		Diffuse	32	—	—	—	12	30	52	71	84	94	94	92	90	71	64	38	—	—	—
	Horiz.	Beam	99	—	—	—	8	68	176	295	361	359	352	312	246	144	56	6	—	—	—
	Horiz.	Diffuse	41	—	—	—	24	51	77	91	105	127	129	130	111	83	55	25	—	—	—
	Horiz.	Global	140	—	—	—	32	119	253	386	466	486	481	442	357	227	111	31	—	—	—
Nov 4	Normal to beam		194	—	—	—	—	173	428	612	693	718	642	569	463	324	130	—	—	—	—
	N	Beam	0	—	—	—	—	0	0	0	0	0	0	0	0	0	0	—	—	—	—
Sunrise: 07:21		Diffuse	17	—	—	—	—	10	26	45	56	64	66	60	46	28	12	—	—	—	—
Sunset: 16:39	NE	Beam	3	—	—	—	—	47	43	0	0	0	0	0	0	0	0	—	—	—	—
		Diffuse	18	—	—	—	—	29	35	51	56	64	66	60	46	28	12	—	—	—	—
	E	Beam	47	—	—	—	—	151	327	359	256	90	0	0	0	0	0	—	—	—	—
		Diffuse	25	—	—	—	—	39	93	106	94	72	76	60	46	28	12	—	—	—	—
	SE	Beam	119	—	—	—	—	166	420	584	603	527	357	198	57	0	0	—	—	—	—
		Diffuse	37	—	—	—	—	41	111	143	145	139	128	99	57	32	12	—	—	—	—
	S	Beam	155	—	—	—	—	84	267	468	597	655	586	490	353	202	63	—	—	—	—
		Diffuse	44	—	—	—	—	31	81	124	144	158	166	152	119	79	35	—	—	—	—
	SW	Beam	105	—	—	—	—	0	0	77	241	400	472	495	442	318	125	—	—	—	—
		Diffuse	37	—	—	—	—	11	30	56	92	121	147	153	136	106	46	—	—	—	—
	W	Beam	37	—	—	—	—	0	0	0	0	0	81	210	272	248	113	—	—	—	—
		Diffuse	25	—	—	—	—	10	26	45	56	73	77	102	103	90	44	—	—	—	—
	NW	Beam	2	—	—	—	—	0	0	0	0	0	0	0	0	32	36	—	—	—	—
		Diffuse	18	—	—	—	—	10	26	45	56	64	66	60	52	37	32	—	—	—	—
	Horiz.	Beam	58	—	—	—	—	8	68	165	241	279	250	198	125	51	6	—	—	—	—
	Horiz.	Diffuse	24	—	—	—	—	21	43	62	71	78	91	88	73	51	24	—	—	—	—
	Horiz.	Global	82	—	—	—	—	29	111	227	312	357	341	286	198	102	30	—	—	—	—
Dec 4	Normal to beam		149	—	—	—	—	—	208	456	592	624	591	533	410	187	—	—	—	—	—
	N	Beam	0	—	—	—	—	—	0	0	0	0	0	0	0	0	—	—	—	—	—
Sunrise: 08:03		Diffuse	11	—	—	—	—	—	13	29	42	49	50	41	29	13	—	—	—	—	—
Sunset: 15:57	NE	Beam	0	—	—	—	—	—	7	0	0	0	0	0	0	0	—	—	—	—	—
		Diffuse	12	—	—	—	—	—	33	32	42	49	50	41	29	13	—	—	—	—	—
	E	Beam	29	—	—	—	—	—	152	257	210	75	0	0	0	0	—	—	—	—	—
		Diffuse	17	—	—	—	—	—	42	86	84	60	57	41	29	13	—	—	—	—	—
	SE	Beam	94	—	—	—	—	—	208	443	527	474	348	207	72	0	—	—	—	—	—
		Diffuse	30	—	—	—	—	—	50	125	144	136	116	83	45	15	—	—	—	—	—
	S	Beam	130	—	—	—	—	—	142	369	535	595	563	482	332	127	—	—	—	—	—
		Diffuse	37	—	—	—	—	—	41	110	145	157	156	135	102	41	—	—	—	—	—
	SW	Beam	91	—	—	—	—	—	0	80	230	368	449	474	398	187	—	—	—	—	—
		Diffuse	29	—	—	—	—	—	15	47	88	117	135	134	116	50	—	—	—	—	—
	W	Beam	26	—	—	—	—	—	0	0	0	0	71	189	231	137	—	—	—	—	—
		Diffuse	17	—	—	—	—	—	13	29	42	56	61	80	81	42	—	—	—	—	—
	NW	Beam	0	—	—	—	—	—	0	0	0	0	0	0	0	7	—	—	—	—	—
		Diffuse	12	—	—	—	—	—	13	29	42	49	50	41	32	33	—	—	—	—	—
	Horiz.	Beam	32	—	—	—	—	—	12	74	141	173	164	127	67	11	—	—	—	—	—
	Horiz.	Diffuse	17	—	—	—	—	—	25	48	63	70	72	63	48	25	—	—	—	—	—
	Horiz.	Global	49	—	—	—	—	—	37	122	204	243	236	190	115	36	—	—	—	—	—

* Mean over hour centred at stated solar time

Table 8.2 (continued): Design 97.5 percentile of beam and diffuse irradiance on vertical and horizontal surfaces: London area (Bracknell) (1981–1992) (Oct-Dec) extracted from CIBSE Guide A (2006)

Appendix.4: Overheating calculation for each classroom in 2005, 2007 and 2008 according different criteria

Year	School's Name	Classroom's Name	I-Buttons	BB101 Criteria				Hours above 28 °C		CIBSE Criteria	BB101 & BB87 Criteria	CIBSE	BB 87	BB 101
				Occurrence >32 for each I-Button	Occurrence >32 for each classroom	Difference between Indoor and outdoor for each I button	Difference between indoor and outdoor for each classroom	Number of hours >28 °C for each I Button (for duration of study -302 hour)	Number of hours > 28 °C for each classroom (for duration of study -302 hour)	% of hours >28 °C Proportional Estimate for 1274 hrs (Annual occupied timeframe)	Number hours >28 °C Proportional Estimate for 425 hrs (Summer occupied duration)	Less than 1% of occupied hours <28 °C	1. Number of hours above 28°C <80 hrs	1. Number of hours above 28°C <120 hrs 2. Occurrence <32°C 3. Difference between Inside and outside <5°C
2008	Hounslow	Class.1	A	0	0	5.38	5	4.5	2.25	0	5	Pass	Pass	Pass
			B	0		4.63		0						
		Class.2	A	0	0	3.35	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.55		0						
		Class.3	A	0	0	3.52	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.17		0						
		Class.4	A	0	0	4.32	4	1	0.5	0	1	Pass	Pass	Pass
			B	0		4.15		0						
	Wellington	Class.1	A	0	0	3.44	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.05		0						
		Class.2	A	0	0	4.1	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.42		0						
		Class.3	A	0	0	2.96	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.58		0						
	Cranford	Class.1	A	0	0	3.64	5	0	0	0	0	Pass	Pass	Pass
			B	0		3.93		0						
		Class.2	A	0	0	5.3	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.22		0						
		Class.3	A	0	0	4.95	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.26		0						
	Grove Road	Class.1	A	0	0	4.87	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.02		0						
		Class.2	A	0	0	5.35	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.62		0						
		Class.3	A	0	0	4.35	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.83		0						
		Class.4	A	0	0	4.78	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.4		0						
		Class.5	A	0	0	4.56	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.6		0						
		Class.6	A	0	0	4.86	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.52		0						
		Class.7	A	0	0	4.38	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.1		0						
		Class.8	A	0	0	3.68	4	0	0	0	0	Pass	Pass	Pass
	Andrew	Class.1	A	0	0	2.95	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.18		0						
		Class.2	A	0	0	5.06	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.75		0						
		Class.3	A	0	0	4.82	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.77		0						
		Class.4	A	0	0	6.67	6	7	3.5	0	7	Pass	Pass	Pass
			B	0		5.85		0						
		Class.5	A	0	0	4.62	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.98		0						
	STMM	Class.1	A	0	0	4.80	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.75		0						
		Class.2	A							0	0	Pass	Pass	Pass
			B											
		Class.3	A	0	0	5.08	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.24		0						
		Class.4	A	0	0	5.49	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.61		0						
	Heston	Class.1	A	0	0	3.74	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.88		0						
		Class.2	A	0	0	3.7	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.75		0						
		Class.3	A	0	0	5.5	5	15.5	14	1	29	Fail	Pass	Pass
			B	0		4.88		12.5						
	Rosary	Class.1	A	0	0	3.38	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.86		0						
		Class.2	A	0	0	3.52	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.32		0						
		Class.3	A	0	0	3	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.26		0						
	Feltham	Class.1	A	0	0	2.74	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.86		0						
		Class.2	A	0	0	5.18	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.76		0						
		Class.3	A	0	0	2.88	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.28		0						
	Poole	Class.1	A	0	0	4.44	4	0	0	0	0	Pass	Pass	Pass
		Class.2	A	0	0	4.9	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.6		0						
		Class.3	A	0	0	5.34	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.87		0						
	Ambler	Class.1	A	0	0	4.41	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.2		0						
		Class.2	A	0	0	4.22	4	0	0	0	0	Pass	Pass	Pass
			B	0		4		0						
		Class.3	A	0	0	3.26	3	0	0	0	0	Pass	Pass	Pass
			B	0		2.97		0						
	Norwood	Class.1	A	0	0	4.30	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.25		0						
		Class.2	A	0	0	4.19	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.00		0						
		Class.3	A	0	0	8.04	6	4.5	5.5	0	12	Pass	Pass	Pass
			B	0		6.61		6.5						
	Lady	Class.1	A	0	0	3.21	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.43		0						
		Class.2	A	0	0	4.58	5	0	0.25	0	1	Pass	Pass	Pass
			B	0		5.58		0.5						
		Class.3	A	0	0	4.31	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.39		0						
	Hungerford	Class.1	[illegible]	[illegible]	0	[illegible]	4	[illegible]	0	0	0	Pass	Pass	Pass
			B	0		3.76		0						
		Class.2	A	0	0	3.73	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.98		0						
		Class.3	A	0	0	2.65	3	0	0	0	0	Pass	Pass	Pass
			B	0		2.35		0						
		Class.4	A	0	0	3.25	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.14		0						
		Class.5	A	0	0	3.16	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.53		0						
		Class.6	A	0	0	2.84	3	0	0	0	0	Pass	Pass	Pass
			B	0		2.66		0						
		Class.7	A	0	0	3.49	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.3		0						
	Colerain	Class.1	A	0	0	2.21	2	0	0	0	0	Pass	Pass	Pass
			B	0		2.1		0						
		Class.2	A	0	0	2	2	0	0	0	0	Pass	Pass	Pass
			B	0		1.93		0						
		Class.3	A	0	0	3.89	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.12		0						
	Orchard	Class.2	A	0	0	2.01	2	0	0	0	0	Pass	Pass	Pass
			B	0		1.94		0						

Table 8.3: Overheating calculation for each school according different criteria in 2008

Year	School's Name	Classroom's Name	I-Buttons	BB101 Criteria: Occurance >32 for each Ibutton	BB101 Criteria: Occurance >32 for each classroom	BB101 Criteria: Differences between indoor and outdoor for each I button	BB101 Criteria: Differences between indoor and outdoor for each classroom	Hours above 28 °C: Number of hours > 28 °C for each I Button (for duration of study -202 hour)	Hours above 28 °C: Number of hours > 28 °C for each classroom (for duration of study -202 hour)	CIBSE Criteria: % of hours >28 °C Proportional Estimate for 1274 hrs (Annual occupied duration)	BB101 & BB87 Criteria: Number hours >28 °C Proportional Estimate for 423 hrs (Summer occupied duration)	CIBSE: Less than 1% of occupied hours <28 °C	BB 87: 1. Number of hours above 28°C < 80 hrs	BB 101: 1. Number of hours above 28°C < 120 hrs 2. Occurance < 32°C 3. Differences between inside and outside <5°C
2007	Hounslow	Class.1	A	0	0	4.3	5	0	1	0	2	Pass	Pass	Pass
			B	0		3.59		2						
		Class.2	A	0	0	3.65	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.65		0						
		Class.3	A	0	0	2.81	3	0	0	0	0	Pass	Pass	Pass
			B	0		2.88		0						
		Class.4	A	0	0	3.54	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.11		0						
	Wellington	Class.1	A	0	0	2.72	3	0	0	0	0	Pass	Pass	Pass
			B	0		2.6		0						
		Class.2	A	0	0	4.16	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.24		0						
		Class.3	A	0	0	3.65	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.85		0						
	Cranford	Class.1	A	0	0	5.28	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.68		0						
		Class.2	A	0	0	4.79	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.47		0						
		Class.3	A	0	0	4.89	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.82		0						
	Grove Road	Class.1	A	0	0	5.08	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.09		0						
		Class.2	A	0	0	4.63	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.59		0						
		Class.3	A	0	0	4.97	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.75		0						
		Class.4	A	0	0	4.55	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.51		0						
		Class.5	A	0	0	5.08	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.4		0						
		Class.6	A	0	0	4.43	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.67		0						
		Class.7	A	0	0	4.81	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.58		0						
		Class.8	A	0	0	4.2	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.32		0						
	Andrew	Class.1	A	0	0	4.98	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.81		0						
		Class.2	A	0	0	4.39	4	0	0	0	0	Pass	Pass	Pass
		Class.3	A	0	0	4.44	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.4		0						
		Class.4	A	0	0	4.51	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.92		0						
		Class.5	A	0	0	4.25	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.34		0						
	STMM	Class.1	A	0	0	5.19	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.99		0						
		Class.2	A	0	0	5.69	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.06		0						
		Class.3	A	0	0	4.77	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.2		0						
		Class.4	A	0	0	4.5	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.03		0						
	Heston	Class.1	A	0	0	4.51	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.23		0						
		Class.2	A	0	0	3.78	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.75		0						
		Class.3	A	0	0	3.85	5	2.5	13.25	1	28	Fail	Pass	Pass
			B	0		5.4		24						
	Rosary	Class.1	A	0	0	3.59	3	0	0	0	0	Pass	Pass	Pass
			B	0		2.92		0						
		Class.2	A	0	0	3.29	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.03		0						
		Class.3	A	0	0	3.43	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.92		0						
	Feltham	Class.1	A	0	0	4.3	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.56		0						
		Class.2	A	0	0	4.81	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.05		0						
		Class.3	A	0	0	3.34	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.38		0						
	Pools	Class.1	A	0	0	4.31	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.03		0						
		Class.2	A	0	0	4.77	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.21		0						
		Class.3	A	0	0	4.82	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.6		0						
	Ambler	Class.1	A	0	0	4.18	4	0.5	0.25	0	1	Pass	Pass	Pass
			B	0		4.74		0						
		Class.2	A	0	0	3.94	5	0	0	0	0	Pass	Pass	Pass
			B	0		5.3		0						
		Class.3	A	0	0	3.63	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.3		0						
	Norwood	Class.1	A	0	0	3.53	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.3		0						
		Class.2	A	0	0	4.35	5	0	0	0	0	Pass	Pass	Pass
			B	0		4.81		0						
		Class.3	A	0	0	5.56	6	0	1.25	0	3	Pass	Pass	Pass
			B	0		6.31		2.5						
	Lady	Class.1	A	0	0	3.71	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.73		0						
		Class.2	A	0	0	3.92	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.86		0						
		Class.3	A	0	0	4.25	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.36		0						
	Hungerford	Class.1	A	0	0	3.88	4	0	0	0	0	Pass	Pass	Pass
			B	0		4.07		0						
		Class.2	A	0	0	4.59	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.17		0						
		Class.3	A	0	0	3.63	3	0	0	0	0	Pass	Pass	Pass
			B	0		2.72		0						
	Colerain	Class.1	A	0	0	3.39	4	0	0	0	0	Pass	Pass	Pass
			B	0		3.76		0						
		Class.2	A	0	0	2.84	3	0.5	0.25	0	1	Pass	Pass	Pass
			B	0		2.45		0						
		Class.3	A	0	0	3.11	3	0	0	0	0	Pass	Pass	Pass
			B	0		3.09		0						
	Orchard	Class.2	A	0	0	3.07	3	0	0	0	0	Pass	Pass	Pass
			B	0		2.9		0						
		Class.3	A	0	0	4.13	4	1	1.5	0	3	Pass	Pass	Pass
			B	0		4.2		2						

Appendix 8.4: Overheating calculation for each school according different criteria in 2007

Year	School's Name	Classroom's Name	I-Buttons	BB101 Criteria				Hours above 28 °C		CIBSE Criteria	BB101 & BB87 Criteria	CIBSE	BB 87	BB 101
				Occurance >32 for each Ibutton	Occurance >32 for each classroom	Differences between indoor and outdoor for each I button	Differences between indoor and outdoor for each classroom	Number of hours > 28 °C for each I Button (for duration of study -202 hour)	Number of hours > 28 °C for each classroom (for duration of study -202 hour)	% of hours >28 °C Proportional Estimate for 1274 hrs (Annual occupied suration)	Number hours >28 °C Proportional Estimate for 423 hrs (Summer occupied duration)	Less than 1% of occupied hours <28 °C	1. Number of hours above 28°C < 80 hrs	1. Number of hours above 28°C < 120 hrs 2. Occurance < 32°C 3. Differences between inside and outside <5°C
2005	Pools	Class.1	A B	0 0	0	3.32 3.81	4	4 5.5	4.75	0	10	Pass	Pass	Pass
		Class.2	A B	0 0	0	3.04 2.78	3	6 3.5	4.75	0	10	Pass	Pass	Pass
		Class.3	A B	0 0	0	3.12 2.85	3	14.5 12	13.25	1	28	Fail	Pass	Pass
	St.Gildas	Class.1	A B	0 0	0	2.17 3.07	3	1 3.5	2.25	0	5	Pass	Pass	Pass
		Class.2	A B	0 0	0	2.56 2.77	3	4.5 9	6.75	1	14	Pass	Pass	Pass
		Class.3	A B	0 0	0	2.79 2.72	3	3.5 4	3.75	0	8	Pass	Pass	Pass
	Ambler	Class.1	A	0	0	3.16	3	9.5	9.5	1	20	Pass	Pass	Pass
		Class.2	A B	0 0	0	3.07 3.2	3	8.5 7	7.75	1	16	Pass	Pass	Pass
		Class.3	A B	0 0	0	3.76 3.74	4	25.5 34.5	30	2	63	Fail	Pass	Pass
	Colerain	Class.1	A B	0 0	0	3.12 3.95	4	20 38	29	2	61	Fail	Pass	Pass
		Class.2	A B	0 0	0	2.72 2.63	3	6.5 6.5	6.5	1	14	Pass	Pass	Pass
		Class.3	A	0	0	3.91	4	27	27	2	57	Fail	Pass	Pass
	Green Churc	Class.1	A B	0 0	0	2.81 2.29	2	0 0	0	0	0	Pass	Pass	Pass
		Class.2	A B	0 0	0	2.11 2.52	2	0 2.5	1.25	0	3	Pass	Pass	Pass
		Class.3	A	0	0	3.08	3	24	24	2	50	Fail	Pass	Pass
		Class.4	A B	0 0	0	2.93 3.18	3	21 25	23	2	48	Fail	Pass	Pass
	Hungerford	Class.1	A	0	0	3.71	4	14.5	14.5	1	30	Fail	Pass	Pass
		Class.2	A	0	0	2.37	2	0	0	0	0	Pass	Pass	Pass
		Class.3	B	0	0	2.77	3	3.5	3.5	0	7	Pass	Pass	Pass
	Andrew	Class.1	A B	0 0	0	2.63 3.05	3	7.5 23.5	15.5	1	32	Fail	Pass	Pass
		Class.2	A B	0 0	0	3.81 3.99	4	16.5 16	16.25	1	34	Fail	Pass	Pass
		Class.3	B	0	0	3.83	4	8	8	1	17	Pass	Pass	Pass
	ramlow Tov	Class.1	A B	0 6	3	3.85 4.84	4	31.5 56	43.75	3	92	Fail	Fail	Pass
		Class.2	A B	0 3	1.5	3.45 4.7	4	19 55	37	3	77	Fail	Pass	Pass
		Class.3	A B	0 2	1	3.76 4.27	4	20 43.5	31.75	2	66	Fail	Pass	Pass

Table 8.5: Overheating calculation for each school according different criteria in 2005

Appendix.5: Overhang coefficient

Correction factors for very wide overhangs
(where overhang is at least twice as wide as window,
or where window width and overhang width are at leat five times the window height)

Ration D/H	Correction factor for stated window orientation				
	N	NE/NW	E/W	SE/SW	S
0.2	0.919	0.893	0.875	0.83	0.767
0.4	0.846	0.797	0.76	0.671	0.545
0.6	0.785	0.716	0.661	0.537	0.382
0.8	0.734	0.649	0.579	0.433	0.324
1	0.692	0.594	0.512	0.36	0.301
1.2	0.657	0.549	0.459	0.312	0.285

D is depth of overhand measured from glass and H is height of window

Correction factors for very wide windows
(where the window width and overhang width are twice the window height)

Ration D/H	Correction factor for stated window orientation				
	N	NE/NW	E/W	SE/SW	S
0.2	0.928	0.902	0.88	0.837	0.78
0.4	0.877	0.824	0.776	0.694	0.592
0.6	0.841	0.764	0.686	0.578	0.459
0.8	0.816	0.72	0.619	0.495	0.414
1	0.798	0.686	0.563	0.444	0.398
1.2	0.784	0.661	0.519	0.416	0.388

D is depth of overhand measured from glass and H is height of window

Correction factors for square windows
(where the window width and overhang width are equal to the window height)

Ration D/H	Correction factor for stated window orientation				
	N	NE/NW	E/W	SE/SW	S
0.2	0.937	0.91	0.885	0.843	0.794
0.4	0.9	0.849	0.792	0.715	0.636
0.6	0.877	0.811	0.717	0.617	0.531
0.8	0.861	0.786	0.658	0.552	0.497
1	0.85	0.77	0.611	0.518	0.486
1.2	0.842	0.759	0.574	0.503	0.479

D is depth of overhand measured from glass and H is height of window

Correction factors for narrow windows
(where the window width and overhang width are half the window height)

Ration D/H	Correction factor for stated window orientation				
	N	NE/NW	E/W	SE/SW	S
0.2	0.949	0.924	0.895	0.856	0.794
0.4	0.926	0.89	0.821	0.756	0.636
0.6	0.912	0.873	0.767	0.685	0.531
0.8	0.903	0.864	0.727	0.643	0.497
1	0.897	0.858	0.694	0.625	0.486
1.2	0.892	0.854	0.669	0.619	0.479

D is depth of overhand measured from glass and H is height of window

Table 8.6: Overhang coefficient for different overhang extracted from extracted from CIBSE.TM37 (2006)

Appendix.6: Maximum hourly and daily global solar irradiances for the months of June and July

The following tables, which were extracted from the CIBSE Guide A, show the maximum hourly and also maximum daily (sum) global solar irradiances on different vertical as well as horizontal surfaces for the months of June and July. The data from CIBSE is for a day with a clear sky and therefore the maximum possible daily (sum) global solar irradiance.

June																				
ientatic	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Sum (Wat.hour/Sqm) June
		Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																		
N	Beam	40	100	132	85	0	0	0	0	0	0	0	0	0	0	82	133	100	40	
	Diffuse	25	55	76	85	111	117	125	134	139	140	135	127	121	114	85	77	58	25	
	Globe	**65**	**155**	**208**	**170**	**111**	**117**	**125**	**134**	**139**	**140**	**135**	**127**	**121**	**114**	**167**	**210**	**158**	**65**	**2461**
NE	Beam	64	185	342	417	397	285	134	0	0	0	0	0	0	0	0	0	0	0	
	Diffuse	32	72	124	157	158	150	134	158	139	140	135	127	113	94	69	42	21	9	
	Globe	**96**	**257**	**466**	**574**	**555**	**435**	**268**	**158**	**139**	**140**	**135**	**127**	**113**	**94**	**69**	**42**	**21**	**9**	**3698**
E	Beam	50	162	352	504	579	544	445	290	100	0	0	0	0	0	0	0	0	0	
	Diffuse	27	66	126	175	189	189	180	163	140	149	135	127	113	94	69	42	20	8	
	Globe	**77**	**228**	**478**	**679**	**768**	**733**	**625**	**453**	**240**	**149**	**135**	**127**	**113**	**94**	**69**	**42**	**20**	**8**	**5038**
SE	Beam	7	44	155	296	422	484	496	447	345	204	36	0	0	0	0	0	0	0	
	Diffuse	21	50	82	133	163	180	187	183	173	157	123	134	113	94	69	42	20	8	
	Globe	**28**	**94**	**237**	**429**	**585**	**664**	**683**	**630**	**518**	**361**	**159**	**134**	**113**	**94**	**69**	**42**	**20**	**8**	**4868**
S	Beam	0	0	0	0	18	141	256	342	387	389	335	247	133	17	0	0	0	0	
	Diffuse	8	18	41	77	83	125	154	170	179	180	172	158	130	87	77	42	20	8	
	Globe	**8**	**18**	**41**	**77**	**101**	**266**	**410**	**512**	**566**	**569**	**507**	**405**	**263**	**104**	**77**	**42**	**20**	**8**	**3994**
SW	Beam	0	0	0	0	0	0	0	37	203	346	438	479	457	395	284	157	44	7	
	Diffuse	8	18	41	69	91	110	132	122	156	175	185	193	188	169	133	83	52	21	
	Globe	**8**	**18**	**41**	**69**	**91**	**110**	**132**	**159**	**359**	**521**	**623**	**672**	**645**	**564**	**417**	**240**	**96**	**28**	**4793**
W	Beam	0	0	0	0	0	0	0	0	0	101	284	431	513	542	483	355	163	51	
	Diffuse	8	18	41	69	91	110	125	134	148	140	165	185	197	196	175	128	69	27	
	Globe	**8**	**18**	**41**	**69**	**91**	**110**	**125**	**134**	**148**	**241**	**449**	**616**	**710**	**738**	**658**	**483**	**232**	**78**	**4949**
NW	Beam	0	0	0	0	0	0	0	0	0	0	0	130	269	371	399	345	186	65	
	Diffuse	9	19	41	69	91	110	125	134	139	140	159	138	156	164	157	126	75	32	
	Globe	**9**	**19**	**41**	**69**	**91**	**110**	**125**	**134**	**139**	**140**	**159**	**268**	**425**	**535**	**556**	**471**	**261**	**97**	**3649**
H	Beam	1	17	91	214	362	493	610	694	735	738	679	590	465	339	205	92	18	1	
	Diffuse	16	37	71	104	120	132	140	141	144	146	146	149	146	131	107	72	38	16	
	Globe	**17**	**54**	**162**	**318**	**482**	**625**	**750**	**835**	**879**	**884**	**825**	**739**	**611**	**470**	**312**	**164**	**56**	**17**	**8200**

Table 8.7: Hourly and maximum daily (sum) global solar irradiances on different vertical as well as horizontal surfaces for the month of June

July																				
ientatic	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Sum (Wat.hour/Sqm) July
		Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																		
N	Beam	35	88	122	75	0	0	0	0	0	0	0	0	0	0	74	121	87	35	
	Diffuse	20	47	64	73	103	110	121	133	140	141	132	123	113	102	78	62	43	18	
	Globe	**55**	**135**	**186**	**148**	**103**	**110**	**121**	**133**	**140**	**141**	**132**	**123**	**113**	**102**	**152**	**183**	**130**	**53**	**2260**
NE	Beam	57	165	320	379	353	260	119	0	0	0	0	0	0	0	0	0	0	0	
	Diffuse	25	61	103	132	146	143	132	156	140	141	132	123	107	85	64	35	15	6	
	Globe	**82**	**226**	**423**	**511**	**499**	**403**	**251**	**156**	**140**	**141**	**132**	**123**	**107**	**85**	**64**	**35**	**15**	**6**	**3399**
E	Beam	45	145	331	461	519	502	409	265	90	0	0	0	0	0	0	0	0	0	
	Diffuse	22	57	106	147	174	179	176	166	144	150	132	123	107	85	64	35	14	5	
	Globe	**67**	**202**	**437**	**608**	**693**	**681**	**585**	**431**	**234**	**150**	**132**	**123**	**107**	**85**	**64**	**35**	**14**	**5**	**4653**
SE	Beam	7	40	148	273	381	450	459	412	315	190	37	0	0	0	0	0	0	0	
	Diffuse	16	43	69	113	151	171	183	186	179	162	124	131	107	85	64	35	14	5	
	Globe	**23**	**83**	**217**	**386**	**532**	**621**	**642**	**598**	**494**	**352**	**161**	**131**	**107**	**85**	**64**	**35**	**14**	**5**	**4550**
S	Beam	0	0	0	0	20	135	240	318	355	361	317	236	132	20	0	0	0	0	
	Diffuse	6	16	35	67	81	121	152	173	185	186	172	156	124	80	71	35	14	5	
	Globe	**6**	**16**	**35**	**67**	**101**	**256**	**392**	**491**	**540**	**547**	**489**	**392**	**256**	**100**	**71**	**35**	**14**	**5**	**3813**
SW	Beam	0	0	0	0	0	0	0	37	187	320	411	451	440	385	272	147	40	7	
	Diffuse	6	16	35	60	85	104	129	124	161	180	185	188	176	150	121	67	39	15	
	Globe	**6**	**16**	**35**	**60**	**85**	**104**	**129**	**161**	**348**	**500**	**596**	**639**	**616**	**535**	**393**	**214**	**79**	**22**	**4538**
W	Beam	0	0	0	0	0	0	0	0	0	92	264	402	491	524	459	329	144	45	
	Diffuse	6	16	35	60	85	104	121	133	149	144	165	181	184	173	157	102	52	20	
	Globe	**6**	**16**	**35**	**60**	**85**	**104**	**121**	**133**	**149**	**236**	**429**	**583**	**675**	**697**	**616**	**431**	**196**	**65**	**4637**
NW	Beam	0	0	0	0	0	0	0	0	0	0	0	117	254	357	377	318	164	57	
	Diffuse	6	17	35	60	85	104	121	133	140	141	155	135	147	145	141	100	56	23	
	Globe	**6**	**17**	**35**	**60**	**85**	**104**	**121**	**133**	**140**	**141**	**155**	**252**	**401**	**502**	**518**	**418**	**220**	**80**	**3388**
H	Beam	0	14	83	191	319	449	554	627	658	668	626	545	439	323	190	82	14	0	
	Diffuse	13	31	60	90	116	130	143	154	162	162	153	150	137	114	97	58	29	12	
	Globe	**13**	**45**	**143**	**281**	**435**	**579**	**697**	**781**	**820**	**830**	**779**	**695**	**576**	**437**	**287**	**140**	**43**	**12**	**7593**

Table 8.8: Hourly and maximum daily (sum) global solar irradiances on different vertical as well as horizontal surfaces for the month of July

Appendix.7: Internal gain

Appendix.7.1: Equipment gain

Type of equipment	Power consumed / W		
	Full operation	Standby mode	Average when switched on
Desktop PC (without monitor)	55	25	50
Laptop PC	15	3	6
CRT monitors:			
— 15 inch	61	19	40
— 17 inch	90	9	50
— 19 inch	104	13	58
— 21 inch	135	14	73
LCD monitors:			
— 15 inch	12	3	7
— 17 inch	17	5	11
— 20 inch	32	9	20
Printers:			
— dot matrix	50	25	30
— impact	37	17	19
— inkjet	43	13	15
— small desktop laser	130	10	22
— desktop laser	215	35	53
— small office laser	320	70	115
— large office laser	550	125	200
Copiers:			
— desktop	400	20	53
— office	1100	300	350
Fax machine	30	15	16
Scanner	25	15	16

Table 8.9: Average power consumption for office equipment extracted from CIBSE TM37 (2006)

Type of equipment	Power consumed / W		
	Full operation	Standby mode	Average on residential summer day*
Televisions:			
— CRT (small)	45	3	11
— CRT (large)	90	7	24
— plasma screen (large)	400	1	81
— LCD (up to 60 cm diag.)	50	1	11
— digital light projection	130	1	27
Digital TV adapter box	9	7	8
Video recorder	17	6	7
DVD player	17	4	5
Component stereo	44	3	11
Compact stereo	22	10	12
Microwave oven	1390	4	9
Refrigerators:			
— A-rated	16	—	16
— C-rated	31	—	31
Freezers:			
— chest (A-rated)	24	—	24
— chest (C-rated)	36	—	36
— upright (A-rated)	24	—	24
— upright (C-rated)	41	—	41
Fridge-freezers:			
— A-rated	36	—	36
— C-rated	60	—	60

* 07:30–17:30

Table 8.10: Average power consumption for domestic equipment extracted from CIBSE.TM37 (2006)

Appendix.7.2: Lighting gain

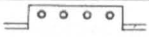
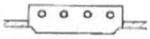
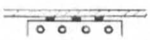
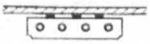
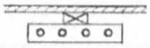
Type of fitting			Energy distribution / %	
Mounting	Schematic	Description	Upwards	Downwards
Recessed		Open	38	62
		Louvre	45	55
		Prismatic or opal diffuser	53	47
Surface		Open	12	88
		Enclosed prismatic or opal	22	78
		Enclosed prismatic on metal spine	6	94

Table 8.11: Measured energy distribution for fluorescent fitting having for 70 W lamps extracted from CIBSE TM37 (2006)

Appendix.8: Compare indoor temperature with adaptive, fixed thermal comfort and maximum allowable deviation from adaptive thermal comfort.

Appendix 8.1: Daily mean outside temperature (i.e. Mean T out), thermal running temperature (i.e. Trm), adaptive thermal comfort (Tc) and maximum allowable deviation from adaptive thermal comfort (CatII and CatIII). 'Tc', 'CatII' and 'CatIII' are calculated from the following formula:

- $Tc=0.33Trm+18.8$
- $CatII= Tc+3K$ and $CatIII= Tc+4K$

Appendix.8-1

2008							2007							2005						
Day	Date	Mean Tout	Trm	Tc	CatII	CatIII	Day	Date	Mean Tout	Trm	Tc	CatII	CatIII	Day	Date	Mean Tout	Trm	Tc	CatII	CatIII
Mon	09/06/2008	20.96	16.68	24.30	27.30	28.30	Mon	11/06/2007	18.38	17.50	24.58	27.58	28.58	Wed	15/06/2005	15.38	15.00	23.75	26.75	27.75
Tue	10/06/2008	19.22	17.53	24.59	27.59	28.59	Tue	12/06/2007	18.63	17.68	24.63	27.63	28.63	Thu	16/06/2005	17.29	15.08	23.77	26.77	27.77
Wed	11/06/2008	16.42	17.87	24.70	27.70	28.70	Wed	13/06/2007	18.23	17.87	24.70	27.70	28.70	Fri	17/06/2005	21.42	15.52	23.92	26.92	27.92
Thu	12/06/2008	13.21	17.58	24.60	27.60	28.60	Thu	14/06/2007	18.13	17.94	24.72	27.72	28.72	Mon	20/06/2005	23.13	19.63	25.28	28.28	29.28
Fri	13/06/2008	13.38	16.70	24.31	27.31	28.31	Fri	15/06/2007	17.06	17.98	24.73	27.73	28.73	Tue	21/06/2005	20.73	20.33	25.51	28.51	29.51
Mon	16/06/2008	14.38	15.58	23.94	26.94	27.94	Mon	18/06/2007	16.00	17.25	24.49	27.49	28.49	Wed	22/06/2005	22.27	20.41	25.54	28.54	29.54
Tue	17/06/2008	15.96	15.34	23.86	26.86	27.86	Tue	19/06/2007	18.63	17.00	24.41	27.41	28.41	Thu	23/06/2005	24.46	20.78	25.66	28.66	29.66
Wed	18/06/2008	15.44	15.46	23.90	26.90	27.90	Wed	20/06/2007	18.14	17.32	24.52	27.52	28.52	Fri	24/06/2005	21.19	21.52	25.90	28.90	29.90
Thu	19/06/2008	17.00	15.46	23.90	26.90	27.90	Thu	21/06/2007	17.00	17.49	24.57	27.57	28.57	Mon	27/06/2005	18.98	19.74	25.31	28.31	29.31
Fri	20/06/2008	15.29	15.77	24.00	27.00	28.00	Fri	22/06/2007	15.71	17.39	24.54	27.54	28.54	Tue	28/06/2005	19.29	19.59	25.26	28.26	29.26
Mon	23/06/2008	16.67	16.25	24.16	27.16	28.16	Mon	25/06/2007	13.75	16.34	24.19	27.19	28.19	Wed	29/06/2005	19.23	19.53	25.24	28.24	29.24
Tue	24/06/2008	17.38	16.34	24.19	27.19	28.19	Tue	26/06/2007	13.50	15.83	24.02	27.02	28.02	Thu	30/06/2005	16.65	19.47	25.22	28.22	29.22
Wed	25/06/2008	17.81	16.54	24.26	27.26	28.26	Wed	27/06/2007	14.09	15.36	23.87	26.87	27.87	Fri	01/07/2005	17.04	18.90	25.04	28.04	29.04
Thu	26/06/2008	16.40	16.80	24.34	27.34	28.34	Thu	28/06/2007	14.75	15.11	23.79	26.79	27.79	Mon	04/07/2005	14.44	18.20	24.80	27.80	28.80
Fri	27/06/2008	17.48	16.72	24.32	27.32	28.32	Fri	29/06/2007	17.25	15.04	23.76	26.76	27.76	Tue	05/07/2005	14.15	17.44	24.56	27.56	28.56
Mon	30/06/2008	17.42	17.34	24.52	27.52	28.52	Mon	02/07/2007	16.00	15.98	24.07	27.07	28.07	Wed	06/07/2005	15.94	16.78	24.34	27.34	28.34
Tue	01/07/2008	20.25	17.36	24.53	27.53	28.53	Tue	03/07/2007	15.50	15.98	24.07	27.07	28.07	Thu	07/07/2005	15.48	16.61	24.28	27.28	28.28
Wed	02/07/2008	17.52	17.94	24.72	27.72	28.72	Wed	04/07/2007	15.50	15.89	24.04	27.04	28.04	Fri	08/07/2005	16.56	16.39	24.21	27.21	28.21
Thu	03/07/2008	16.25	17.85	24.69	27.69	28.69	Thu	05/07/2007	16.13	15.81	24.02	27.02	28.02	Mon	11/07/2005	23.02	17.68	24.63	27.63	28.63
Fri	04/07/2008	16.44	17.53	24.59	27.59	28.59	Fri	06/07/2007	16.25	15.87	24.04	27.04	28.04	Tue	12/07/2005	20.60	18.75	24.99	27.99	28.99
Mon	07/07/2008	15.10	17.11	24.45	27.45	28.45	Mon	09/07/2007	14.75	16.14	24.13	27.13	28.13	Wed	13/07/2005	22.63	19.12	25.11	28.11	29.11
Tue	08/07/2008	16.02	16.71	24.31	27.31	28.31	Tue	10/07/2007	15.25	15.87	24.04	27.04	28.04	Thu	14/07/2005	24.23	19.82	25.34	28.34	29.34
Wed	09/07/2008	15.13	16.57	24.27	27.27	28.27	Wed	11/07/2007	16.71	15.74	23.99	26.99	27.99	Fri	15/07/2005	22.17	20.70	25.63	28.63	29.63
Thu	10/07/2008	17.19	16.28	24.17	27.17	28.17	Thu	12/07/2007	18.29	15.94	24.06	27.06	28.06	Mon	18/07/2005	19.23	20.97	25.72	28.72	29.72
Fri	11/07/2008	16.02	16.46	24.23	27.23	28.23	Fri	13/07/2007	19.00	16.41	24.21	27.21	28.21	Tue	19/07/2005	17.73	20.62	25.61	28.61	29.61
Mon	14/07/2008	18.35	15.93	24.06	27.06	28.06	Mon	16/07/2007	19.38	17.77	24.66	27.66	28.66	Wed	20/07/2005	19.33	20.04	25.41	28.41	29.41
Tue	15/07/2008	20.60	16.42	24.22	27.22	28.22	Tue	17/07/2007	17.38	18.09	24.77	27.77	28.77	Thu	21/07/2005	17.46	19.90	25.37	28.37	29.37
Wed	16/07/2008	17.73	17.25	24.49	27.49	28.49	Wed	18/07/2007	18.13	17.95	24.72	27.72	28.72	Fri	22/07/2005	17.13	19.41	25.21	28.21	29.21
Thu	17/07/2008	16.40	17.35	24.53	27.53	28.53	Thu	19/07/2007	17.50	17.98	24.73	27.73	28.73	Mon	25/07/2005	16.02	18.60	24.94	27.94	28.94
Fri	18/07/2008	16.85	17.16	24.46	27.46	28.46	Fri	20/07/2007	16.75	17.89	24.70	27.70	28.70	Tue	26/07/2005	16.67	18.09	24.77	27.77	28.77
Mon	21/07/2008	15.96	16.88	24.37	27.37	28.37	Mon	23/07/2007	16.00	16.94	24.39	27.39	28.39	Wed	27/07/2005	13.72	17.80	24.67	27.67	28.67

Table 8.12: Daily mean outside temperature (i.e. Mean T out), thermal running temperature (i.e. Trm), adaptive thermal comfort (Tc) and maximum allowable deviation from adaptive thermal comfort (CatII and CatIII) in 2008, 2007 & 2005

Appendix.8.2: Mean and maximum percentage of dissatisfaction from overheating for each day.

Appendix.8.3: Maximum allowable deviation from adaptive thermal comfort for each day

Appendix.8.4: The percentages of occasions that indoor temperature exceeds 25° / 28°C for each day

It should be noted that the following tables only show part of the whole data that are calculated as sample.

Year	Classroom. Day	Appendix.8					
		Appendix.8-2		Appendix. 8-3		Appendix.8-4	
		Mean and maximum percentage of dissatisfaction from overheating for each day		Maximum allowable deviation from adaptive thermal comfort for each day		The percentages of occasions that indoor temperature exceeds 25° / 28°C for each day	
		PDH.Mean	PHD.Max	PGrCat2	PGrCat3	PGR25	PGr28
2005	Pooles1A.Jun.2005.23	16.17	26.41	7.14	0.00	100.00	28.57
2005	Pooles1A.Jun.2005.24	13.47	16.61	0.00	0.00	100.00	0.00
2005	Pooles1A.Jun.2005.27	4.64	7.45	0.00	0.00	7.14	0.00
2005	Pooles1A.Jun.2005.28	5.94	7.62	0.00	0.00	21.43	0.00
2005	Pooles1A.Jun.2005.29	4.49	6.16	0.00	0.00	0.00	0.00
2005	Pooles1A.Jun.2005.30	3.51	4.97	0.00	0.00	0.00	0.00
2005	Pooles1A.July.2005.01	3.82	5.41	0.00	0.00	0.00	0.00
2005	Pooles1A.July.2005.04	1.90	3.04	0.00	0.00	0.00	0.00
2005	Pooles1A.July.2005.05	2.32	3.41	0.00	0.00	0.00	0.00
2005	Pooles1A.July.2005.06	2.98	3.77	0.00	0.00	0.00	0.00
2005	Pooles1A.July.2005.07	2.53	3.07	0.00	0.00	0.00	0.00
2005	Pooles1A.July.2005.08	2.49	2.53	0.00	0.00	0.00	0.00
2005	Pooles1A.July.2005.11	8.04	12.34	0.00	0.00	35.71	0.00
2005	Pooles1A.July.2005.19	5.81	6.56	0.00	0.00	42.86	0.00
2007	Wlngtn3B.Jun.2007.13	11.84	18.00	0.00	0.00	64.29	0.00
2007	Wlngtn3B.Jun.2007.14	9.20	14.63	0.00	0.00	57.14	0.00
2007	Wlngtn3B.Jun.2007.15	8.24	11.85	0.00	0.00	50.00	0.00
2007	Wlngtn3B.Jun.2007.18	4.84	8.58	0.00	0.00	0.00	0.00
2007	Wlngtn3B.Jun.2007.19	8.06	20.09	0.00	0.00	28.57	0.00
2007	Wlngtn3B.Jun.2007.20	9.88	15.87	0.00	0.00	50.00	0.00
2007	Wlngtn3B.Jun.2007.21	7.52	12.67	0.00	0.00	42.86	0.00
2007	Wlngtn3B.Jun.2007.22	2.17	2.17	0.00	0.00	0.00	0.00
2007	Wlngtn3B.Jun.2007.25	0.56	0.63	0.00	0.00	0.00	0.00
2007	Wlngtn3B.Jun.2007.26	3.11	8.46	0.00	0.00	0.00	0.00
2007	Wlngtn3B.Jun.2007.27	4.75	7.28	0.00	0.00	0.00	0.00
2007	Wlngtn3B.Jun.2007.28	6.31	17.39	0.00	0.00	7.14	0.00
2007	Wlngtn3B.Jun.2007.29	7.36	14.38	0.00	0.00	7.14	0.00
2007	Wlngtn3B.July.2007.02	7.60	18.87	0.00	0.00	14.29	0.00
2007	Wlngtn3B.July.2007.03	4.05	6.65	0.00	0.00	0.00	0.00
2007	Wlngtn3B.July.2007.04	4.87	8.39	0.00	0.00	0.00	0.00
2008	Wlngtn1B.July.2008.18	1.64	2.25	0.00	0.00	0.00	0.00
2008	Wlngtn1B.July.2008.21	1.36	2.34	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.09	10.18	14.14	0.00	0.00	28.57	0.00
2008	Wlngtn2A.Jun.2008.10	9.36	10.21	0.00	0.00	57.14	0.00
2008	Wlngtn2A.Jun.2008.11	7.51	7.85	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.12	4.07	4.20	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.13	1.96	2.41	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.16	3.07	3.59	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.17	4.08	4.67	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.18	3.08	3.66	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.19	3.05	3.66	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.20	3.49	3.49	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.23	2.72	3.25	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.24	4.41	5.05	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.25	6.58	9.48	0.00	0.00	0.00	0.00
2008	Wlngtn2A.Jun.2008.26	6.23	7.36	0.00	0.00	0.00	0.00

Table 8.13: Sample of comparison of indoor temperature with adaptive, fixed thermal comfort and maximum allowable differences from adaptive model in 2005, 2007 and 2008

Appendix 9: Classroom characteristic part:

In the following pages the history of each school as well as the classrooms characteristics are reviewed. The classrooms characteristics are as follows:

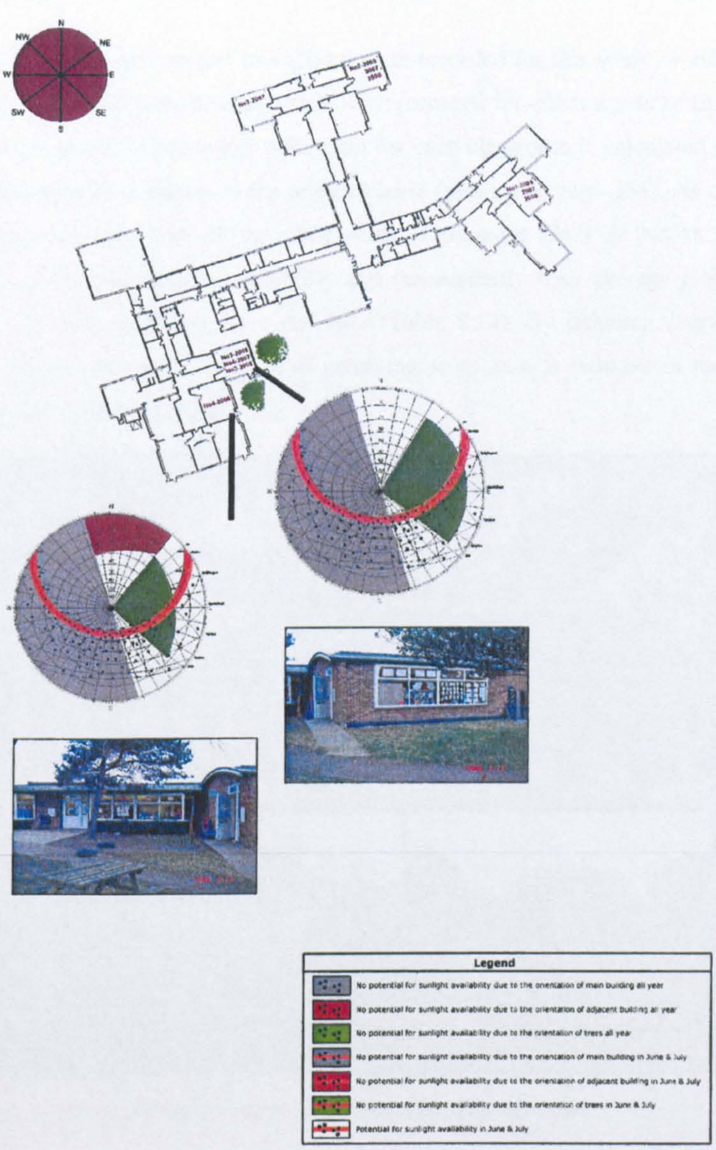
- Maximum risk of receiving solar gain for each classroom for the average months of June and July
- Thermal mass level
- Regions which can be Noisy or Quiet

In this section the maximum risk of receiving solar gain for the perimeter and total zone for each classroom for the months of June and July are stated. To calculate the maximum risk of receiving solar gain on the premier zone, the following parameters should be extracted from the available data:

- Perimeter zone
- Window area
- Average solar irradiance for a specific direction while considering shading and overshadowing

If the classrooms' windows do not have any overhang and are not overshadowed by any tree or building the average irradiance for a peak day in the mouths of June and July in each direction is extracted from Tables 3-2.4 and 3-2.5 on Chapter Three. Alternatively the average irradiance should be adjusted by the overhang coefficient and sunlight probability. For this reason, the sunlight probability for each classroom that has the potential of overshadowing by trees and other buildings or part of the original building is obtained for each classroom. As can be seen in the following pages, based on the sunlight probability the average global daily solar irradiance for some classrooms are adjusted. If a classroom is overshadowed by a tree, the beam solar irradiance data for the duration that the classroom is overshadowed is multiplied by 0.15. And if a classroom is overshadowed by a part of main building or adjacent building, the solar irradiance for the duration that classroom is overshadowed is multiplied by zero.

Appendix 9.1: Housnlow Town Primary School



Hounslow Town primary school is a Post War school, built after the World War II in 1952. This school is categorised as a low thermal mass school (due to the reasons which are explained in chapter 3) and is identified as noisy school since it is located on aircraft noise counter map above 57dBA.

The indoor temperatures of 5 classrooms of this school were recorded for this study in 2005, 2007 & 2008. The indoor temperatures of classrooms were recorded for either a year or three year periods. The maximum risk of receiving solar gain for each classroom is calculated for the summer (June and July) and is shown in the relevant table (please see page 354). As can be seen from the school's map, two of the classrooms (Classroom No.3 & No.4) are overshadowed by trees and their sunlight probability and consequently their average global daily solar irradiance are reduced during June and July (Table 8.14). By reducing average global daily solar irradiance the maximum risk of receiving solar gain is reduced in these classrooms during summer (June and July).

Figure 8.1: Images of Hounslow Town Primary School (Taken by the author)

		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) June	Average (W/m²) June & July
				June																			
				Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
Hounslow	No.3 (2005) No.3 (2007) No.3 (2008)	E	Beam	50	162	53	76	87	82	67	290	100	0	0	0	0	0	0	0	0	0		160
			Diffuse	27	66	126	175	189	189	180	163	140	149	135	127	113	94	69	42	20	8		
			Globe	77	228	179	251	276	271	247	453	240	149	135	127	113	94	69	42	20	8	165	
				July																			
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July	
				Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
		E	Beam	45	145	49.7	69.2	77.9	75.3	61.4	265	90	0	0	0	0	0	0	0	0	0		
			Diffuse	22	57	106	147	174	179	176	166	144	150	132	123	107	85	64	35	14	5		
			Globe	67	202	156	216	252	254	237	431	234	150	132	123	107	85	64	35	14	5	154	

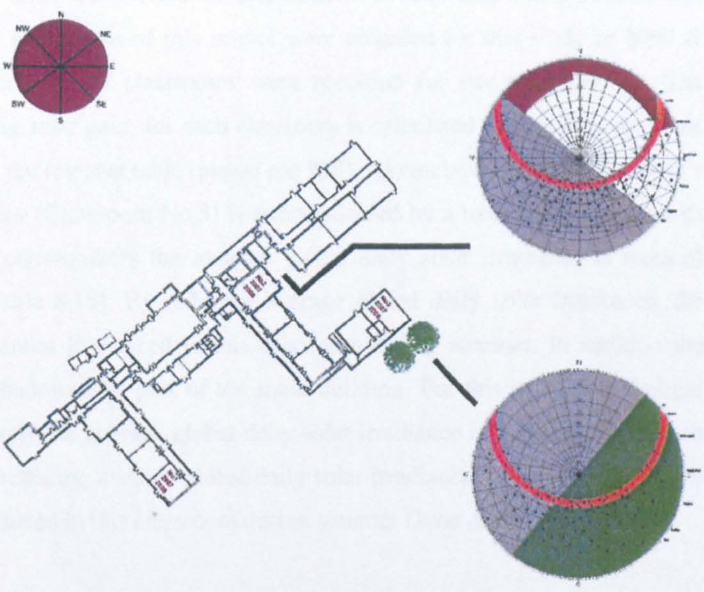
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²)June	Average (W/m²) June & July
				June																			
				Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
Hounslow	No.4 (2008)	E	Beam	50	162	352	76	87	82	67	44	100	0	0	0	0	0	0	0	0	0		163
			Diffuse	27	66	126	175	189	189	180	163	140	149	135	127	113	94	69	42	20	8		
			Globe	77	228	478	251	276	271	247	207	240	149	135	127	113	94	69	42	20	8	168	
				July																			
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July	
				Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
		E	Beam	45	145	331	69	78	75	61	40	90	0	0	0	0	0	0	0	0	0		
			Diffuse	22	57	106	147	174	179	176	166	144	150	132	123	107	85	64	35	14	5		
			Globe	67	202	437	216	252	254	237	206	234	150	132	123	107	85	64	35	14	5	157	

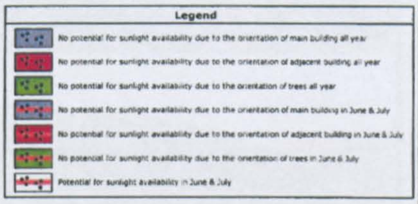
Table 8.14: Adjusted average global daily solar irradiance considering the impact of overshadowing in Hounslow Town Primary School

Hounslow Town Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2005	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	60	54	12.2	NE	197	No	No	No	197	2403	2403	40	45	Low	Noisy
No.2	GF	59	44	9.1	E	269	No	No	No	269	2445	2445	42	56	Low	Noisy
No.3	GF	57	44	9.7	E	269	No	No	[illegible]	[illegible]	1558	1558	27	36	Low	Noisy
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	60	54	12.2	NE	197	No	No	No	197	2403	2403	40	45	Low	Noisy
No.2	GF	59	44	9.1	E	269	No	No	No	269	2445	2445	42	56	Low	Noisy
No.3	GF	58	44	9.3	W	266	No	No	No	266	2463	2463	42	56	Low	Noisy
No.4	GF	57	44	9.7	E	269	No	No	[illegible]	[illegible]	1558	1558	27	36	Low	Noisy
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	60	54	12.2	NE	197	No	No	No	197	2403	2403	40	45	Low	Noisy
No.2	GF	59	44	9.1	E	269	No	No	No	269	2445	2445	42	56	Low	Noisy
No.3	GF	57	44	9.7	E	269	No	No	[illegible]	[illegible]	1558	1558	27	36	Low	Noisy
No.4	GF	61	54	13.9	E	269	No	No	[illegible]	[illegible]	2266	2266	37	42	Low	Noisy

Appendix 9.2: Wellington Primary School





Wellington primary school is an open air school, built after the World War I in 1930 and was redesigned after the oil crisis (i.e. closed corridors were added). This school is categorised as a low thermal mass school (due to the reasons which are explained in chapter 3) and is identified as noisy school since it is located on aircraft noise counter map above 57dBA. The indoor temperatures of 3 classrooms of this school were recorded for this study in 2007 & 2008. The indoor temperatures of classrooms were recorded for two year periods. The maximum risk of receiving solar gain for each classroom is calculated for the summer (June and July) and is shown in the relevant table (please see 358). As can be seen from the school's map, one of the classrooms (Classroom No.3) is overshadowed by a tree. For this reason its sunlight probability and consequently the average global daily solar irradiance is reduced during June and July (Table 8.15). By reducing average global daily solar irradiance, the maximum solar gain potential is reduced in this classroom during summer. In addition the Classroom No.2 is overshadowed by part of the main building. For this reason its sunlight probability and consequently the average global daily solar irradiance is reduced during June and July (Table 8.2). By reducing average global daily solar irradiance, the maximum risk of receiving solar gain is reduced in this classroom during summer (June & July).

Figure 8.2: Images of Wellington Primary School (Taken by the author)

School	Building	Month	Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) (month)	Average (W/m²) June & July
					Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
Wellington	No.2 (2007) No.2 (2008)	June	NE	Beam	0	0	0	417	397	285	134	0	0	0	0	0	0	0	0	0	0	0		166
				Diffuse	32	72	124	157	158	150	134	158	139	140	135	127	113	94	69	42	21	9		
				Globe	**32**	**72**	**124**	**574**	**555**	**435**	**268**	**158**	**139**	**140**	**135**	**127**	**113**	**94**	**69**	**42**	**21**	**9**	**173**	
		July	NE	Beam	0	0	0	379	353	260	119	0	0	0	0	0	0	0	0	0	0	0		
				Diffuse	25	61	103	132	146	143	132	156	140	141	132	123	107	85	64	35	15	6		
				Globe	**25**	**61**	**103**	**511**	**499**	**403**	**251**	**156**	**140**	**141**	**132**	**123**	**107**	**85**	**64**	**35**	**15**	**6**	**159**	

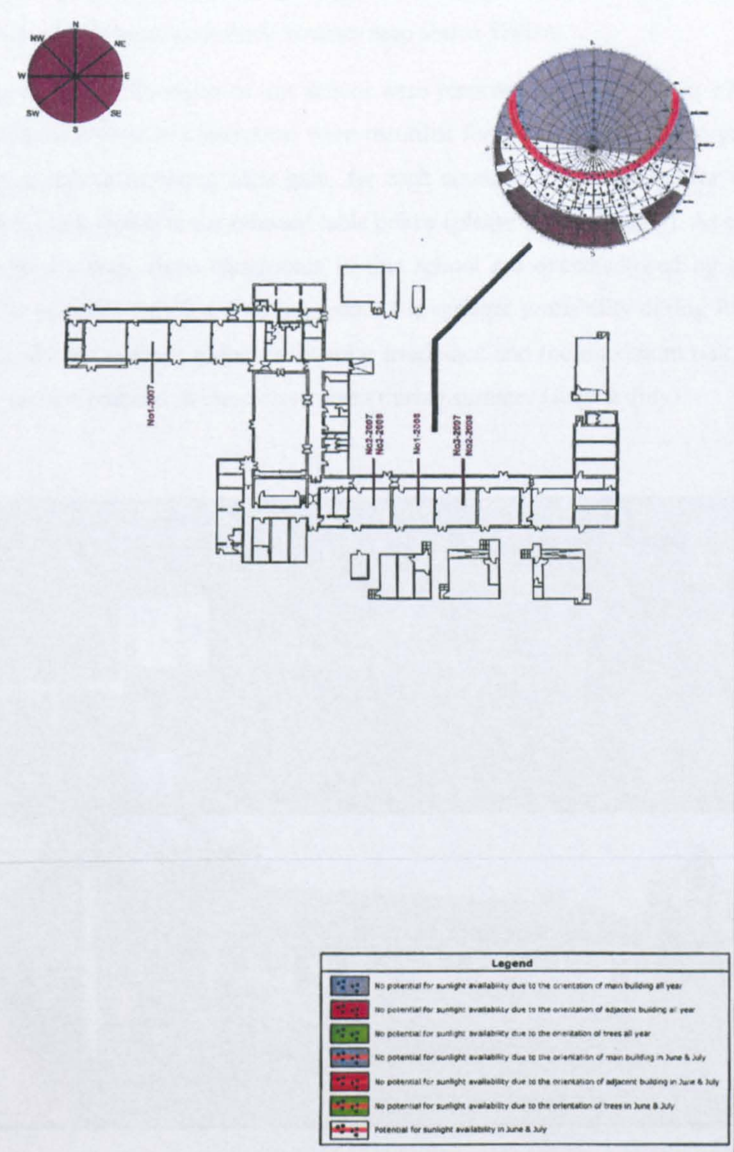
School	Building	Month	Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) (month)	Average (W/m²) June & July
					Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
Wellington	No.3 (2007) No.3 (2008)	June	SE	Beam	1.05	6.6	23.3	44.4	63.3	72.6	74.4	67.1	51.8	30.6	5.4	0	0	0	0	0	0	0		129
				Diffuse	21	50	82	133	163	180	187	183	173	157	123	134	113	94	69	42	20	8		
				Globe	**22.1**	**56.6**	**105**	**177**	**226**	**253**	**261**	**250**	**225**	**188**	**128**	**134**	**113**	**94**	**69**	**42**	**20**	**8**	**132**	
		July	SE	Beam	1.05	6	22.2	41	57.2	67.5	68.9	61.8	47.3	28.5	5.55	0	0	0	0	0	0	0		
				Diffuse	16	43	69	113	151	171	183	186	179	162	124	131	107	85	64	35	14	5		
				Globe	**17.1**	**49**	**91.2**	**154**	**208**	**239**	**252**	**248**	**226**	**191**	**130**	**131**	**107**	**85**	**64**	**35**	**14**	**5**	**125**	

Table 8.15: Adjusted average global daily solar irradiance considering the impact of overshadowing in Wellington Primary School

Wellington Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	52	46	9.5	SW	259	No	No	No	259	2463	2463	47	54	Low	Noisy
No.2	GF	69	45	12.0	NE	197	No	[illegible]	No	[illegible]	1992	3040	44	67	Low	Noisy
				4.0	SE	262	No	No	No	262	1048					
No.3	GF	62	62	4.0	NW	195	No	No	No	195	780	1296	21	21	Low	Noisy
				4.0	SE	262	No	No	[illegible]	[illegible]	516					
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	52	46	9.5	SW	259	No	No	No	259	2463	2463	47	54	Low	Noisy
No.2	GF	69	45	12.0	NE	197	No	[illegible]	No	[illegible]	1992	3040	44	67	Low	Noisy
				4.0	SE	262	No	No	No	262	1048					
No.3	GF	62	62	4.0	NW	195	No	No	No	195	780	1296	21	21	Low	Noisy
				4.0	SE	262	No	No	[illegible]	[illegible]	516					

Appendix 9.3: Cranford Primary School



Cranford Primary School is an open air school, built after the World War I in 1937 which was redesigned after oil crisis (i.e. closed corridors were added). This school is categorised as a low thermal mass (due to the reasons which are explained in chapter 3) and is identified as noisy school since it is located on aircraft noise counter map above 57dBA.

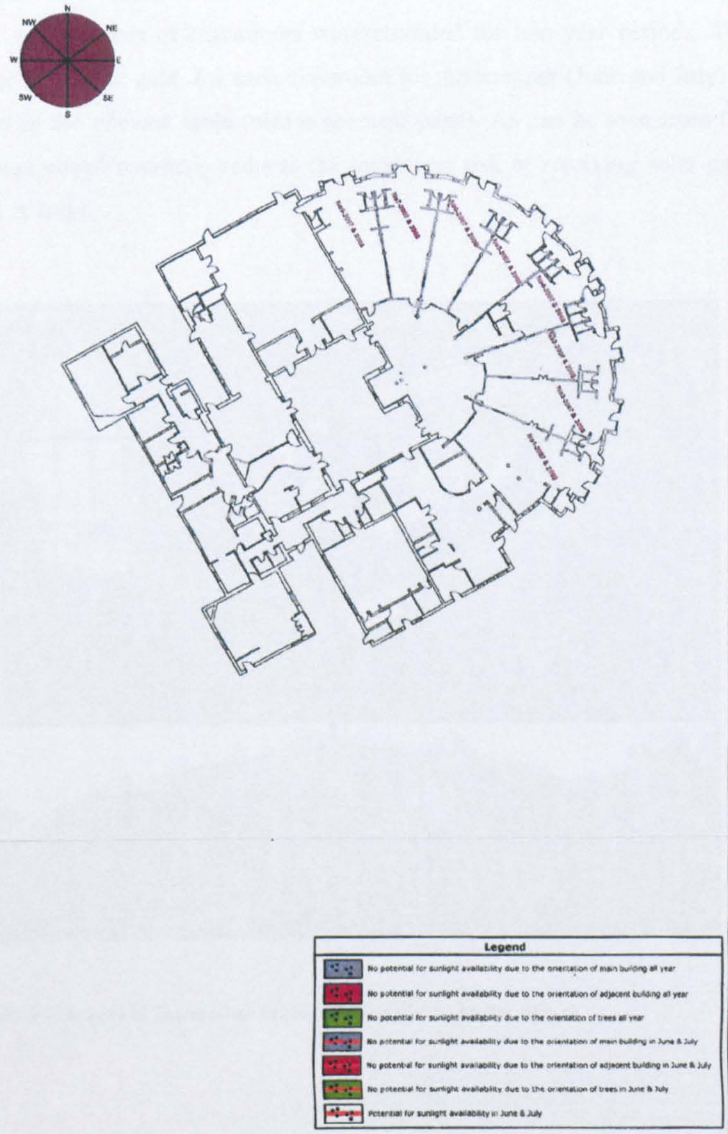
The indoor temperatures of 4 classrooms of this school were recorded for this study in 2007 & 2008. The indoor temperatures of classrooms were recorded for either a year or two year periods. The maximum risk of receiving solar gain for each classroom is calculated for the summer (June and July) and shown in the relevant table below (please see next page). As can be seen from the school's map, three classrooms in this school are overshadowed by the opposite building. The opposite building does not reduce the sunlight probability during June & July and consequently the average global daily solar irradiance and the maximum risk of receiving solar gain are not reduced in these classrooms during summer (June & July).

Figure 8.3: Images of Cranford Primary School (Taken by the author)

Cranford Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	48	44	10.0	S	217	No	No	No	217	2170	2170	45	49	Low	Noisy
No.2	GF	48	44	10.0	S	217	No	No	No	217	2170	2170	45	49	Low	Noisy
No.3	GF	48	44	10.0	S	217	No	No	No	217	2170	2170	45	49	Low	Noisy
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	48	44	10.0	S	217	No	No	No	217	2170	2170	45	49	Low	Noisy
No.2	GF	48	44	10.0	S	217	No	No	No	217	2170	2170	45	49	Low	Noisy
No.3	GF	48	44	10.0	S	217	No	No	No	217	2170	2170	45	49	Low	Noisy

Appendix 9.4: Grove Road Primary School



Grove Road primary school was built after the oil crisis. This school is categorised as a medium thermal mass school (due to the reasons which are explained in chapter 3) and is identified as noisy school since it is located on aircraft noise counter map above 57dBA.

The indoor temperatures of 8 classrooms of this school were recorded for this study in 2007 & 2008. The indoor temperatures of classrooms were recorded for two year periods. The maximum risk of receiving solar gain for each classroom for the summer (June and July) is calculated and shown in the relevant table (please see next page). As can be seen from the relevant table, the classrooms' overhang reduces the maximum risk of receiving solar gain during summer (June & July).

Figure 8.4: Images of Grove Road Primary School (Taken by the author)

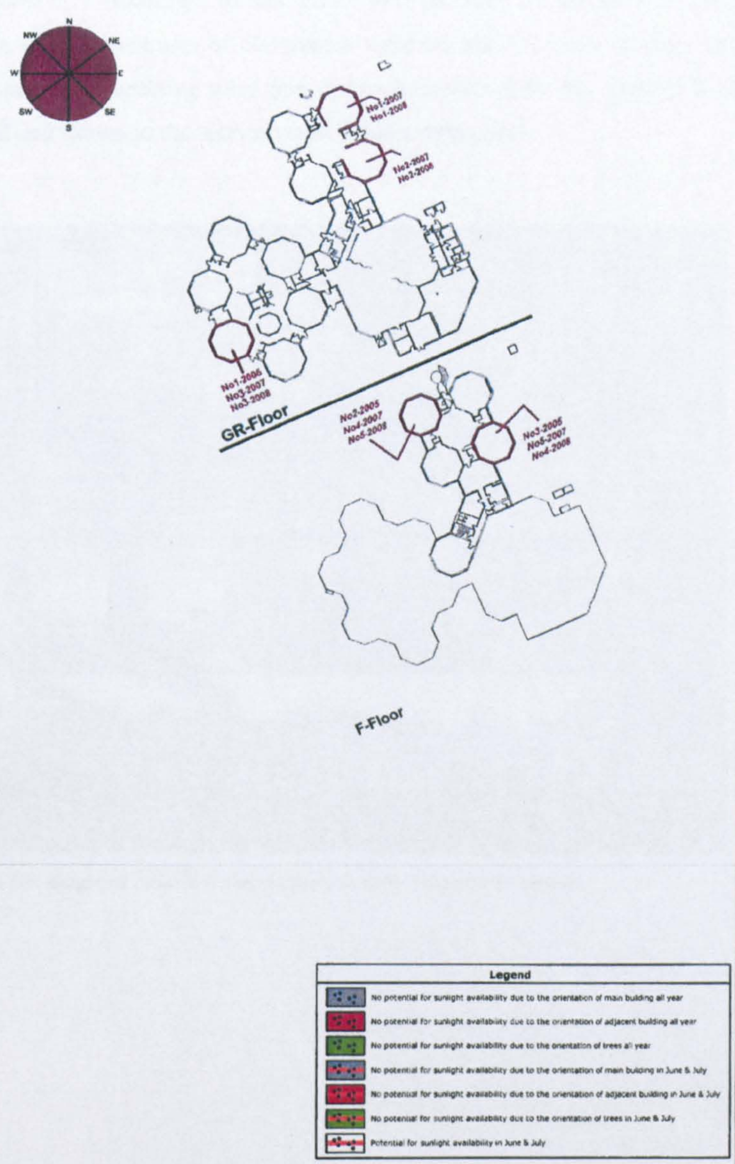
Grove Road Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average Irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	80	43	8.6	SE	262.0	0.433	No	No	113.4	974.5	974	12	23	Medium	Noisy
No.2	GF	57	28	8.6	E	269.0	0.579	No	No	155.8	1337.9	1338	23	49	Medium	Noisy
No.3	GF	55	27	8.6	E	269.0	0.579	No	No	155.8	1337.9	1338	24	49	Medium	Noisy
No.4	GF	40	23	8.6	E	269.0	0.579	No	No	155.8	1337.9	1338	33	57	Medium	Noisy
No.5	GF	54	25	8.6	NE	197.0	0.649	No	No	127.9	1098.3	1098	20	43	Medium	Noisy
No.6	GF	61	30	8.6	N	131.0	0.734	No	No	96.2	826.0	826	14	27	Medium	Noisy
No.7	GF	60	30	8.6	N	131.0	0.734	No	No	96.2	826.0	826	14	28	Medium	Noisy
No.8	GF	64	32	8.6	N	131.0	0.734	No	No	96.2	826.0	826	13	26	Medium	Noisy

Grove Road Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	80	43	8.6	SE	262.0	0.433	No	No	113.4	974	974	12	23	Medium	Noisy
No.2	GF	57	28	8.6	E	269.0	0.579	No	No	155.8	1338	1338	23	49	Medium	Noisy
No.3	GF	55	27	8.6	E	269.0	0.579	No	No	155.8	1338	1338	24	49	Medium	Noisy
No.4	GF	40	23	8.6	E	269.0	0.579	No	No	155.8	1338	1338	33	57	Medium	Noisy
No.5	GF	54	25	8.6	NE	197.0	0.649	No	No	127.9	1098	1098	20	43	Medium	Noisy
No.6	GF	61	30	8.6	N	131.0	0.734	No	No	96.2	826	826	14	27	Medium	Noisy
No.7	GF	60	30	8.6	N	131.0	0.734	No	No	96.2	826	826	14	28	Medium	Noisy
No.8	GF	64	32	8.6	N	131.0	0.734	No	No	96.2	826	826	13	26	Medium	Noisy

Appendix 9.5: Andrew Ewing Primary School



Andrew Ewing primary school was built after the oil crisis. This school is categorised as a medium thermal mass school (due to the reasons which are explained in chapter 3) and is identified as noisy school since it is located on aircraft noise counter map above 57dBA.

The indoor temperatures of 5 classrooms of this school were recorded for this study in 2005, 2007 & 2008. The indoor temperatures of classrooms were recorded for two or three year periods. The maximum risk of receiving solar gain for each classroom for the summer (June and July) is calculated and shown in the relevant table (please next page).

Figure 8.5: Images of Andrew Ewing Primary School (Taken by the author)

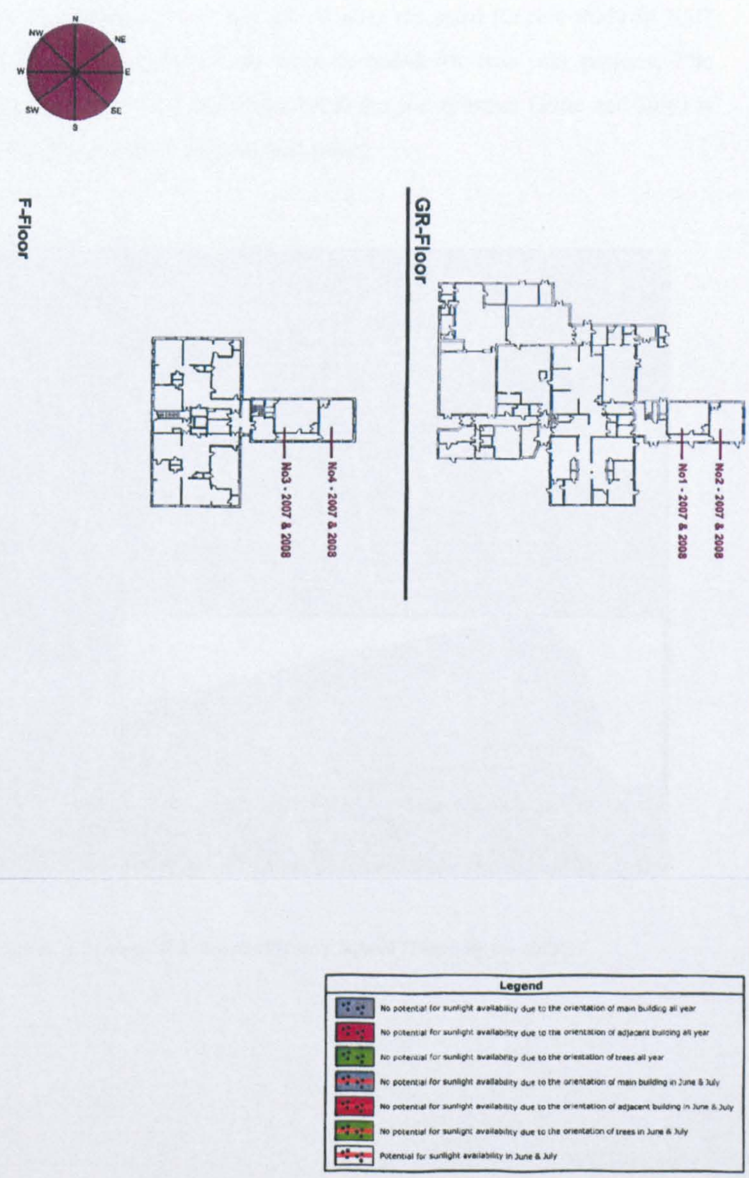
Andrew Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2005	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	49	49	1.1	NW	195	No	No	No	195	215	2709	55	55	Medium	Noisy
				3.3	W	266	No	No	No	266	878					
				4.4	SW	259	No	No	No	259	1140					
				2.2	S	217	No	No	No	217	477					
No.2	FF	49	49	1.1	N	131	No	No	No	131	144	1728	36	36	Medium	Noisy
				2.2	NW	195	No	No	No	195	429					
				2.2	W	266	No	No	No	266	585					
				2.2	SW	259	No	No	No	259	570					
No.3	FF	48	48	2.2	NE	197	No	No	No	197	433	2129	44	44	Medium	Noisy
				2.2	E	269	No	No	No	269	592					
				3.3	SE	262	No	No	No	262	865					
				1.1	S	217	No	No	No	217	239					
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	48	48	2.2	NW	195	No	No	No	195	429	3040	63	63	Medium	Noisy
				4.4	N	131	No	No	No	131	576					
				4.4	NE	197	No	No	No	197	867					
				2.2	E	269	No	No	No	269	592					
				2.2	SE	262	No	No	No	262	576					
No.2	GF	49	49	2.2	N	131	No	No	No	131	288	3102	63	63	Medium	Noisy
				4.4	E	269	No	No	No	269	1184					
				4.4	SE	262	No	No	No	262	1153					
				2.2	S	217	No	No	No	217	477					
No.3	GF	49	49	1.1	NW	195	No	No	No	195	215	2709	55	55	Medium	Noisy
				3.3	W	266	No	No	No	266	878					
				4.4	SW	259	No	No	No	259	1140					
				2.2	S	217	No	No	No	217	477					
No.4	FF	49	49	1.1	N	131	No	No	No	131	144	1728	36	36	Medium	Noisy
				2.2	NW	195	No	No	No	195	429					
				2.2	W	266	No	No	No	266	585					
				2.2	SW	259	No	No	No	259	570					
No.5	FF	48	48	2.2	NE	197	No	No	No	197	433	2129	44	44	Medium	Noisy
				2.2	E	269	No	No	No	269	592					
				3.3	SE	262	No	No	No	262	865					
				1.1	S	217	No	No	No	217	239					

Andrew Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone Wat.Sqm	Thermal Mass	Location
No.1	GF	48	48	2.2	NW	195	No	No	No	195	429	3040	63	63	Medium	Noisy
				4.4	N	131	No	No	No	131	576					
				4.4	NE	197	No	No	No	197	867					
				2.2	E	269	No	No	No	269	592					
				2.2	SE	262	No	No	No	262	576					
No.2	GF	49	49	2.2	N	131	No	No	No	131	288	3102	63	63	Medium	Noisy
				4.4	E	269	No	No	No	269	1184					
				4.4	SE	262	No	No	No	262	1153					
				2.2	S	217	No	No	No	217	477					
No.3	GF	49	49	1.1	NW	195	No	No	No	195	215	2709	55	55	Medium	Noisy
				3.3	W	266	No	No	No	266	878					
				4.4	SW	259	No	No	No	259	1140					
				2.2	S	217	No	No	No	217	477					
No.4	FF	49	49	1.1	N	131	No	No	No	131	144	1728	36	36	Medium	Noisy
				2.2	NW	195	No	No	No	195	429					
				2.2	W	266	No	No	No	266	585					
				2.2	SW	259	No	No	No	259	570					
No.5	FF	48	48	2.2	NE	197	No	No	No	197	433	2129	44	44	Medium	Noisy
				2.2	E	269	No	No	No	269	592					
				3.3	SE	262	No	No	No	262	865					
				1.1	S	217	No	No	No	217	239					

Appendix 9.6: St M&M Primary School



St Michael & St Martin primary school was built after the oil crisis. This school is categorised as a medium thermal mass school (due to the reasons which are explained in chapter 3) and is identified as noisy school since it is located on aircraft noise counter map above 57dBA.

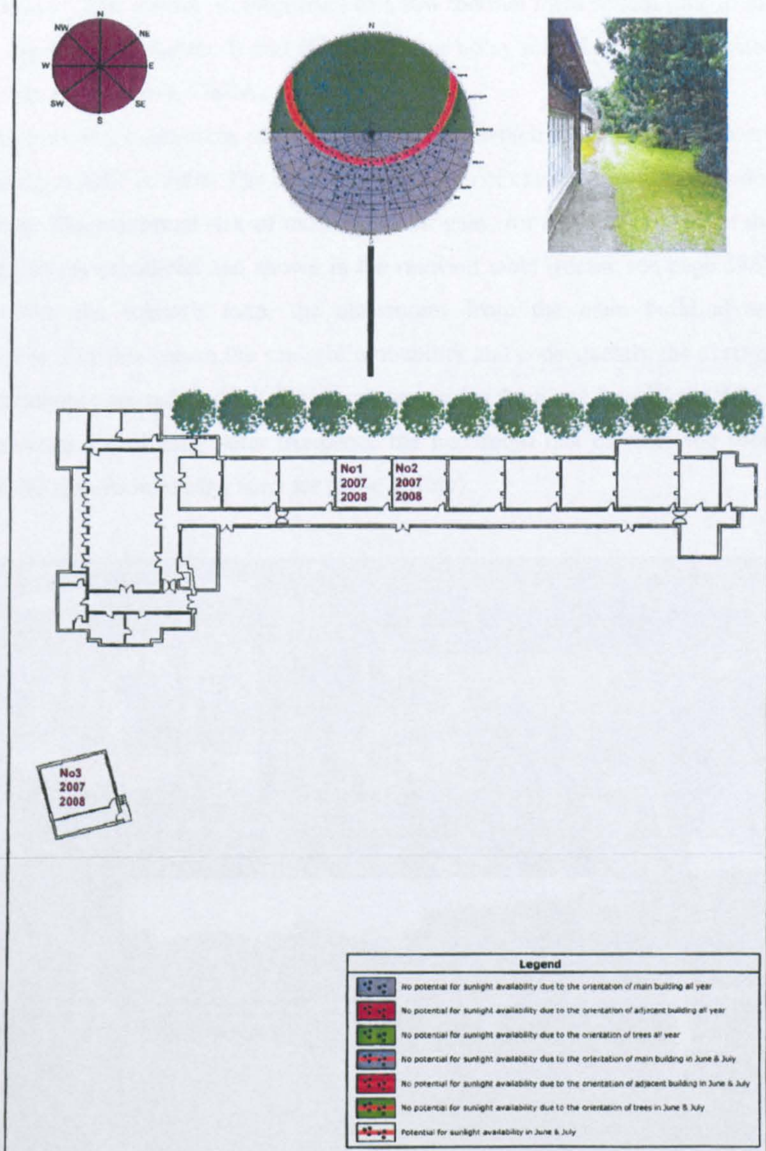
. The indoor temperatures of 4 classrooms of this school were recorded for this study in 2007 & 2008. The indoor temperatures of classrooms were recorded for two year periods. The maximum risk of receiving solar gain for each classroom for the summer (June and July) is calculated and shown in the relevant table (please next page).

Figure 8.6: Images of St Michael & St Martin Primary School (Taken by the author)

STMM Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	55	55	5.4	S	217	No	No	No	217	1174	3139	58	58	Medium	Noisy
				3.2	E	269	No	No	No	269	858					
				4.2	W	266	No	No	No	266	1107					
No.2	GF	56	51	7.7	N	131	No	No	No	131	1008	1008	18	20	Medium	Noisy
No.3	FF	56	51	6.1	N	131	No	No	No	131	797	797	14	16	Medium	Noisy
No.4	FF	56	56	3.8	S	217	No	No	No	217	816	2365	42	42	Medium	Noisy
				2.5	E	269	No	No	No	269	675					
				3.3	W	266	No	No	No	266	874					
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	55	55	5.4	S	217	No	No	No	217	1174	3139	58	58	Medium	Noisy
				3.2	E	269	No	No	No	269	858					
				4.2	W	266	No	No	No	266	1107					
No.2	GF	56	51	7.7	N	131	No	No	No	131	1008	1008	18	20	Medium	Noisy
No.3	FF	56	51	6.1	N	131	No	No	No	131	797	797	14	16	Medium	Noisy
No.4	FF	56	56	3.8	S	217	No	No	No	217	816	2365	42	42	Medium	Noisy
				2.5	E	269	No	No	No	269	675					
				3.3	W	266	No	No	No	266	874					

Appendix 9.7: Heston Primary School



Heston Primary School is an open air school, built after the World War I in 1936 which has been redesigned after the oil crisis (i.e. closed corridors were added). This school has some prefabricated classrooms. This school is categorised as a low thermal mass school (due to the reasons which are explained in chapter 3) and is identified as noisy school since it is located on aircraft noise counter map above 57dBA.

The indoor temperatures of 3 classrooms of this school (one of which is prefabricated) were recorded for this study in 2007 & 2008. The indoor temperatures of classrooms were recorded for a two year period. The maximum risk of receiving solar gain for each classroom for the summer (June and July) is calculated and shown in the relevant table (please see page 376). As can be seen from the school's map, the classrooms from the main building are overshadowed by trees. For this reason the sunlight probability and consequently the average global daily solar irradiance are reduced for this classroom during June and July (Table 8.16). By reducing the average global daily solar irradiance the maximum risk of receiving solar gain is reduced for this classroom during summer (June & July).

Figure 8.7: Images of Heston Primary School (Taken by the author)

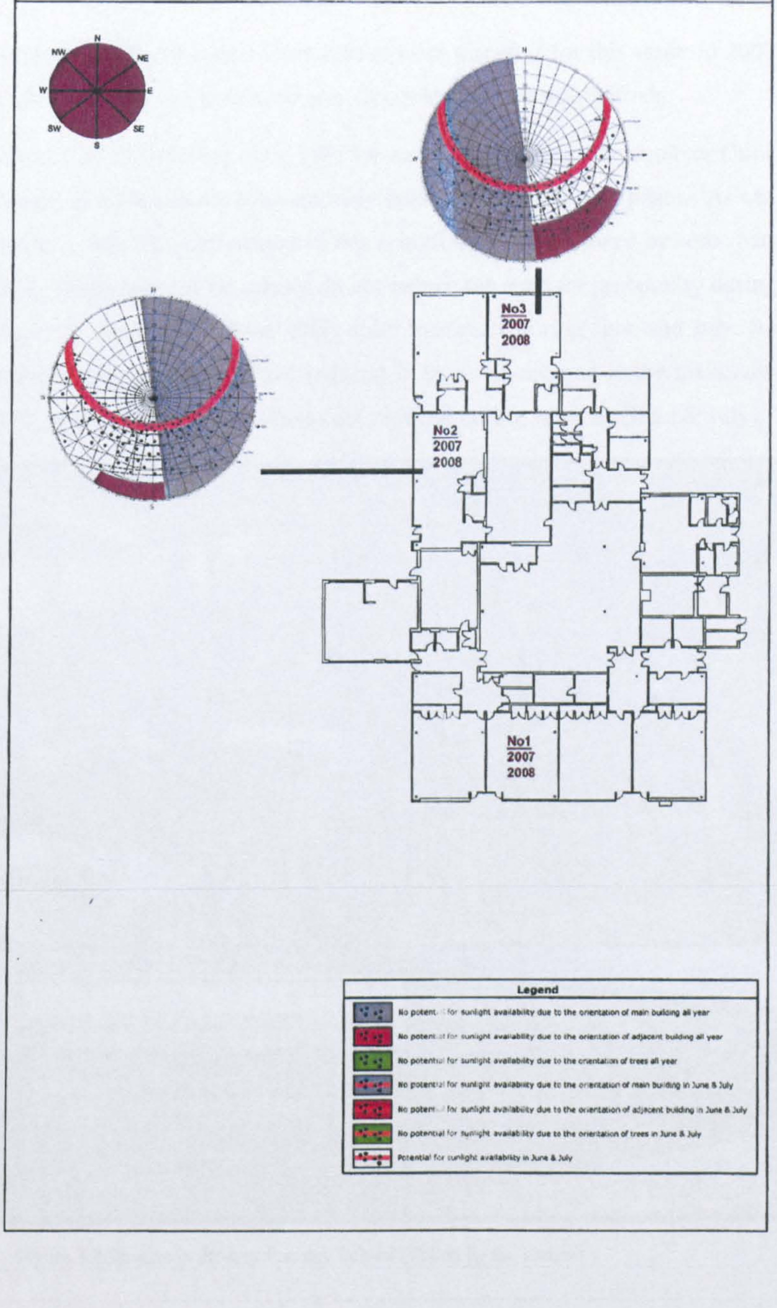
Heston	No.2 (2007) No.2 (2008) No.3 (2007) No.3 (2008)	June																					Average (W/m²) June & July
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) June	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
		N	Beam	6	15	19.8	12.8	0	0	0	0	0	0	0	0	0	0	12.3	20	15	6		99
			Diffuse	25	55	76	85	111	117	125	134	139	140	135	127	121	114	85	77	58	25		
			Globe	**31**	**70**	**95.8**	**97.8**	**111**	**117**	**125**	**134**	**139**	**140**	**135**	**127**	**121**	**114**	**97.3**	**97**	**73**	**31**	**103**	
		July																					
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
		N	Beam	5.25	13.2	18.3	11.3	0	0	0	0	0	0	0	0	0	0	11.1	18.2	13.1	5.25		
			Diffuse	20	47	64	73	103	110	121	133	140	141	132	123	113	102	78	62	43	18		
			Globe	**25.3**	**60.2**	**82.3**	**84.3**	**103**	**110**	**121**	**133**	**140**	**141**	**132**	**123**	**113**	**102**	**89.1**	**80.2**	**56.1**	**23.25**	**95**	

Table 8.16: Adjusted average daily global solar irradiance amount considering the impact of overshadowing in Heston Primary School

Heston Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	48	44	11.0	N	131	No	No	3:30/20:30	99	1089	1089	23	25	Low	Noisy
No.2	GF	48	44	11.0	N	131	No	No	3:30/20:30	99	1089	1089	23	25	Low	Noisy
No.3	GF	48	46	6.7	E	269	No	No	No	269	1808	3595	75	79	Low	Noisy
				6.7	W	266	No	No	No	266	1788					
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	48	44	11.0	N	131	No	No	[illegible]	99	1089	1089	23	25	Low	Noisy
No.2	GF	48	44	11.0	N	131	No	No	[illegible]	[illegible]	1089	1089	23	25	Low	Noisy
No.3	GF	48	46	6.7	E	269	No	No	No	269	1808	3595	75	79	Low	Noisy
				6.7	W	266	No	No	No	266	1788					

Appendix 9.8: Rosary Primary School



Rosary Primary School is an open air school, built after the World War II in 1965. This school is categorised as a low thermal mass (due to the reasons which are explained in chapter 3) and is identified as noisy school since it is located on aircraft noise counter map above 57dBA.

The indoor temperatures of 3 classrooms of this school were recorded for this study in 2007 & 2008. The indoor temperatures of classrooms were recorded for two year periods.

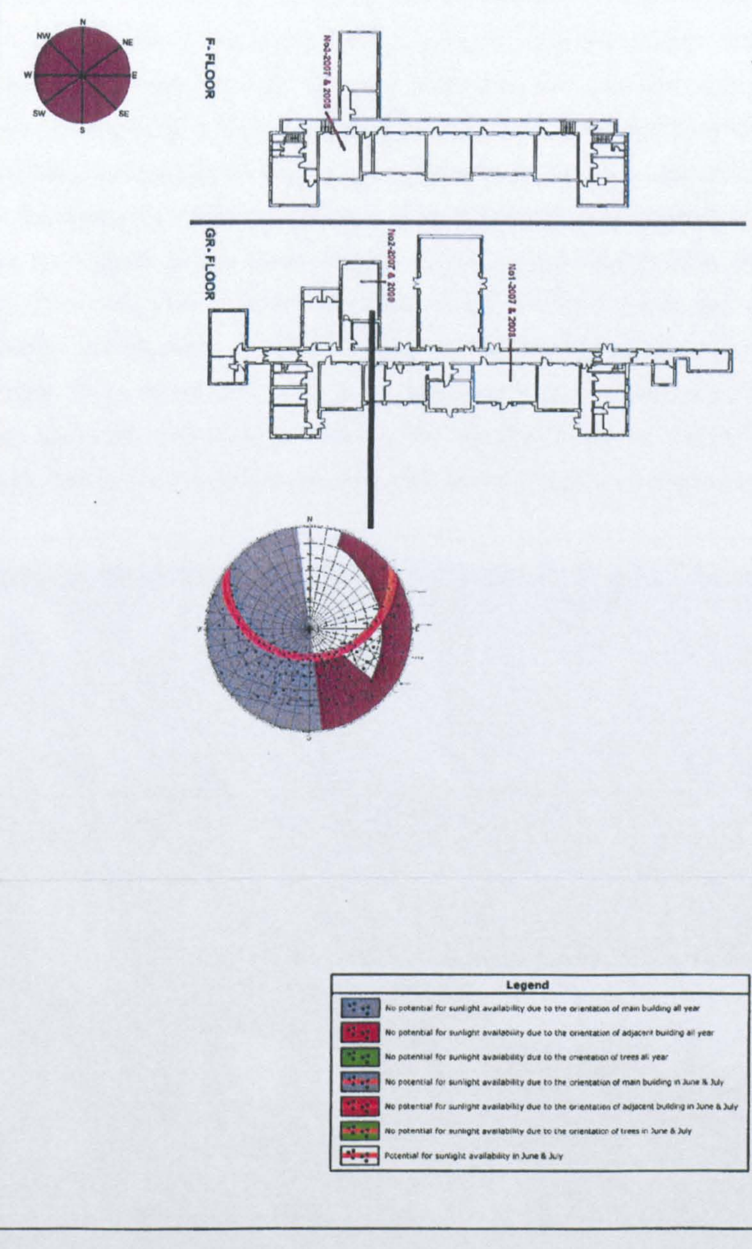
The summer maximum risk of receiving solar gain for each classroom for the summer (June and July) is calculated and shown in the relevant table below (please see next page). As can be seen from the school's map, two classrooms in this school are overshadowed by some part of the school building. These parts of the school do not reduce the sunlight probability during summer and consequently the average global daily solar irradiance during June and July. As the average global daily solar irradiance is not reduced in these classrooms so the maximum risk of receiving solar gain for these classrooms is not reduced during summer (June & July).

Figure 8.8: Images of Rosary Primary School (Taken by the author)

Rosary Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	62	44	10.0	S	217	0.545	No	No	118	1183	1183	19	27	Low	Noisy
No.2	GF	84	76	21.0	W	266	No	No	No	266	5586	5586	67	73	Low	Noisy
No.3	GF	69	69	4.0	N	131	No	No	No	131	524	3483	51	51	Low	Noisy
				11.0	E	269	No	No	No	269	2959					
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	64	43	10.0	S	217	0.545	No	No	118	1183	1183	19	27	Low	Noisy
No.2	GF	83	76	21.0	W	266	No	No	No	266	5586	5586	67	73	Low	Noisy
No.3	GF	70	69	4.0	N	131	No	No	No	131	524	3483	50	51	Low	Noisy
				11.0	E	269	No	No	No	269	2959					

Appendix 9.9: Feltham Primary School



Feltham Hill Primary School is a Victorian school built in 1965. This school is categorised as a heavy thermal mass school (due to the reasons which are explained in chapter 3) and is identified as quiet school since it is located on aircraft noise counter map below 57dBA.
The indoor temperatures of 3 classrooms of this school were recorded for this study in 2007 & 2008. The indoor temperatures of classrooms were recorded for two year periods. The maximum risk of receiving solar gain for each classroom for the summer (June and July) is calculated and shown in the relevant table (please see page 383). As can be seen from the school's map, one of the classrooms (classroom No.2) is overshadowed by some part of the school building. For this reason the sunlight probability and consequently the average global daily solar irradiance are reduced for this classroom during June and July (Table 8.17). By reducing the average global daily solar irradiance the maximum risk of receiving solar gain is reduced for this classroom during summer (June & July). In this school a solar reflective film is used on the windows. The solar reflective film has a significant impact on reducing the amount of solar gain that each classroom can receive. The discount factor for the solar reflective film is about 70% so the calculated maximum solar gain potential is multiplied by this amount.

Figure 8.9: Images of Feltham Primary School (Taken by the author)

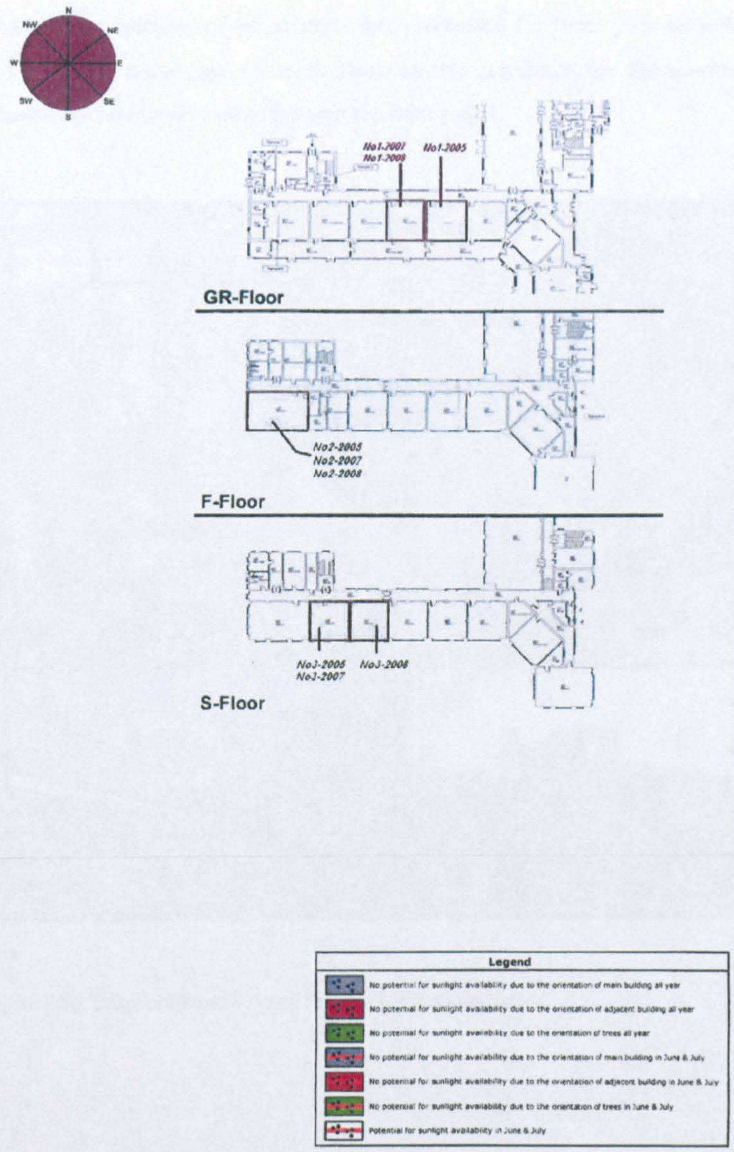
Feltham	No.2 (2007) No.2 (2008)	June																					Average (W/m²) June & July
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) June	
				Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
		E	Beam	0	0	0	0	579	544	0	0	0	0	0	0	0	0	0	0	0	0		168
			Diffuse	27	66	126	175	189	189	180	163	140	149	135	127	113	94	69	42	20	8		
			Globe	27	66	126	175	768	733	180	163	140	149	135	127	113	94	69	42	20	8	174	
		July																					
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²)July	
				Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
		E	Beam	0	0	0	0	519	502	0	0	0	0	0	0	0	0	0	0	0	0		
			Diffuse	22	57	106	147	174	179	176	166	144	150	132	123	107	85	64	35	14	5		
			Globe	22	57	106	147	693	681	176	166	144	150	132	123	107	85	64	35	14	5	162	

Table 8.17: Adjusted average daily global solar irradiance amount considering the impact of overshadowing in Feltham Primary School

Feltham Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	56	56	17.1	S	217	No	No	No	217	3711	3711	67	67	Heavy	Quiet
No.2	GF	50	50	9.1	N	131	No	No	No	131	1192	1750	35	35	Heavy	Quiet
				3.3	E	269	No	(1:30-6:30) (9:30-11:30)	No	168	558					
No.3	FF	46	46	9.7	S	217	No	No	No	217	2109	2109	46	46	Heavy	Quiet
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	56	56	17.1	S	217	No	No	No	217	3711	3711	67	67	Heavy	Quiet
No.2	GF	50	50	9.1	N	131	No	No	No	131	1192	1750	35	35	Heavy	Quiet
				3.3	E	269	No	(1:30-6:30) (9:30-11:30)	No	168	558					
No.3	FF	46	46	9.7	S	217	No	No	No	217	2109	2109	46	46	Heavy	Quiet

Appendix 9.10: Pools Primary School



Pools primary school was built after the oil crisis. This school is categorised as a medium thermal mass school (due to the reasons which are explained in chapter 3) is identified as quiet school since it is located on aircraft noise counter map below 57dBA.

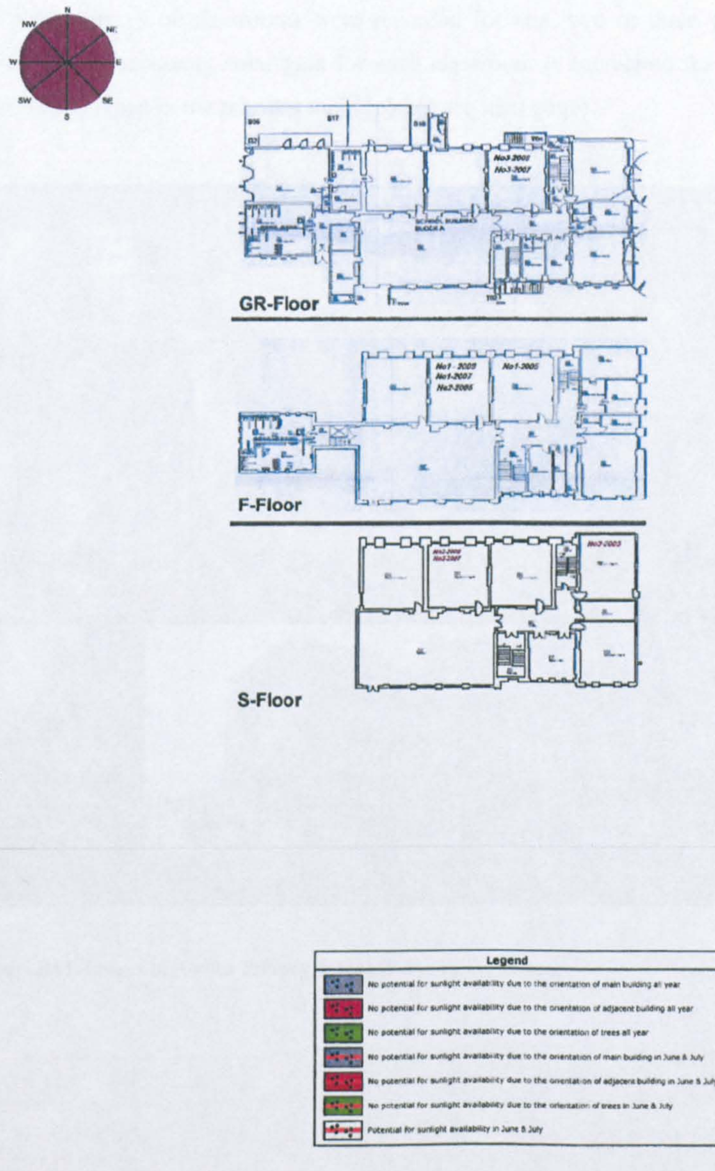
The indoor temperatures of 5 classrooms of this school were recorded for this study in 2005, 2007 & 2008. The indoor temperatures of classrooms were recorded for three year periods. The maximum risk of receiving solar gain for each classroom is calculated for the summer (June and July) and shown in the relevant table (please see next page).

Figure 8.10: Images of Pools Primary School (Taken by the author)

Pools Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2005	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	45	41	16.1	SE	262	No	No	No	262	4218	4218	94	103	Heavy	Quiet
No.2	FF	75	70	9.2 14.2	SW SE	259 262	No	No	No	259 262	2393 3718	6111	82	87	Heavy	Quiet
No.3	SF	55	41	7.9	SE	262	No	No	No	262	2059	2059	37	50	Heavy	Quiet
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	45	41	16.1	SE	262	No	No	No	262	4218	4218	94	103	Heavy	Quiet
No.2	FF	75	70	9.2 14.2	SW SE	259 262	No No	No No	No No	259 262	2393 3718	6111	82	87	Heavy	Quiet
No.3	SF	64	41	7.9	SE	262	No	No	No	262	2059	2059	32	50	Heavy	Quiet
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	45	41	16.1	SE	262	No	No	No	262	4218	4218	94	103	Heavy	Quiet
No.2	FF	75	70	9.2 14.2	SW SE	259 262	No No	No No	No No	259 262	2393 3718	6111	82	87	Heavy	Quiet
No.3	SF	64	41	7.9	SE	262	No	No	No	262	2059	2059	32	50	Heavy	Quiet

Appendix 9.11: Ambler Primary School



Ambler primary school is a Victorian school built in 1898. This school is categorised as a heavy thermal mass (due to the reasons which are explained in chapter 3) and is identified as quiet school since it is located on aircraft noise counter map below 57dBA.

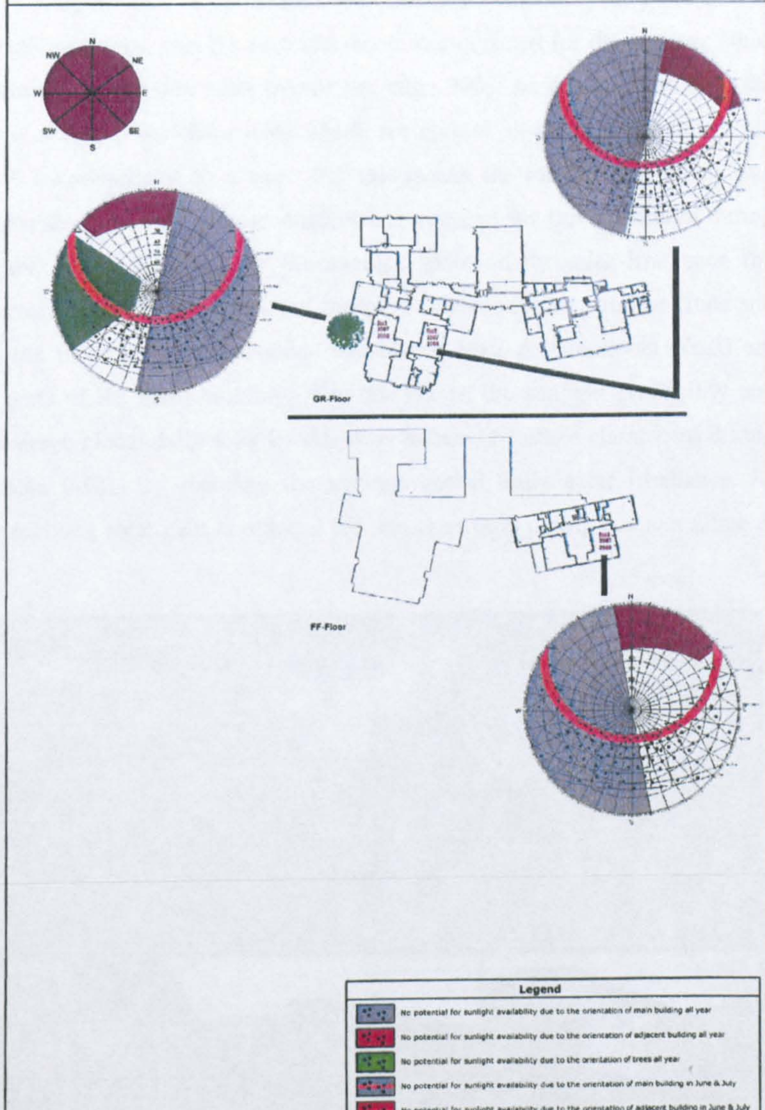
The indoor temperatures of 4 classrooms of this school were recorded for this study in 2007 & 2008. The indoor temperatures of classrooms were recorded for one, two or three year periods. The maximum risk of receiving solar gain for each classroom is calculated for the summer (June and July) and shown in the relevant table (please see next page).

Figure 8.11: Images of Ambler Primary School (Taken by the author)

Ambler Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2005	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	FF	56	44	13.0	NW	195	No	No	No	195	2541	2541	46	57	Heavy	Quiet
No.2	FF	56	44	13.0	NW	195	No	No	No	195	2541	2541	46	57	Heavy	Quiet
No.3	SF	52	48	2.0	NW	195	No	No	No	195	390	2793	54	59	Heavy	Quiet
				12.2	NE	197	No	No	No	197	2403					
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	FF	56	44	13.0	NW	195	No	No	No	195	2541	2541	46	57	Heavy	Quiet
No.2	SF	56	44	13.0	NW	195	No	No	No	195	2541	2541	46	57	Heavy	Quiet
No.3	GF	56	44	13.0	NW	195	No	No	No	195	2541	2541	46	57	Heavy	Quiet
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	FF	56	44	13.0	NW	195	No	No	No	195	2541	2541	46	57	Heavy	Quiet
No.2	SF	56	44	13.0	NW	195	No	No	No	195	2541	2541	46	57	Heavy	Quiet
No.3	GF	56	44	13.0	NW	195	No	No	No	195	2541	2541	46	57	Heavy	Quiet

Appendix 9.12: Norwood Primary School



Norwood primary school is a post war school built in 1955. This school is categorised as a low thermal mass school (due to the reasons which are explained in chapter 3) and is identified as quiet school since it is located on aircraft noise counter map below 57dBA.

The indoor temperatures of 3 classrooms of this school were recorded for this study in 2007 & 2008. The indoor temperatures of classrooms were recorded for two year periods. The maximum risk of receiving solar gain for each classroom is calculated for the summer (June and July) and shown in the relevant table (please see page 393). As can be seen from the school's map, 1 out of the 3 the classrooms which are chosen as samples for this study (Classroom No.1) is overshadowed by a tree. For this reason the sunlight probability and consequently the average global daily solar irradiance is reduced for this classroom during June and July (Table 8.18). By reducing the average global daily solar irradiance the maximum risk of receiving solar gain is reduced for this classroom during summer (June and July). In addition the remaining 2 classrooms (Classroom No.2 & Classroom No.3) are overshadowed by parts of the main building. For this reason the sunlight probability and consequently the average global daily solar irradiance is reduced for these classrooms during June and July (Table 8.18). By reducing the average global daily solar irradiance the maximum risk of receiving solar gain is reduced for this classroom during summer (June & July).

Figure 8.12: Images of Norwood Green Primary School (Taken by the author)

Site	Building	Month	Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) (month)	Average (W/m²) June & July
					Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
Norwood	No.1 (2007) No.1 (2008)	June	W	Beam	0	0	0	0	0	0	0	0	0	101	284	64.65	76.95	81.3	72.45	53.25	24.45	51		153
				Diffuse	8	18	41	69	91	110	125	134	148	140	165	185	197	196	175	128	69	27		
				Globe	**8**	**18**	**41**	**69**	**91**	**110**	**125**	**134**	**148**	**241**	**449**	**250**	**274**	**277**	**247**	**181**	**93.5**	**78**	**158**	
		July	W	Beam	0	0	0	0	0	0	0	0	0	92	264	60.3	73.7	78.6	68.9	49.4	21.6	45		
				Diffuse	6	16	35	60	85	104	121	133	149	144	165	181	184	173	157	102	52	20		
				Globe	**6**	**16**	**35**	**60**	**85**	**104**	**121**	**133**	**149**	**236**	**429**	**241**	**258**	**252**	**226**	**151**	**73.6**	**65**	**147**	

Site	Building	Month	Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) (month)	Average (W/m²) June & July
					Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
Norwood	No.2 (2007) No.2 (2008)	June	E	Beam	0	0	0	504	579	544	445	290	100	0	0	0	0	0	0	0	0	0		240
				Diffuse	27	66	126	175	189	189	180	163	140	149	135	127	113	94	69	42	20	8		
				Globe	**27**	**66**	**126**	**679**	**768**	**733**	**625**	**453**	**240**	**149**	**135**	**127**	**113**	**94**	**69**	**42**	**20**	**8**	**249**	
		July	E	Beam	0	0	0	461	519	502	409	265	90	0	0	0	0	0	0	0	0	0		
				Diffuse	22	57	106	147	174	179	176	166	144	150	132	123	107	85	64	35	14	5		
				Globe	**22**	**57**	**106**	**608**	**693**	**681**	**585**	**431**	**234**	**150**	**132**	**123**	**107**	**85**	**64**	**35**	**14**	**5**	**230**	

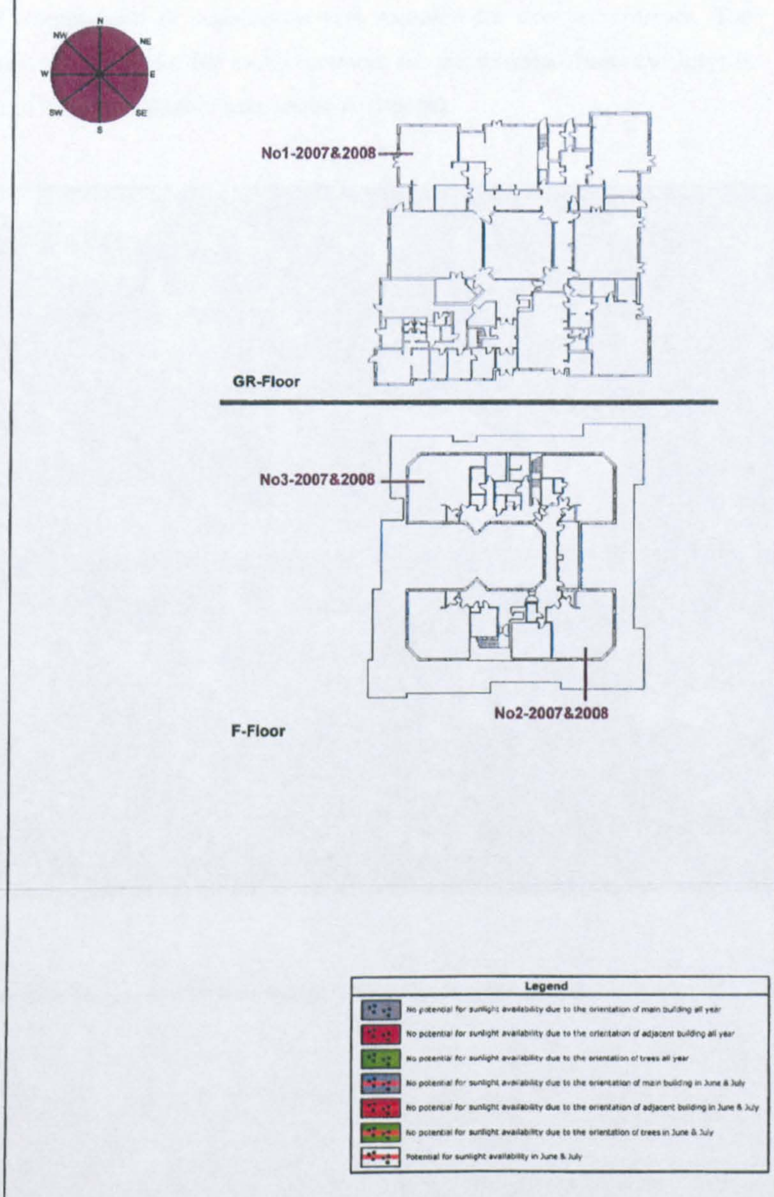
Site	Building	Month	Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) (month)	Average (W/m²) June & July
					Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
Norwood	No.3 (2007) No.3 (2008)	June	E	Beam	0	0	0	504	579	544	445	290	100	0	0	0	0	0	0	0	0	0		240
				Diffuse	27	66	126	175	189	189	180	163	140	149	135	127	113	94	69	42	20	8		
				Globe	**27**	**66**	**126**	**679**	**768**	**733**	**625**	**453**	**240**	**149**	**135**	**127**	**113**	**94**	**69**	**42**	**20**	**8**	**249**	
		July	E	Beam	0	0	0	461	519	502	409	265	90	0	0	0	0	0	0	0	0	0		
				Diffuse	22	57	106	147	174	179	176	166	144	150	132	123	107	85	64	35	14	5		
				Globe	**22**	**57**	**106**	**608**	**693**	**681**	**585**	**431**	**234**	**150**	**132**	**123**	**107**	**85**	**64**	**35**	**14**	**5**	**230**	

Table 8.18: Adjusted average daily global solar irradiance amount considering the impact of overshadowing in Norwood Primary School

Norwood Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	66	54	9.6	W	266	No	No	11:30-19:30	133	1464	1464	22	27	Low	Quiet
No.2	GF	66	53	9.6	E	269	No	1:30-5:30	No	240	2297	2297	35	43	Low	Quiet
No.3	GF	61	53	9.5	E	269	No	1:30-5:30	No	240	2275	2275	37	43	Low	Quiet
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	66	54	9.6	W	266	No	No	11:30-19:30	133	1464	1464	22	27	Low	Quiet
No.2	GF	66	53	9.6	E	269	No	1:30-5:30	No	240	2297	2297	35	43	Low	Quiet
No.3	GF	61	53	9.5	E	269	No	1:30-5:30	No	240	2275	2275	37	43	Low	Quiet

Appendix 9.13: Lady Primary School



Lady primary school was built after the oil crisis. This school is categorised as a medium thermal mass school (due to the reasons which are explained in chapter 3) and is identified as quiet school since it is located on aircraft noise counter map below 57dBA.

The indoor temperatures of 3 classrooms of this school were recorded for this study in 2007 & 2008. The indoor temperatures of classrooms were recorded for two year periods. The maximum risk of receiving solar gain for each classroom for the summer (June and July) is calculated and shown in the relevant table (please see next page).

Figure 8.13: Images of Lady Green Primary School (Taken by the author)

Lady Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	66	44	10.0	SW	259	No	No	No	259	2590	2590	39	58	Medium	Quiet
No.2	FF	77	72	4.9	NE	197	No	No	No	197	957	1905	25	26	Medium	Quiet
				4.9	NW	195	No	No	No	195	948					
No.3	FF	74	69	4.9	SE	262	No	No	No	262	1273	2742	37	40	Medium	Quiet
				5.7	SW	259	No	No	No	259	1469					
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	66	44	10.0	SW	259	No	No	No	259	2590	2590	39	58	Medium	Quiet
No.2	FF	77	72	4.9	NE	197	No	No	No	197	957	1905	25	26	Medium	Quiet
				4.9	NW	195	No	No	No	195	948					
No.3	FF	74	69	4.9	SE	262	No	No	No	262	1273	2742	37	40	Medium	Quiet
				5.7	SW	259	No	No	No	259	1469					

Appendix 9.14: Hungerford Primary School

Hungerford primary school is a Victorian school. This school is categorised as a heavy thermal mass school (due to the reasons which are explained in chapter 3) and is identified as quiet school since it is located on aircraft noise counter map below 57dBA.

The indoor temperatures of 7 classrooms of this school were recorded for this study in 2005, 2007 & 2008. The indoor temperatures of classrooms were recorded for either one or three year periods. The maximum risk of receiving solar gain for each classroom is calculated for the summer (June and July) and shown in the relevant table (please see page 400). As can be seen from the school's map, 6 out of 7 the classrooms which are chosen as samples for this study are overshadowed by trees during summer (June and July). For this reason the sunlight probability and consequently the average global daily solar irradiance are reduced for these classrooms during June & July (Table 8.19). By reducing the average global daily solar irradiance the maximum risk of receiving solar gain is reduced for these classrooms during summer (June and July).

Figure 8.14: Images of Hungerford Primary School (Taken by the author)

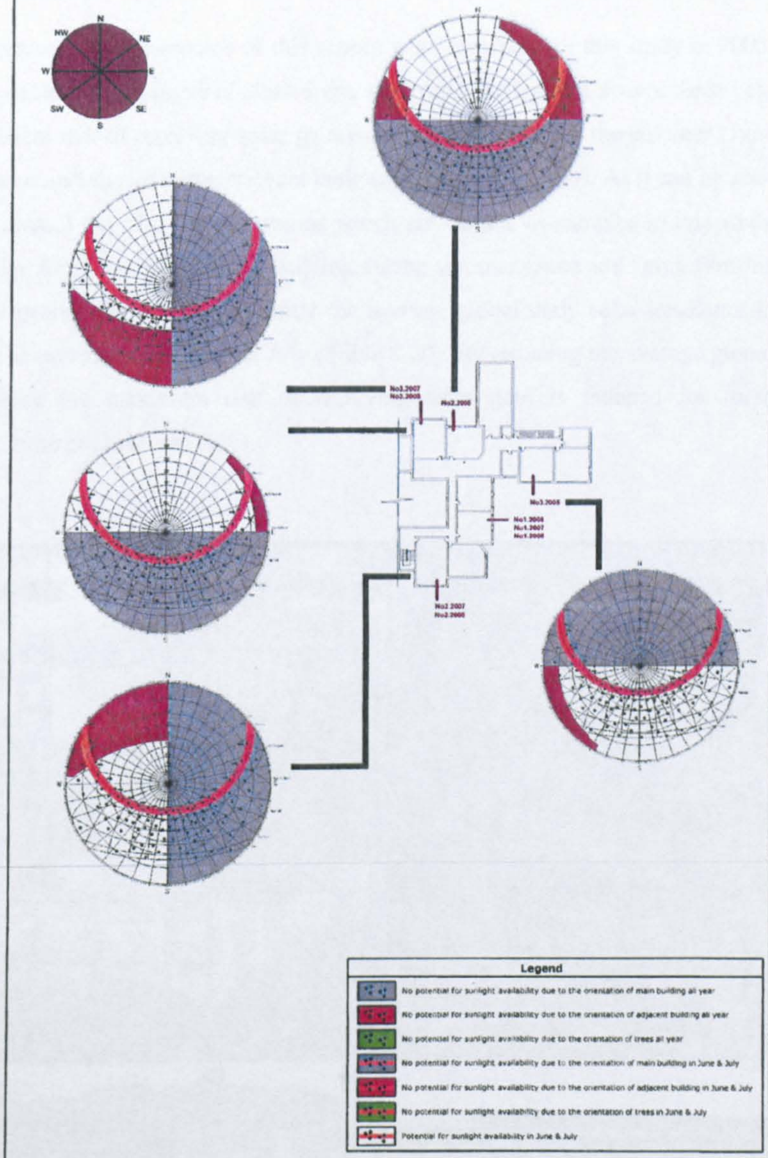
Hungerford	No.2(2005) No.3(2005) No.1(2007) No.3(1007) No.1(2008) No.3(2008) No.4(2008) No.5(2008) No.6(2008) No.7(2008)	June																					Average (W/m²) June & July
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
		NE	Beam	0	0	0	0	0	0	0	0	0	0	0	19.5	40.4	55.7	59.9	51.8	27.9	9.75		115
			Diffuse	9	19	41	69	91	110	125	134	139	140	159	138	156	164	157	126	75	32		
			Globe	**9**	**19**	**41**	**69**	**91**	**110**	**125**	**134**	**139**	**140**	**159**	**158**	**196**	**220**	**217**	**178**	**103**	**41.75**	**119**	
		July																					
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
		NE	Beam	0	0	0	0	0	0	0	0	0	0	0	17.6	38.1	53.6	56.6	47.7	24.6	8.55		
			Diffuse	6	17	35	60	85	104	121	133	140	141	155	135	147	145	141	100	56	23		
			Globe	**6**	**17**	**35**	**60**	**85**	**104**	**121**	**133**	**140**	**141**	**155**	**153**	**185**	**199**	**198**	**148**	**80.6**	**31.55**	**111**	

Table 8.19: Adjusted average daily global solar irradiance amount considering the impact of overshadowing in Hungerford Primary School

Hungerford Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2005	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	71	59	17.5	SW	259	None	None	None	259	4535	4535	63	77	Heavy	Quiet
No.2	GF	63	49	13.9	NW	195	None	None	[illegible]	115	1601	1601	25	33	Heavy	Quiet
No.3	GF	63	49	13.9	NW	195	None	None	[illegible]	115	1601	1601	25	33	Heavy	Quiet
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No 1	GF	63	49	13.9	NW	195	None	None	[illegible]	115	2714	2714	43	55	Heavy	Quiet
No.2	GF	71	59	17.5	SW	259	None	None	[illegible]	115	4535	4535	63	77	Heavy	Quiet
No.3	GF	63	49	13.9	NW	195	None	None	[illegible]	115	2714	2714	43	55	Heavy	Quiet
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	63	49	13.9	NW	195	None	None	[illegible]	115	1601	1601	25	33	Heavy	Quiet
No.2	GF	71	59	17.5	SW	259	None	None	None	259	4535	4535	63	77	Heavy	Quiet
No.3	GF	63	49	13.9	NW	195	None	None	[illegible]	115	1601	1601	25	33	Heavy	Quiet
No.4	GF	63	49	13.9	NW	195	None	None	[illegible]	115	1601	1601	25	33	Heavy	Quiet
No.5	FF	65	61	14.3 4.4	NW SW	195 259	None None	None None	[illegible] None	115 259	1649 1134	2784	43	45	Heavy	Quiet
No.6	FF	63	49	13.9	NW	195	None	None	[illegible]	115	1601	1601	25	33	Heavy	Quiet
No.7	FF	63	49	13.9	NW	195	None	None	[illegible]	115	1601	1601	25	33	Heavy	Quiet

Appendix 9.15: Coleraine Primary School



Colerain primary school is a Victorian school which was redesigned and extended through time. This school is categorised as a heavy thermal mass school (due to the reasons which are explained in chapter 3) and is identified as quiet school since it is located on aircraft noise counter map below 57dBA.

The indoor temperatures of 5 classrooms of this school were recorded for this study in 2005, 2007 & 2008. The indoor temperatures of classrooms were recorded for one, two or three year periods. The maximum risk of receiving solar gain for each classroom for the summer (June and July) is calculated and shown in the relevant table (please see page 404). As it can be seen from the school's map, 3 out of 7 the classrooms which are chosen as samples in this study are overshadowed by some part of the main building during summer (June and July). For this reason the sunlight probability and consequently the average global daily solar irradiance is reduced for these classrooms during June & July (Table 8.20). By reducing the average global daily solar irradiance the maximum risk of receiving solar gain is reduced for these classrooms during summer (June and July).

Figure 8.15: Images of Colerain Primary School (Taken by the author)

				June																			Average (W/m²) June & July
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) June	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
Coleraine	No2 (2005)	N	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40		100
			Diffuse	25	55	76	85	111	117	125	134	139	140	135	127	121	114	85	77	58	25		
			Globe	25	55	76	85	111	117	125	134	139	140	135	127	121	114	85	77	58	65	99	
				July																			
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
		N	Beam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35		
			Diffuse	20	47	64	73	103	110	121	133	140	141	132	123	113	102	78	62	43	18		
			Globe	20	47	64	73	103	110	121	133	140	141	132	123	113	102	78	62	43	53	92	

				June																			Average (W/m²) June & July
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) June	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
Coleraine	No2 (2007) No2 (2008)	W	Beam	0	0	0	0	0	0	0	0	0	101	284	431	513	542	483	0	0	0		236
			Diffuse	8	18	41	69	91	110	125	134	148	140	165	185	197	196	175	128	69	27		
			Globe	8	18	41	69	91	110	125	134	148	241	449	616	710	738	658	128	69	27	243	
				July																			
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
		W	Beam	0	0	0	0	0	0	0	0	0	92	264	402	491	524	459	0	0	0		
			Diffuse	6	16	35	60	85	104	121	133	149	144	165	181	184	173	157	102	52	20		
			Globe	6	16	35	60	85	104	121	133	149	236	429	583	675	697	616	102	52	20	229	

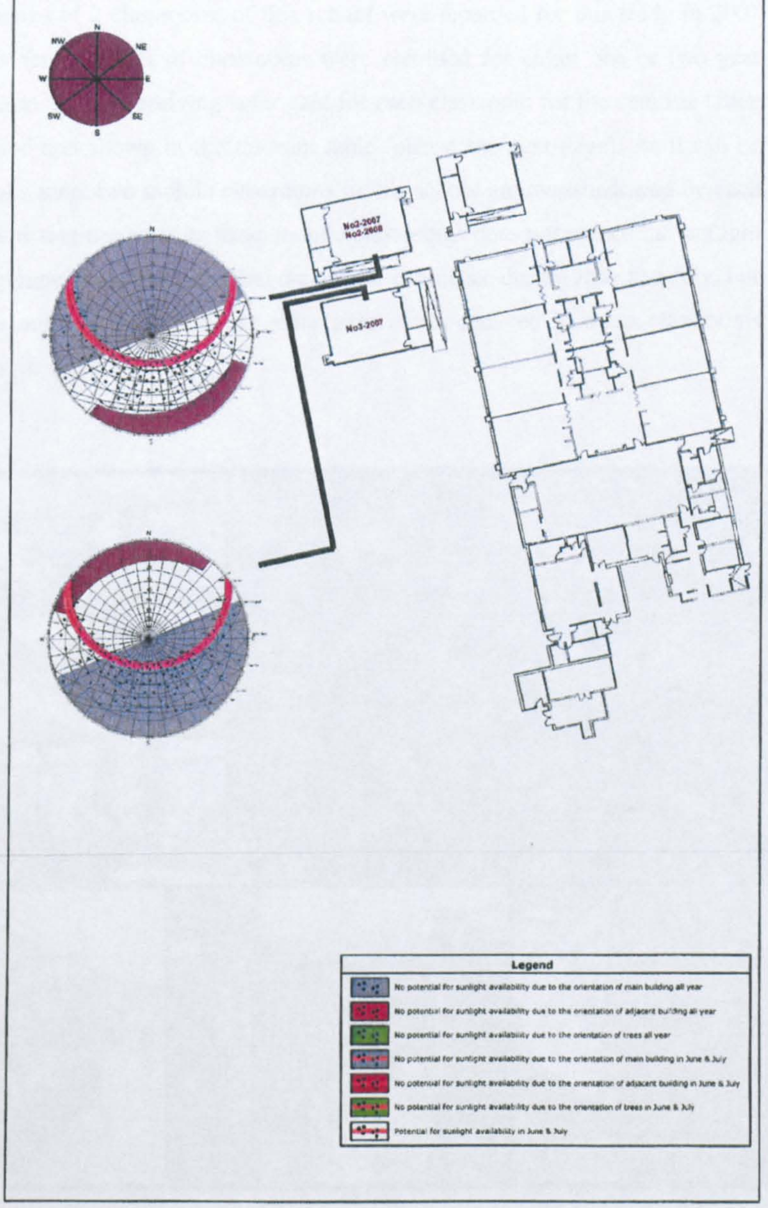
				June																			Average (W/m²) June & July
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) June	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
Coleraine	No3 (2007) No3 (2008)	W	Beam	0	0	0	0	0	0	0	0	0	101	284	431	513	542	0	0	163	51		221
			Diffuse	8	18	41	69	91	110	125	134	148	140	165	185	197	196	175	128	69	27		
			Globe	8	18	41	69	91	110	125	134	148	241	449	616	710	738	175	128	232	78	228	
				July																			
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
		W	Beam	0	0	0	0	0	0	0	0	0	92	264	402	491	524	0	0	144	45		
			Diffuse	6	16	35	60	85	104	121	133	149	144	165	181	184	173	157	102	52	20		
			Globe	6	16	35	60	85	104	121	133	149	236	429	583	675	697	157	102	196	65	214	

Table 8.20: Adjusted average daily global solar irradiance amount considering the impact of overshadowing in Colerain Primary School

Coleraine Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2005	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	FF	45	39	8.7	E	269	No	No	No	269	2335	2335	52	60	Heavy	Quiet
No.2	FF	47	44	8.7	N	131	No	(4:30-8:30) (17:30-19:30)	No	100	868	868	18	20	Heavy	Quiet
No.3	FF	47	41	9.9	S	217	No	No	No	217	2148	2148	45	52	Heavy	Quiet
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	FF	45	39	8.7	E	269	No	No	No	269	2335	2335	52	60	Heavy	Quiet
No.2	FF	62	56	3.2	W	266	No	18:30-20:30	No	[illegible]	753	2359	38	42	Heavy	Quiet
				7.4	S	217	No	No	No	217	1606					
No.3	FF	46	46	11.1	N	131	No	5:30-7:30	No	[illegible]	2460	3577	78	78	Heavy	Quiet
				4.2	W	266	No	No	No	266	1117					
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	FF	45	39	8.7	E	269	No	No	No	269	2335	2335	52	60	Heavy	Quiet
No.2	FF	62	56	3.2	NW	195	No	18:30-20:30	No	[illegible]	755	2361	38	42	Heavy	Quiet
				7.4	S	217	No	No	No	217	1606					
No.3	FF	46	46	11.1	N	131	No	5:30-7:30	No	[illegible]	2460	3577	78	78	Heavy	Quiet
				4.2	W	266	No	No	No	266	1117					

Appendix 9.16: Orchard Primary School



Two prefabricated classrooms of Orchard Primary School are chosen from this school for the purpose of this study. These classrooms are categorised as a low thermal mass (due to the reasons which are explained in chapter 3) and is identified as quiet school since it is located on aircraft noise counter map below 57dBA.

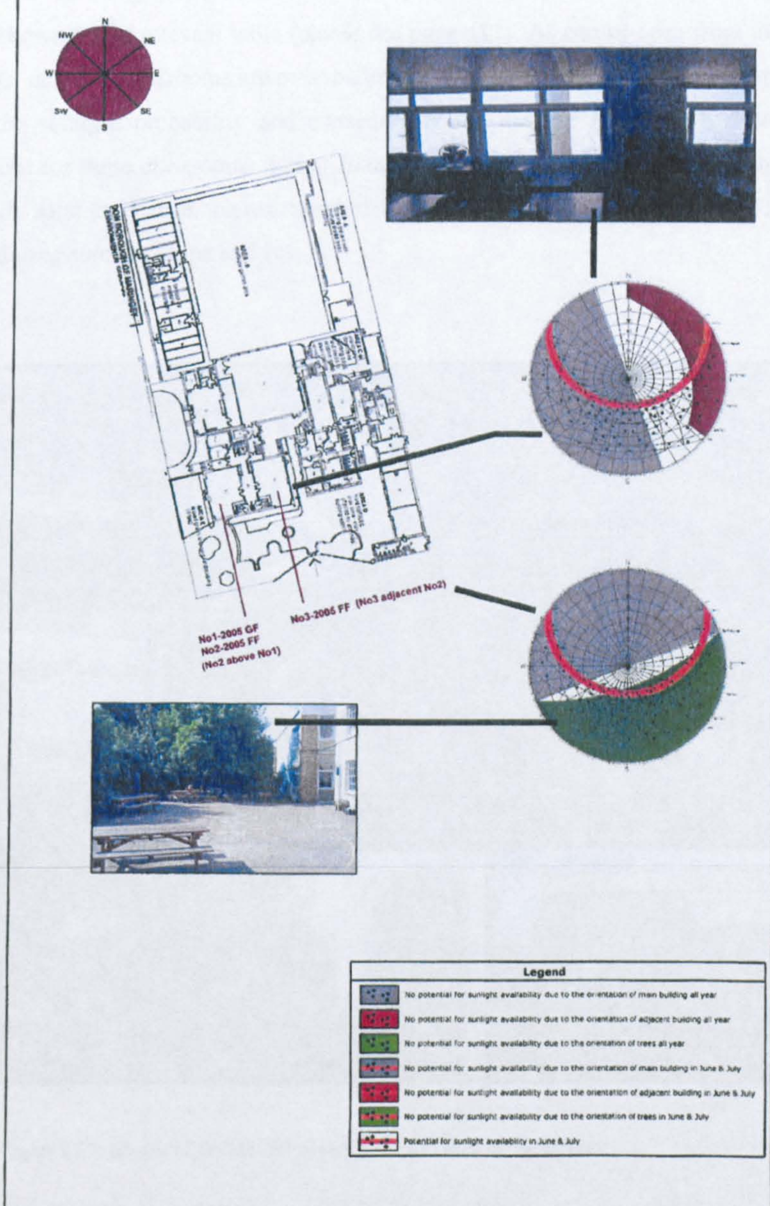
The indoor temperatures of 2 classrooms of this school were recorded for this study in 2007 & 2008. The indoor temperatures of classrooms were recorded for either one or two year periods. The maximum risk of receiving solar gain for each classroom for the summer (June and July) is calculated and shown in the relevant table (please see next page). As it can be seen from the school's map, two mobile classrooms in this school are overshadowed by each other. The overshadow that occurs from these mobile classrooms does not reduce the sunlight probability during summer and average global daily solar irradiance during June and July. For this reason the maximum risk of receiving solar gain is not reduced in these classrooms during summer (June & July).

Figure 8.16: Images of Orchard Primary School (Taken by the author)

Orchard Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2007	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.2	GF	71	71	7.5	N	131	No	No	No	131	983	2610	37	37	Low	Noisy
				7.5	S	217	No	No	No	217	1628					
No.3	GF	71	71	6.7	N	131	No	No	No	131	878	2332	33	33	Low	Noisy
				6.7	S	217	No	No	No	217	1454					
Year 2008	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.2	GF	71	71	6.7	N	131	No	No	No	131	878	2332	33	33	Low	Noisy
				6.7	S	217	No	No	No	217	1454					

Appendix 9.17: St-Gildas Primary School



St Gilda's primary school is a school built after the oil crisis. This school is categorised as a medium thermal mass school (due to the reasons which are explained in chapter 3) and is identified as quiet school since it is located on aircraft noise counter map below 57dBA.

The indoor temperatures of 3 classrooms of this school were recorded for this study in 2005. The maximum risk of receiving solar gain for each classroom for the summer (June and July) is calculated and shown in the relevant table (please see page 411). As can be seen from the school's map, 2 out of these classrooms are overshadowed by trees and an adjacent building. For this reason the sunlight probability and consequently the average global daily solar irradiance is reduced for these classrooms during June & July (Table 8.21). By reducing the average global daily solar irradiance, the maximum risk of receiving solar gain is reduced for these classrooms during summer (June and July).

Figure 8.17: Images of St Gilda's Primary School (Taken by the author)

School	Building	Month	Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) month	Average (W/m²) June & July
					Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
St.Gildas	No3 (2005)	June	NE	Beam	0	0	0	0	0	285	134	0	0	0	0	0	0	0	0	0	0	0		144
				Diffuse	32	72	124	157	158	150	134	158	139	140	135	127	113	94	69	42	21	9		
				Globe	**32**	**72**	**124**	**157**	**158**	**435**	**268**	**158**	**139**	**140**	**135**	**127**	**113**	**94**	**69**	**42**	**21**	**9**	**127**	
		July	NE	Beam	0	0	0	0	0	260	119	0	0	0	0	0	0	0	0	0	0	0		
				Diffuse	25	61	103	132	146	143	132	156	140	141	132	123	107	85	64	35	15	6		
				Globe	**25**	**61**	**103**	**132**	**146**	**403**	**251**	**156**	**140**	**141**	**132**	**123**	**107**	**85**	**64**	**35**	**15**	**6**	**118**	

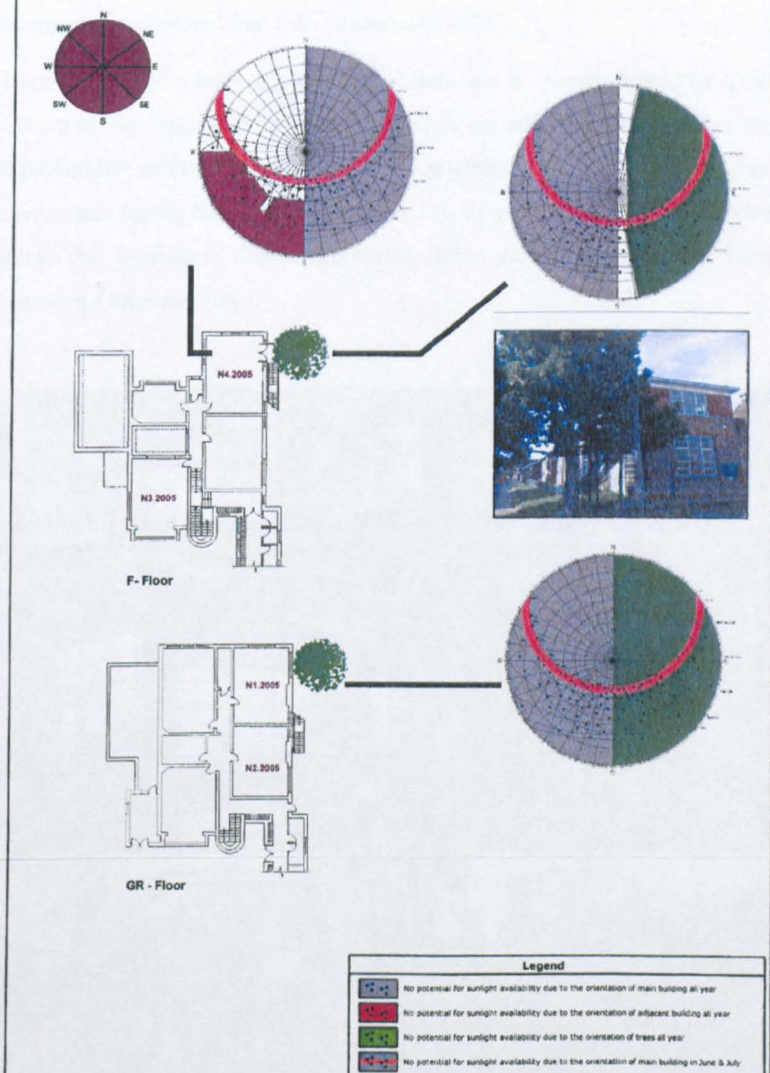
School	Building	Month	Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) month	Average (W/m²) June & July
					Mean hourly irradiance (/ W.m–2) for stated solar time from sunrise to sunset																			
St.Gildas	No3 (2005)	June	S	Beam	7	44	155	44.4	63.3	72.6	74.4	67.1	51.8	30.6	36	0	0	0	0	0	0	0		140
				Diffus	21	50	82	133	163	180	187	183	173	157	123	134	113	94	69	42	20	8		
				Globe	**28**	**94**	**237**	**177**	**226**	**253**	**261**	**250**	**225**	**188**	**159**	**134**	**113**	**94**	**69**	**42**	**20**	**8**	**143**	
		July	S	Beam	7	40	148	41	57.2	67.5	68.9	61.8	47.3	28.5	37	0	0	0	0	0	0	0		
				Diffuse	16	43	69	113	151	171	183	186	179	162	124	131	107	85	64	35	14	5		
				Globe	**23**	**83**	**217**	**154**	**208**	**239**	**252**	**248**	**226**	**191**	**161**	**131**	**107**	**85**	**64**	**35**	**14**	**5**	**136**	

Table 8.21: Adjusted average daily global solar irradiance amount considering the impact of overshadowing in St Gilda's Primary School

St-Gildas Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2005	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	57	55	11.8	SW	259	No	No	No	259	3056	3056	54	56	Medium	Quiet
No.2	FF	57	55	11.1	SW	259	No	No	No	259	2865	2865	50	52	Medium	Quiet
No.3	FF	57	55	6.5	SE	262	No	No	9:30-12:30	140	910	2782	49	51	Medium	Quiet
				13.0	NE	197	No	3:30-6:30	No	144	1872					

Appendix 9.18: Green Church Primary School



Green Church School (the new part) is built after the oil crisis. This school is categorised as a medium thermal mass school (due to the reasons which are explained in chapter 3) and is identified as quiet school since it is located on aircraft noise counter map below 57dBA.

The indoor temperatures of 5 classrooms of this school were recorded for this study in 2005. The maximum risk of receiving solar gain for each classroom for the summer (June and July) is calculated and shown in the relevant table (please see page 415).

As it can be seen from the school's map, one of these classrooms is overshadowed by a tree and another one of them is overshadowed by a tree as well as the adjacent building. For this reason the sunlight probability and consequently the average global daily solar irradiance are reduced for these classrooms during June & July (Table 8.22). By reducing the average global daily solar irradiance, the maximum risk of receiving solar gain is reduced for these classrooms during summer (June and July).

Figure 8.18: Images of Green church Primary School (Taken by the author)

		June																					Average (W/m²) June & July
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) June	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
Green-church	No1 (2005)	E	Beam	7.5	24.3	52.8	75.6	86.9	81.6	66.8	43.5	15	0	0	0	0	0	0	0	0	0		133
			Diffuse	27	66	126	175	189	189	180	163	140	149	135	127	113	94	69	42	20	8		
			Globe	**34.5**	**90.3**	**179**	**251**	**276**	**271**	**247**	**207**	**155**	**149**	**135**	**127**	**113**	**94**	**69**	**42**	**20**	**8**	**137**	
		July																					
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
		E	Beam	6.75	21.8	49.7	69.2	77.9	75.3	61.4	39.8	13.5	0	0	0	0	0	0	0	0	0		
			Diffuse	22	57	106	147	174	179	176	166	144	150	132	123	107	85	64	35	14	5		
			Globe	**28.8**	**78.8**	**156**	**216**	**252**	**254**	**237**	**206**	**158**	**150**	**132**	**123**	**107**	**85**	**64**	**35**	**14**	**5**	**128**	

		June																					Average (W/m²) June & July
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) June	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
Green-church	No4 (2005)	E	Beam	1.13	3.65	7.92	11.3	13	12.2	10	6.53	2.25	0	0	0	0	0	0	0	0	0		112
			Diffuse	27	66	126	175	189	189	180	163	140	149	135	127	113	94	69	42	20	8		
			Globe	**28.1**	**69.6**	**134**	**186**	**202**	**201**	**190**	**170**	**142**	**149**	**135**	**127**	**113**	**94**	**69**	**42**	**20**	**8**	**116**	
		July																					
		Orientation	Type	03:30	04:30	05:30	06:30	07:30	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30	19:30	20:30	Average (W/m²) July	
				Mean hourly irradiance (/ W.m-2) for stated solar time from sunrise to sunset																			
		E	Beam	1.01	3.26	7.45	10.4	11.7	11.3	9.2	5.96	2.03	0	0	0	0	0	0	0	0	0		
			Diffuse	22	57	106	147	174	179	176	166	144	150	132	123	107	85	64	35	14	5		
			Globe	**23**	**60.3**	**113**	**157**	**186**	**190**	**185**	**172**	**146**	**150**	**132**	**123**	**107**	**85**	**64**	**35**	**14**	**5**	**108**	

Table 8.22: Adjusted average daily global solar irradiance amount considering the impact of overshadowing in Green Church Primary School

Greeen Church Primary School

Classroom	Design					Irradiance according to window direction	Shading			Irradiance according to window direction and shading	Solar gain				Thermal Mass	Location
Year 2005	Level	Floor area (m2)	Perimeter zones (m2)	Window area (m2)	Window Direction	Average irradiance (Wat/Sqm) during a day in June & July (disregarding shading impact)	Overhang	Duration blockage by other building	Duration blockage by tree	Average Irradiance (Wat/Sqm) during a day in June & July (considering shading impact)	Solar Gain (W)	Total Solar Gain (W)	Solar Gain per sqm - Total zone Wat.Sqm	Solar Gain per sqm - Perimeter zone (Wat.Sqm)	Thermal Mass	Location
No.1	GF	49	49	8.4	N	131	No	No	No	131	1100	2364	48	48	Meduim	Quiet
				9.5	E	269	No	No	[illegible]	113	1264					
No.2	GF	45.4	45	10.7	E	269	No	No	No	269	2878	2878	63	63	Meduim	Quiet
No.3	FF	47.6	48	7.0	W	266	No	No	No	266	1862	3056	64	64	Meduim	Quiet
				5.5	S	217	No	No	No	217	1194					
No.4	FF	54	54	5.2	N	131	No	No	No	131	681	3875	72	72	Meduim	Quiet
				6.7	W	266	No	No	No	266	1782					
				12.6	E	269	No	No	[illegible]	[illegible]	1411					

- **Appendix 10: Justification based on SPSS software**

In this part of the appendix that is related in to the justification that is carried out based on SPSS software are gathered.

- **Appendix 10.1: Relationship between various environmental factors with students and teachers' health and also students' academic achievements**

The relationship between various environmental factors with students and teachers' health and also students' academic achievements based on the subjective survey

a) **Students' productivity versus Classrooms' overall comfort**

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Overall. comfort.t.p[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Students.Productivity

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.388[a]	.150	.141	1.34807

a. Predictors: (Constant), Overall.comfort.t.p

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	28.922	1	28.922	15.915	.000[a]
	Residual	163.556	90	1.817		
	Total	192.478	91			

a. Predictors: (Constant), Overall.comfort.t.p

b. Dependent Variable: Students.Productivity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.505	.446		5.613	.000
	Overall.comfort.t.p	.376	.094	.388	3.989	.000

a. Dependent Variable: Students.Productivity

b) Teachers' productivity versus Classrooms' overall comfort

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Overall. comfort.t.p[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Teachers.prodictivity

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.462[a]	.214	.205	1.22214

a. Predictors: (Constant), Overall.comfort.t.p

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	35.336	1	35.336	23.658	.000[a]
	Residual	129.944	87	1.494		
	Total	165.281	88			

a. Predictors: (Constant), Overall.comfort.t.p

b. Dependent Variable: Teachers.prodictivity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.216	.406		5.451	.000
	Overall.comfort.t.p	.416	.086	.462	4.864	.000

a. Dependent Variable: Teachers.prodictivity

c) Teachers' health versus Classrooms' overall comfort

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Overall. comfort.t.p[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Teachers.health

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.418[a]	.174	.165	1.05652

a. Predictors: (Constant), Overall.comfort.t.p

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	21.454	1	21.454	19.220	.000[a]
	Residual	101.578	91	1.116		
	Total	123.032	92			

a. Predictors: (Constant), Overall.comfort.t.p

b. Dependent Variable: Teachers.health

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.095	.349		6.002	.000
	Overall.comfort.t.p	.322	.073	.418	4.384	.000

a. Dependent Variable: Teachers.health

- **Appendix 10.2: Study the relation between adaptive and fixed thermal comfort models with schools occupants' perceptions regarding thermal comfort.**

a) Adaptive

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Adaptive[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Vote

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.636[a]	.405	.377	.94632

a. Predictors: (Constant), Adaptive

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12.804	1	12.804	14.298	.001[a]
	Residual	18.806	21	.896		
	Total	31.610	22			

a. Predictors: (Constant), Adaptive

b. Dependent Variable: Vote

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.707	.373		9.933	.000
	Adaptive	.063	.017	.636	3.781	.001

a. Dependent Variable: Vote

b) Fixed

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Fixed[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Vote

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.462[a]	.214	.176	1.08789

a. Predictors: (Constant), Fixed

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6.756	1	6.756	5.708	.026[a]
	Residual	24.854	21	1.184		
	Total	31.610	22			

a. Predictors: (Constant), Fixed

b. Dependent Variable: Vote

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.171	.382		10.929	.000
	Fixed	.092	.038	.462	2.389	.026

a. Dependent Variable: Vote

- **Appendix 10.3:** Relation between schools' location on aircraft noise contour map with aircraft noise perception.

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	School. Location[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Noise.Perception

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.316[a]	.100	.084	1.27901

a. Predictors: (Constant), School.Location

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10.316	1	10.316	6.306	.015[a]
	Residual	93.244	57	1.636		
	Total	103.559	58			

a. Predictors: (Constant), School.Location

b. Dependent Variable: Noise.Perception

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-4.352	4.045		-1.076	.287
	School.Location	.164	.065	.316	2.511	.015

a. Dependent Variable: Noise.Perception

- **Appendix 10.4:** Solar gain normally distributed test

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Solar.gain	59	100.0%	0	.0%	59	100.0%

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Solar.gain	.123	59	.027	.933	59	.003

a. Lilliefors Significance Correction

- **Appendix 10.5:** Using primitive zone for calculating solar gain

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Floor.area	59	57.0339	10.22331	1.33096

One-Sample Test

	Test Value = 55					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Floor.area	1.528	58	.132	2.03390	-.6303	4.6981

- **Appendix 10.6:** Solar irradiance normally distributed test

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Solar.gain	.123	59	.027	.933	59	.003

a. Lilliefors Significance Correction

- **Appendix 10.7:** Adaptive cooling degree hours normally distributed test

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Adaptive.CDH	.439	93	.000	.357	93	.000

a. Lilliefors Significance Correction

- **Appendix 10.8:** Fixed cooling degree hours normally distributed test

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Fixed.CDH	.451	93	.000	.321	93	.000

a. Lilliefors Significance Correction

- **Appendix 10.9: Relationship between aircraft noise and level thermal comfort in schools with different thermal mass level**

a) Low thermal mass

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Noise.L[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Comfort.L

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.323[a]	.105	.080	1.65906

a. Predictors: (Constant), Noise.L

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11.902	1	11.902	4.324	.045[a]
	Residual	101.841	37	2.752		
	Total	113.744	38			

a. Predictors: (Constant), Noise.L

b. Dependent Variable: Comfort.L

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.051	1.057		2.885	.006
	Noise.L	.372	.179	.323	2.079	.045

a. Dependent Variable: Comfort.L

b) Medium thermal mass

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Noise.M[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Comfort.M

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.343[a]	.117	.094	1.35550

a. Predictors: (Constant), Noise.M

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9.279	1	9.279	5.050	.031[a]
	Residual	69.821	38	1.837		
	Total	79.100	39			

a. Predictors: (Constant), Noise.M

b. Dependent Variable: Comfort.M

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.198	.981		3.258	.002
	Noise.M	.383	.170	.343	2.247	.031

a. Dependent Variable: Comfort.M

- **Appendix 10.10: The relation between schools' location on aircraft noise with teachers' perceptions' regarding aircraft noise and thermal comfort**

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	School. Location[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Thermal.Perception

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.337[a]	.113	.098	1.59908

a. Predictors: (Constant), School.Location

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18.941	1	18.941	7.408	.009[a]
	Residual	148.309	58	2.557		
	Total	167.250	59			

a. Predictors: (Constant), School.Location

b. Dependent Variable: Thermal.Perception

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-8.205	4.948		-1.658	.103
	School.Location	.218	.080	.337	2.722	.009

a. Dependent Variable: Thermal.Perception

- **Appendix 10.11: Demonstrating the impact of building and climate factors (rather than ventilation) based on regression analysis**

a) Mean

- **2008**

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	Thermal. mass, Solar. irad, Mean. out[a]	.	Enter

a. All requested variables entered.

b. Year.Code = 2008

c. Dependent Variable: Mean.ind

Model Summary[b,c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.432[a]	.186	.184	1.43427

a. Predictors: (Constant), Thermal.mass, Solar.irad, Mean. out

b. Year.Code = 2008

c. Dependent Variable: Mean.ind

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	15.513	.368		42.098	.000
	Mean.out	.380	.023	.452	16.229	.000
	Solar.irad	-5.853E-5	.000	-.058	-2.080	.038
	Thermal.mass	.107	.049	.054	2.172	.030

a. Year.Code = 2008

b. Dependent Variable: Mean.ind

Residuals Statistics[a,b]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	20.6918	22.9949	21.8475	.68554	1344
Residual	-4.73055	4.11237	.00000	1.43267	1344
Std. Predicted Value	-1.686	1.674	.000	1.000	1344
Std. Residual	-3.298	2.867	.000	.999	1344

a. Year.Code = 2008

b. Dependent Variable: Mean.ind

- **2007**

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	Thermal. mass, Solar. irad, Mean. out[a]	.	Enter

a. All requested variables entered.

b. Year.Code = 2007

c. Dependent Variable: Mean.ind

Model Summary[b,c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.357[a]	.127	.125	1.30553

a. Predictors: (Constant), Thermal.mass, Solar.irad, Mean. out

b. Year.Code = 2007

c. Dependent Variable: Mean.ind

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	17.244	.428		40.324	.000
	Mean.out	.289	.025	.310	11.443	.000
	Solar.irad	5.916E-5	.000	.069	2.554	.011
	Thermal.mass	-.222	.049	-.119	-4.582	.000

a. Year.Code = 2007

b. Dependent Variable: Mean.ind

Residuals Statistics[a,b]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	20.7782	23.0543	21.9835	.49809	1296
Residual	-11.11214	3.30556	.00000	1.30401	1296
Std. Predicted Value	-2.420	2.150	.000	1.000	1296
Std. Residual	-8.512	2.532	.000	.999	1296

a. Year.Code = 2007

b. Dependent Variable: Mean.ind

- **2005**

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	Thermal.mass, Solar.irad, Mean.out[a]	.	Enter

a. All requested variables entered.

b. Year.Code = 2005

c. Dependent Variable: Mean.ind

Model Summary[b,c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.562[a]	.316	.312	1.95361

a. Predictors: (Constant), Thermal.mass, Solar.irad, Mean.out

b. Year.Code = 2005

c. Dependent Variable: Mean.ind

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	860.436	3	286.812	75.148	.000[a]
	Residual	1862.505	488	3.817		
	Total	2722.941	491			

a. Predictors: (Constant), Thermal.mass, Solar.irad, Mean.out

b. Year.Code = 2005

c. Dependent Variable: Mean.ind

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	17.409	.760		22.905	.000
	Mean.out	.226	.044	.302	5.091	.000
	Solar.irad	.000	.000	.283	4.778	.000
	Thermal.mass	.409	.139	.110	2.937	.003

a. Year.Code = 2005

b. Dependent Variable: Mean.ind

Residuals Statistics[a,b]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	22.1128	26.6958	23.9226	1.32379	492
Residual	-4.57713	5.05861	.00000	1.94764	492
Std. Predicted Value	-1.367	2.095	.000	1.000	492
Std. Residual	-2.343	2.589	.000	.997	492

a. Year.Code = 2005

b. Dependent Variable: Mean.ind

b) Max

- **2008**

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	Max.out, Thermal.mass, Solar.irad[a]	.	Enter

a. All requested variables entered.

b. Year.Code = 2008

c. Dependent Variable: Max.ind

Model Summary[b,c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.499[a]	.249	.247	1.51971

a. Predictors: (Constant), Max.out, Thermal.mass, Solar.irad

b. Year.Code = 2008

c. Dependent Variable: Max.ind

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1024.016	3	341.339	147.797	.000[a]
	Residual	3094.743	1340	2.310		
	Total	4118.759	1343			

a. Predictors: (Constant), Max.out, Thermal.mass, Solar.irad

b. Year.Code = 2008

c. Dependent Variable: Max.ind

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	13.589	.515		26.376	.000
	Solar.irad	.000	.000	.091	3.194	.001
	Thermal.mass	.480	.052	.217	9.170	.000
	Maxout	.396	.029	.392	13.760	.000

a. Year.Code = 2008

b. Dependent Variable: Maxind

Residuals Statistics[a,b]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	21.2252	24.8898	23.0491	.87320	1344
Residual	-4.97464	7.11015	.00000	1.51801	1344
Std. Predicted Value	-2.089	2.108	.000	1.000	1344
Std. Residual	-3.273	4.679	.000	.999	1344

a. Year.Code = 2008

b. Dependent Variable: Maxind

- **2007**

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	Maxout, Thermal.mass, Solar.irad[a]	.	Enter

a. All requested variables entered.

b. Year.Code = 2007

c. Dependent Variable: Maxind

Model Summary[b,c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.505[a]	.255	.253	1.30781

a. Predictors: (Constant), Maxout, Thermal.mass, Solar.irad

b. Year.Code = 2007

c. Dependent Variable: Maxind

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	757.118	3	252.373	147.555	.000[a]
	Residual	2209.789	1292	1.710		
	Total	2966.907	1295			

a. Predictors: (Constant), Maxout, Thermal.mass, Solar.irad

b. Year.Code = 2007

c. Dependent Variable: Maxind

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	15.510	.380		40.770	.000
	Solar.irad	7.836E-5	.000	.085	2.993	.003
	Thermal.mass	.261	.049	.129	5.363	.000
	Maxout	.317	.020	.439	15.524	.000

a. Year.Code = 2007

b. Dependent Variable: Maxind

Residuals Statistics[a,b]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	21.0469	24.1921	22.8985	.76462	1296
Residual	-8.68824	5.49950	.00000	1.30629	1296
Std. Predicted Value	-2.422	1.692	.000	1.000	1296
Std. Residual	-6.643	4.205	.000	.999	1296

a. Year.Code = 2007

b. Dependent Variable: Maxind

- **2005**

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	Maxout, Thermal.mass, Solar.irad[a]	.	Enter

a. All requested variables entered.

b. Year.Code = 2005

c. Dependent Variable: Maxind

Model Summary[b,c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.648[a]	.421	.417	2.36169

a. Predictors: (Constant), Maxout, Thermal.mass, Solar.irad

b. Year.Code = 2005

c. Dependent Variable: Maxind

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1975.185	3	658.395	118.043	.000[a]
	Residual	2721.870	488	5.578		
	Total	4697.054	491			

a. Predictors: (Constant), Maxout, Thermal.mass, Solar.irad

b. Year.Code = 2005

c. Dependent Variable: Maxind

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	19.050	.953		19.995	.000
	Solar.irad	.001	.000	.550	7.910	.000
	Thermal.mass	1.056	.168	.216	6.273	.000
	Maxout	.050	.050	.070	1.004	.316

a. Year.Code = 2005

b. Dependent Variable: Maxind

Residuals Statistics[a,b]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	21.7989	29.1328	25.3709	2.00569	492
Residual	-6.00096	6.86718	.00000	2.35447	492
Std. Predicted Value	-1.781	1.876	.000	1.000	492
Std. Residual	-2.541	2.908	.000	.997	492

a. Year.Code = 2005

b. Dependent Variable: Maxind

- **Appendix 10.12: Study indoor temperature in two days with various climate conditions.**

a) Similar solar irradiance, different outdoor temperature

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Mean.June.28.2008.Out.temp	23.4734	59	1.26480	.16466
	Mean.July.13.2008.Out.temp	20.8931	59	1.56073	.20319
Pair 2	Max.June.28.2008.Out.temp	25.0424	59	1.74763	.22752
	Mean.July.13.2008.Out.temp	20.8931	59	1.56073	.20319

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Mean.June.28.2008.Out.temp & Mean.July.13.2008.Out.temp	59	.657	.000
Pair 2	Max.June.28.2008.Out.temp & Mean.July.13.2008.Out.temp	59	.324	.012

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Mean.June.28.2008.Out.temp - Mean.July.13.2008.Out.temp	2.58E0	1.20077	.15633	2.26742	2.89326	1.65E1	58	.000
Pair 2	Max.June.28.2008.Out.temp - Mean.July.13.2008.Out.temp	4.14E0	1.92900	.25113	3.64662	4.65202	1.65E1	58	.000

b) Similar outdoor temperature , different solar irradiance

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Mean.June.14.2008.Solar	21.2490	59	1.48149	.19287
	Mean.June.21.2008.Solar	21.2247	59	1.38045	.17972
Pair 2	Max.June.14.2008.Solar	22.3686	59	1.59225	.20729
	Max.June.21.2008.Solar	21.7246	59	1.20764	.15722

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Mean.June.14.2008.Solar & Mean.June.21.2008.Solar	59	.765	.000
Pair 2	Max.June.14.2008.Solar & Max.June.21.2008.Solar	59	.610	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Mean.June.14.2008.Solar - Mean.June.21.2008.Solar	.02424	.98515	.12826	-.23249	.28097	.189	58	.851
Pair 2	MaxJune.14.2008.Solar - MaxJune.21.2008.Solar	.64407	1.28335	.16708	.30962	.97851	3.855	58	.000

- **Appendix 10.13: Regression analysis between indoor temperature and global solar irradiance (Percentage greater than 25°C, 26°C, 27°C).**

Three regression analyses are carried out between indoor temperature and global solar irradiance as follows:

a) Gr.25

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	GR.25.P[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Irradiance

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.884[a]	.782	.738	28.83647

a. Predictors: (Constant), GR.25.P

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14919.148	1	14919.148	17.942	.008[a]
	Residual	4157.709	5	831.542		
	Total	19076.857	6			

a. Predictors: (Constant), GR.25.P

b. Dependent Variable: Irradiance

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	116.229	22.405		5.188	.004
	GR.25.P	1.640	.387	.884	4.236	.008

a. Dependent Variable: Irradiance

b) Gr.26

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	GR.26.P[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Irradiance

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.902[a]	.814	.776	26.66299

a. Predictors: (Constant), GR.26.P

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15522.283	1	15522.283	21.834	.005[a]
	Residual	3554.575	5	710.915		
	Total	19076.857	6			

a. Predictors: (Constant), GR.26.P

b. Dependent Variable: Irradiance

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	162.404	12.782		12.706	.000
	GR.26.P	2.388	.511	.902	4.673	.005

a. Dependent Variable: Irradiance

c) Gr.27

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	GR.27.P[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Irradiance

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.554[a]	.307	.168	51.41854

a. Predictors: (Constant), GR.27.P

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5857.524	1	5857.524	2.216	.197[a]
	Residual	13219.333	5	2643.867		
	Total	19076.857	6			

a. Predictors: (Constant), GR.27.P

b. Dependent Variable: Irradiance

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	187.333	20.992		8.924	.000
	GR.27.P	5.373	3.610	.554	1.488	.197

a. Dependent Variable: Irradiance

- **Appendix 10.14: Regression analysis between indoor temperature and global solar irradiance (Mean and Maximum).**

Three regression analyses are carried out between indoor temperature and global solar irradiance as follows:

a) Mean

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Mean[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Irradiance

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.902[a]	.813	.776	26.71431

a. Predictors: (Constant), Mean

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15508.585	1	15508.585	21.731	.006[a]
	Residual	3568.272	5	713.654		
	Total	19076.857	6			

a. Predictors: (Constant), Mean

b. Dependent Variable: Irradiance

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1679.682	403.163		-4.166	.009
	Mean	75.352	16.164	.902	4.662	.006

a. Dependent Variable: Irradiance

b) Maximum

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Max[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Irradiance

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.888[a]	.788	.745	28.45939

a. Predictors: (Constant), Max

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15027.174	1	15027.174	18.554	.008[a]
	Residual	4049.684	5	809.937		
	Total	19076.857	6			

a. Predictors: (Constant), Max

b. Dependent Variable: Irradiance

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1533.199	402.324		-3.811	.012
	Max	66.904	15.532	.888	4.307	.008

a. Dependent Variable: Irradiance

- **Appendix 10.15 : Comparison of the maximum indoor temperature on different thermal mass levels**

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Max.Indoor.Temp	Between Groups	36.274	2	18.137	7.347	.002
	Within Groups	133.304	54	2.469		
	Total	169.579	56			
Mean.Indoor.Temp	Between Groups	27.564	2	13.782	12.642	.000
	Within Groups	58.870	54	1.090		
	Total	86.434	56			

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
MaxIndoor.Temp	H	16	23.6563	.90312	.22578	23.1750	24.1375	22.25	25.00
	M	21	24.9643	1.33530	.29139	24.3565	25.5721	22.00	27.00
	L	20	25.6625	2.12020	.47409	24.6702	26.6548	22.75	31.75
	Total	57	24.8421	1.74017	.23049	24.3804	25.3038	22.00	31.75
Mean.Indoor.Temp	H	16	22.3527	.62248	.15562	22.0210	22.6844	21.26	23.52
	M	21	24.0548	1.04183	.22735	23.5805	24.5290	21.76	26.06
	L	20	23.6297	1.28451	.28723	23.0285	24.2308	21.29	26.56
	Total	57	23.4278	1.24236	.16455	23.0982	23.7575	21.26	26.56

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
MaxIndoor.Temp	Between Groups	36.274	2	18.137	7.347	.002
	Within Groups	133.304	54	2.469		
	Total	169.579	56			
Mean.Indoor.Temp	Between Groups	27.564	2	13.782	12.642	.000
	Within Groups	58.870	54	1.090		
	Total	86.434	56			

• Appendix 10.16: Impact of aircraft noise on occupants' speech intelligibility

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
SPeech.Intl * Window	60	100.0%	0	.0%	60	100.0%

SPeech.Intl * Window Crosstabulation

			Window		Total
			Open	Close	
SPeech.Intl	Bad.SP	Count	29	21	50
		% within SPeech.Intl	58.0%	42.0%	100.0%
		% within Window	96.7%	70.0%	83.3%
		% of Total	48.3%	35.0%	83.3%
		Adjusted Residual	2.8	-2.8	
	Good.SP	Count	1	9	10
		% within SPeech.Intl	10.0%	90.0%	100.0%
		% within Window	3.3%	30.0%	16.7%
		% of Total	1.7%	15.0%	16.7%
		Adjusted Residual	-2.8	2.8	
Total		Count	30	30	60
		% within SPeech.Intl	50.0%	50.0%	100.0%
		% within Window	100.0%	100.0%	100.0%
		% of Total	50.0%	50.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	7.680[a]	1	.006		
Continuity Correction[b]	5.880	1	.015		
Likelihood Ratio	8.647	1	.003		
Fisher's Exact Test				.012	.006
Linear-by-Linear Association	7.552	1	.006		
N of Valid Cases	60				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.00.

b. Computed only for a 2x2 table

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.358	.006
	Cramer's V	.358	.006
N of Valid Cases		60	

- **Appendix 10.17: Impact of aircraft noise on occupants' annoyance level**

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Window. Status, Activity[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Annoyance

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.461[a]	.212	.177	.87247

a. Predictors: (Constant), Window.Status, Activity

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9.225	2	4.613	6.059	.005[a]
	Residual	34.254	45	.761		
	Total	43.479	47			

a. Predictors: (Constant), Window.Status, Activity

b. Dependent Variable: Annoyance

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.229	.333		6.691	.000
	Activity	-.308	.113	-.362	-2.737	.009
	Window.Status	.542	.252	.285	2.151	.037

a. Dependent Variable: Annoyance

- **Appendix 10.18: Share of each activity inside classrooms**

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Activity.2	42.0000	18	16.69801	3.93576
	Activity.Others	19.2778	18	14.22428	3.35269

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Activity.2 & Activity.Others	18	-.392	.108

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Activity.2 - Activity.Others	2.2722E1	2.5833E1	6.08910	9.87534	35.56910	3.E0	17	.002

- **Appendix 10.19: Ventilation control level vs. Aircraft noise in different schools**

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Aircraft[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Ventilation.control

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.271[a]	.073	.064	1.88569

a. Predictors: (Constant), Aircraft

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	27.058	1	27.058	7.609	.007[a]
	Residual	341.360	96	3.556		
	Total	368.418	97			

a. Predictors: (Constant), Aircraft

b. Dependent Variable: Ventilation.control

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.188	.582		5.482	.000
	Aircraft	.297	.107	.271	2.759	.007

a. Dependent Variable: Ventilation.control

- **Appendix 10.20: Relation between aircraft and schools' noise with students' distraction**

a) Year 3- Year 4

Group Statistics

	Noise. Sources	N	Mean	Std. Deviation	Std. Error Mean
Distraction	School Noise	324	2.0185	.66279	.03682
	Aircraft Noise	162	2.2037	.93343	.07334

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Distraction	Equal variances assumed	44.633	.000	-2.5E0	484	.012	-.18519	.07347	-.32955	-.04082
	Equal variances not assumed			-2.2E0	2.4E2	.025	-.18519	.08206	-.34682	-.02355

Case Processing Summary

	Noise. Sources	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
Distraction	Layout	324	99.4%	2	.6%	326	100.0%
	Aircraft	162	99.4%	1	.6%	163	100.0%

b) Year1-Year2

Group Statistics

	Noise.Sources	N	Mean	Std. Deviation	Std. Error Mean
Distraction	Schools' Noise	133	1.2632	.44201	.03833
	Aircrafts' Noise	106	1.3302	.47252	.04589

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Distraction	Equal variances assumed	4.894	.028	-1.130	237	.260	-.06703	.05934	-.18394	.04988
	Equal variances not assumed			-1.121	218.133	.264	-.06703	.05979	-.18488	.05082

Case Processing Summary

		Cases					
		Valid		Missing		Total	
	Noise.Sources	N	Percent	N	Percent	N	Percent
Distraction	Schools' Noise	133	50.0%	133	50.0%	266	100.0%
	Aircrafts' Noise	106	50.0%	106	50.0%	212	100.0%

- **Appendix 10.21: Relation between window status and 'aircraft noise and activity'**

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Windows.status * Activity	33	100.0%	0	.0%	33	100.0%
Windows.status * Aircraft	33	100.0%	0	.0%	33	100.0%

a) Windows.status * Activity

Crosstab

			Activity				
			Silent	Lecturing	Group	Group	Total
Window.status	Open	Count	4	7	6	3	20
		% within Windows.status	20.0%	35.0%	30.0%	15.0%	100.0%
		% within Activity	44.4%	50.0%	85.7%	100.0%	60.6%
		% of Total	12.1%	21.2%	18.2%	9.1%	60.6%
		Adjusted Residual	-1.2	-1.1	1.5	1.5	
	Close	Count	5	7	1	0	13
		% within Windows.status	38.5%	53.8%	7.7%	.0%	100.0%
		% within Activity	55.6%	50.0%	14.3%	.0%	39.4%
		% of Total	15.2%	21.2%	3.0%	.0%	39.4%
		Adjusted Residual	1.2	1.1	-1.5	-1.5	
Total		Count	9	14	7	3	33
		% within Windows.status	27.3%	42.4%	21.2%	9.1%	100.0%
		% within Activity	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	27.3%	42.4%	21.2%	9.1%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.443[a]	3	.142
Likelihood Ratio	6.736	3	.081
Linear-by-Linear Association	4.589	1	.032
N of Valid Cases	33		

a. 5 cells (62.5%) have expected count less than 5. The minimum expected count is 1.18.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.406	.142
	Cramer's V	.406	.142
N of Valid Cases		33	

b) Windows.status * Aircraft

Crosstab

			Aircraft		Total
			Absent	Present	
Windo.status	Open	Count	15	5	20
		% within Windows.status	75.0%	25.0%	100.0%
		% within Aircraft	88.2%	31.3%	60.6%
		% of Total	45.5%	15.2%	60.6%
		Adjusted Residual	3.3	-3.3	
	Close	Count	2	11	13
		% within Windows.status	15.4%	84.6%	100.0%
		% within Aircraft	11.8%	68.8%	39.4%
		% of Total	6.1%	33.3%	39.4%
		Adjusted Residual	-3.3	3.3	
Total		Count	17	16	33
		% within Windows.status	51.5%	48.5%	100.0%
		% within Aircraft	100.0%	100.0%	100.0%
		% of Total	51.5%	48.5%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	11.211[a]	1	.001		
Continuity Correction[b]	8.951	1	.003		
Likelihood Ratio	12.062	1	.001		
Fisher's Exact Test				.001	.001
Linear-by-Linear Association	10.871	1	.001		
N of Valid Cases	33				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.30.

b. Computed only for a 2x2 table

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.583	.001
	Cramer's V	.583	.001
N of Valid Cases		33	

- **Appendix 10.22:** Study indoor air quality based on BB101guideline

a) Criterion 1

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Maximum	11	1455.3636	510.07446	153.79324

One-Sample Test

	Test Value = 5000					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Maximum	-23.048	10	.000	-3544.63636	-3887.3090	-3201.9637

b) Criterion 2

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Average	11	768.9414	228.71205	68.95928

One-Sample Test

	Test Value = 1500					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Average	-10.601	10	.000	-731.05861	-884.7095	-577.4078

c) Criterion 3

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
AE.Y3.15.July	10	1068.8800	60.62861	19.17245
AE.Y4.7.July	41	2264.4854	704.48476	110.02204
AE.Y6.14.July	0[a,b]	.	.	.
Gr.Y2.10.Jul	28	1158.8500	127.36993	24.07065
Gr.Y2.11.Jul	24	1073.2417	58.79315	12.00110
Gr.Y2.24.Jun	0[a,b]	.	.	.
Gr.Y3.25.Jun	107	1573.9355	278.35009	26.90912
Gr.Y3.26.Jun	26	1139.6500	137.22993	26.91300
Gr.Y4.02.Jul	0[a,b]	.	.	.
Gr.Y6.27.Jun	160	1410.4694	284.85593	22.51984
Gr.Y6.30.Jun	174	1395.8121	263.52304	19.97763
Gr.Y4.01.Jul	13	1112.84	45.563	12.637

a. t cannot be computed because the sum of caseweights is less than or equal 1.

b. t cannot be computed. There are no valid cases for this analysis because all caseweights are not positive.

One-Sample Test

	Test Value = 1000					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
AE.Y3.15.July	3.593	9	.006	68.88000	25.5089	112.2511
AE.Y4.7.July	11.493	40	.000	1264.48537	1042.1225	1486.8482
Gr.Y2.10.Jul	6.599	27	.000	158.85000	109.4611	208.2389
Gr.Y2.11.Jul	6.103	23	.000	73.24167	48.4155	98.0678
Gr.Y3.25.Jun	21.329	106	.000	573.93551	520.5856	627.2855
Gr.Y3.26.Jun	5.189	25	.000	139.65000	84.2216	195.0784
Gr.Y6.27.Jun	18.227	159	.000	410.46937	365.9928	454.9460
Gr.Y6.30.Jun	19.813	173	.000	395.81207	356.3808	435.2433
Gr.Y4.01.Jul	8.929	12	.000	112.838	85.30	140.37

- **Appendix 10.23: Study indoor air quality based on BSRIA guideline**

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
AE.Y3.15.July	99	904.1495	79.25480	7.96541
AE.Y4.7.July	72	1670.8917	867.59246	102.24675
AE.Y6.14.July	8	908.9250	38.65003	13.66485
Gr.Y2.10.Jul	67	995.6881	166.73857	20.37036
Gr.Y2.11.Jul	58	975.7172	100.08578	13.14191
Gr.Y2.24.Jun	4	845.5875	45.62292	22.81146
Gr.Y3.25.Jun	126	1472.5111	353.20372	31.46589
Gr.Y3.26.Jun	114	951.2456	132.11758	12.37395
Gr.Y4.02.Jul	51	894.9529	57.90275	8.10801
Gr.Y6.27.Jun	183	1345.8333	317.15064	23.44445
Gr.Y6.30.Jun	243	1258.2523	313.87057	20.13481
Gr.Y4.01.Jul	32	979.8156	125.90973	22.25791

One-Sample Test

	Test Value = 800					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
AE.Y3.15.July	13.075	98	.000	104.14949	88.3424	119.9566
AE.Y4.7.July	8.518	71	.000	870.89167	667.0174	1074.7659
AE.Y6.14.July	7.971	7	.000	108.92500	76.6128	141.2372
Gr.Y2.10.Jul	9.607	66	.000	195.68806	155.0173	236.3588
Gr.Y2.11.Jul	13.371	57	.000	175.71724	149.4010	202.0335
Gr.Y2.24.Jun	1.998	3	.140	45.58750	-27.0087	118.1837
Gr.Y3.25.Jun	21.373	125	.000	672.51111	610.2362	734.7860
Gr.Y3.26.Jun	12.223	113	.000	151.24561	126.7306	175.7606
Gr.Y4.02.Jul	11.711	50	.000	94.95294	78.6675	111.2384
Gr.Y6.27.Jun	23.282	182	.000	545.83333	499.5755	592.0912
Gr.Y6.30.Jun	22.759	242	.000	458.25226	418.5904	497.9141
Gr.Y4.01.Jul	8.079	31	.000	179.81562	134.4203	225.2109

- **Appendix 10.24 : Relation between 'Air quality' VS 'Aircraft noise level'**

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Aircraft.Noise.Level[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Ventilation.Control.Level

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.271[a]	.073	.064	1.88569

a. Predictors: (Constant), Aircraft.Noise.Level

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	27.058	1	27.058	7.609	.007[a]
	Residual	341.360	96	3.556		
	Total	368.418	97			

a. Predictors: (Constant), Aircraft.Noise.Level

b. Dependent Variable: Ventilation.Control.Level

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	3.188	.582		5.482	.000
	Aircraft.Noise.Level	.297	.107	.271	2.759	.007

a. Dependent Variable: Ventilation.Control.Level

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Aircraft noise, overheating and poor air quality in classrooms in London primary schools

Azadeh Montazami [a,*], Mike Wilson [b], Fergus Nicol [a]

[a] London Metropolitan University, United Kingdom
[b] University of Westminster, United Kingdom

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ABSTRACT

The main source of ventilation in the majority of UK schools is windows. The occupants of the classroom (i.e. pupils and teachers) in noisy areas tend to shut windows especially during quiet activities (i.e. silent and lecturing activities) to reduce the effect on teaching of aircraft noise as well as other external noises. Closing windows has two negative impacts on classroom environments. Firstly it increases the likelihood of classrooms experiencing overheating in hot weather and secondly poor air quality due to the lack of sufficient ventilation in the building. Through objective and subjective in a number of schools using surveys, monitoring of indoor temperatures, and testing of air quality and aircraft noise levels it was concluded that those schools located in the vicinity of Heathrow Airport are more likely to experience overheating and poor air quality due to aircraft noise, which can subsequently have a negative impact on students' achievements.

Implications: Overheating is a growing concern in UK schools and is likely to become more so in the context of a warming climate. Poor air quality and excessive noise levels are also known to be a problem for learning. This paper shows that all these effects are exacerbated by airport noise causing teachers to keep windows closed and suggests that this should be a concern for designers and policy makers.

1. Introduction

There is a significant relationship between various environmental factors (e.g. indoor temperature [1], noise level [2], air quality [3] and light level [4]) and students' academic achievements. By looking at the environmental conditions in primary schools' classrooms which are located under the Heathrow flight path, it is possible to investigate the environmental problems and suggest new methods to provide better environmental conditions.

An important role of natural ventilation in buildings in free-running mode (i.e. without mechanical heating or cooling) is to remove excessive heat and provide fresh air in a building. However, this is more difficult in schools under aircraft flight paths due to a high level of aircraft noise entering through openings [5] and making it hard to teach.

This study is conducted in three parts. Each part contains a specific methodology and produces specific results. The methodology employed uses an objective survey to monitor temperature, air quality and noise and subjective surveys. Subjective surveys were carried out by interview and two types of questionnaires that were designed for this study. One type of questionnaire was designed to assess the classrooms' subjective environmental conditions, mainly thermal comfort, noise level, lighting level and indoor air quality. Ninety two questionnaires were filled out by the teachers of 15 naturally ventilated schools in June and July of 2007 and 2008. Another type of questionnaire was designed based on semantic differential questions to assess the impact of aircraft noise on students. In the Students' questionnaires, questions are asked about the frequency of noise from different sources and the impact on students' concentration level and also teachers' speech intelligibility during lecturing are questioned. Students were additionally questioned about whether they had asked the teacher to close windows. One hundred and sixty three questionnaires were completed by the students of two naturally ventilated schools located under Heathrow flight path in June and July 2008.

2. Impact of high level of aircraft noise on overheating level

2.1. Methodology

Indoor temperature is affected by climate and building characteristics. According to CIBSE (2006), the key characteristics for

* Corresponding author. Tel.: +44 795 1133230.
E-mail addresses: azadeh_mo79@yahoo.co.uk, ab0404@coventry.ac.uk (A. Montazami).

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preventing overheating are ventilation rate, solar gain, thermal mass, building design and internal gain [6]. Indoor temperatures of 70 classrooms from 18 naturally ventilated primary schools in London were recorded every half hour by placing two temperature data loggers called 'I Buttons' in each classroom in June and July of the years 2005, 2007 and 2008. The instruments have an accuracy of (±0.5 °C).

Graph 1 shows the average percentage distribution of indoor temperature in all schools in 2005,2007 and 2008.

The schools were simply categorised as noisy or quiet schools. Noisy schools are defined as those lying in the Heathrow noise map of above 57 dBA and Quiet schools are defined as those lying outside the noise map. This is under constant review [7]. Aircraft noise contours are shown in Fig. 1. The lowest level contour provided on noise maps for Heathrow is 57 dBA and regarded as the limit to the noise impact of the airport because the percentage of people who found aircraft noise to be unacceptable, increases from 15% at 57 dBA to around 57% at 69 dBA based on the Aircraft Noise Index Study (ANIS) in 1984 (ibid).

Fig. 1 shows the location of schools which are located in Hounslow borough on the aircraft noise contour map. In addition, the location of all schools on the contour map in this study are summarised in Table 1.

Dimensional measurements, solar gain calculation and thermal mass evaluations were carried out for each classroom. Climate conditions (i.e. outside temperature and solar irradiance) are different for each classroom on each day and each creates a unique 'class-day' scenario. It has been demonstrated that a fixed nationwide threshold temperature is not adequate to evaluate overheating due to the fact that comfort temperature varies in accordance with outdoor running-mean temperature which is not fixed. The severity of overheating is as important as its frequency of occurrence, Severity depends on the occupied hours above threshold, therefore by changing the number of occupied hours, the result can be altered to solve the overheating problem. This is quite unrealistic, deceptive and overall it is debatable whether overheating should be measured over a whole year or a shorter period during a year [8]. Therefore, adaptive and fixed (both) threshold temperatures are used in this study to evaluate occupants' percentage of dissatisfaction from overheating.

To study the impact of high levels of aircraft noise on the percentage of dissatisfaction expected from overheating, comparisons were carried out between the percentages of dissatisfaction from overheating in classrooms located in noisy areas with those classrooms located in quiet areas. Therefore, groups of classrooms with similar properties (i.e. thermal mass, solar gain potential) with the same climate conditions (i.e. on days which have similar solar irradiance and outside temperature) were compared.

For this comparison, all data are categorised for discussion in the following five steps.

2.1.1. First step

The schools (and consequently their classrooms) are categorised into two groups of noisy and quiet based on the 57 dB(A) Leq discussed earlier.

2.1.2. Second step

The classrooms in each group (noisy and quiet) are categorised, firstly according to their thermal mass level and secondly according to the solar gain. The methods of division are summarised as follows:

2.1.2.1. Classrooms division according to the solar gain. The risk of receiving solar gain of 60 classrooms on a clear day in June and July of this study are calculated for the perimeter zone which is within 6 meters on the plan from a window wall.

The risk of receiving solar gain is calculated based on the following formula which is proposed by CIBSE TM37.

$$\left[Qsl = (1/Ap)\sum(Ag\ Qs\ geff)\right]$$

In this formula: Qsl = the solar load per unit floor area in a space (W/m^2); Ap = the perimeter zone floor area which is within 6 meters on plan from a window wall or roof light (m^2); Ag = the net area of glazing of each element in the perimeter zone for a particular orientation of an opening (W/m^2); Qs = the external solar radiation for a particular orientation of an opening which can be

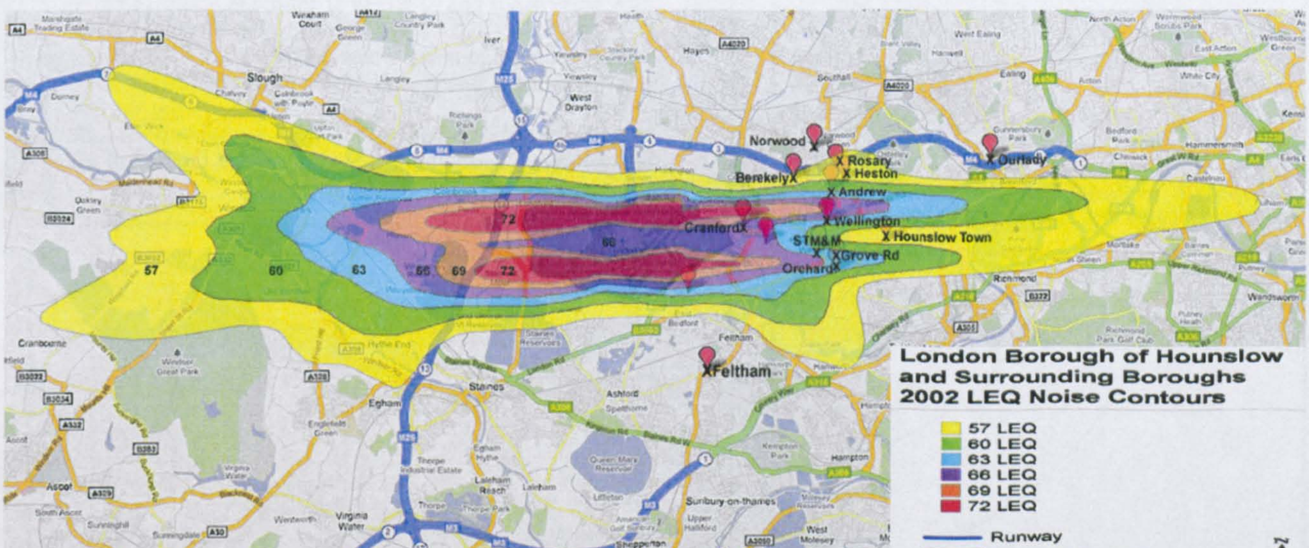


Fig. 1. Locations of schools which are located in Hounslow borough on aircraft noise contour map (Using aircraft noise counter derived from Hounslow Borough website from a report by Civil Aviation Authority. It was carried out on behalf of the Department for Transport. The base map Contains Ordnance Survey data © Crown copyright and database right 2010).

Fig. 2. A classrooms photo when the teacher sits in the chair and students sit around him/her on the floor (Picture courtesy Evening Gazette, Middleborough).

found from the CIBSE irradiance tables; geff = related in to the window specification and type of shading.

It should be noted that in the solar gain calculation, overshadowing impacts (i.e. as the result of any tree or building) on the external solar radiation are considered.

The data are tested and it is discovered that they are normally distributed. The mean and median of these data are 50 W/m^2. For this reason, classrooms in this study are divided into two groups according to their maximum risk of receiving solar gain on a clear day in June and July based on the threshold of 50 W/m^2. The following graph (Graph 2) shows the distribution of risk of receiving solar gain from 60 classrooms.

2.1.2.2. Classrooms division according to the thermal mass. In the preliminary study of this research, the indoor temperatures of 140 number classrooms are recorded at different schools around London. These schools are divided into the following groups according to the thermal mass:

- Heavy thermal mass schools mainly refers to the schools built in the Victorian era (built 1840–1900) and constructed with 'heavy thermal mass' material.
- Low thermal mass schools mainly refers to the schools built after world War I and world War II and constructed low thermal mass material.
- Medium thermal mass school manly refers to the schools that are not placed in the heavy and low thermal categories and mainly after the oil crisis in 1973 and constructed with medium thermal mass material.

In this part of study, only the medium thermal mass classrooms located in noisy regions are compared with those located in quiet regions. This is because only the medium thermal mass schools are evenly distributed in noisy and quiet regions.

2.1.3. Third step

Generally there are two types of models for assessing the overheating which are fixed and adaptive models. In fixed model, comfort temperature is based on a fixed temperature and in adaptive model, comfort temperature is related to the running-mean of external temperature.

The three overheating guidelines which are proposed based on fixed models for the UK primary schools' classrooms are Building Bulletin 101 [9], Building Bulletin 87 [10] (written by the Department for Education and Skills) and the one is written by Chartered Institution of Building Services Engineers (CIBSE). BB101 is the updated version of BB 87 and currently is used for designing and refurbishing UK primary schools. These guidelines are mainly used to assess whether a classroom is overheated or not. Based on these guidelines people may feel warm if the indoor temperature exceeds 25 °C and hot if the indoor temperature exceeds 28 °C.

European Standard EN15251 [11] suggests that comfort temperature (T_c) in naturally ventilated buildings can be calculated from the outdoor running-mean temperature (T_{rm}) from the formula:

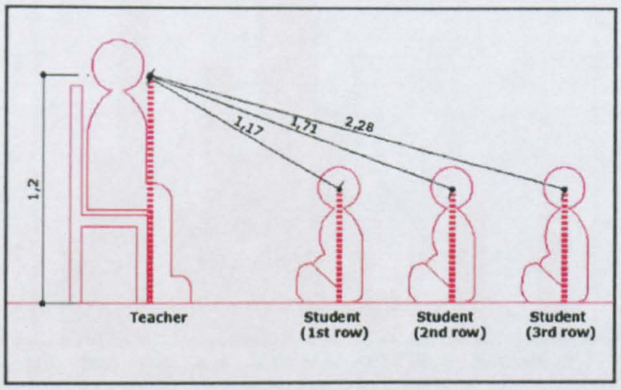


Fig. 3. A classroom layout and the distance between teacher and students when the teacher sits on the chair and students sit around him/her on the floor (A.Montazami).

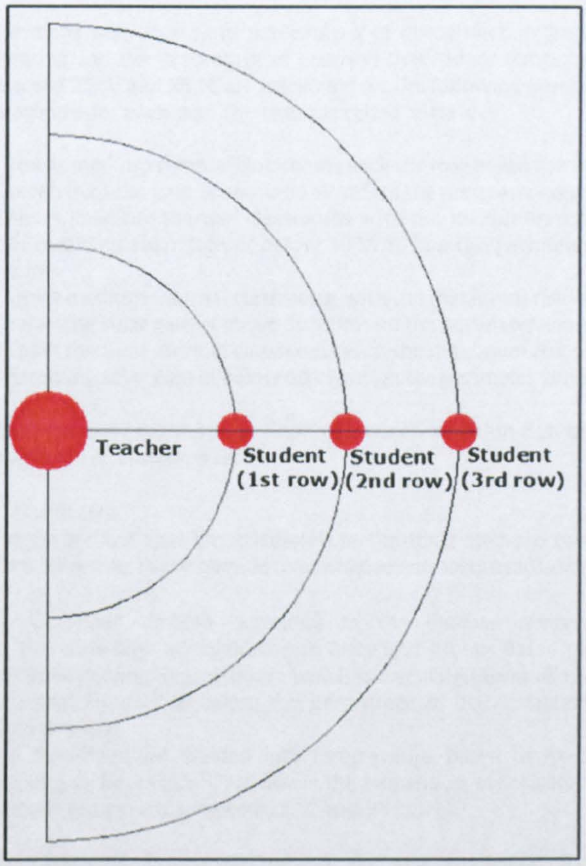
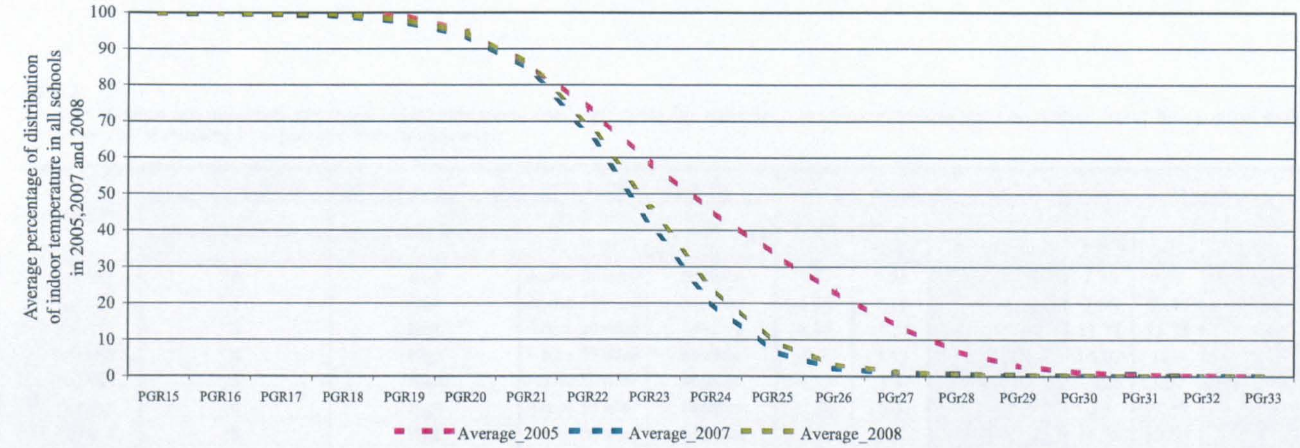


Fig. 4. Classroom layout when students sit on the floor around a teacher (A.Montazami).



Graph 1. Average percentage distribution of indoor temperature in all schools in 2005, 2007 and 2008.

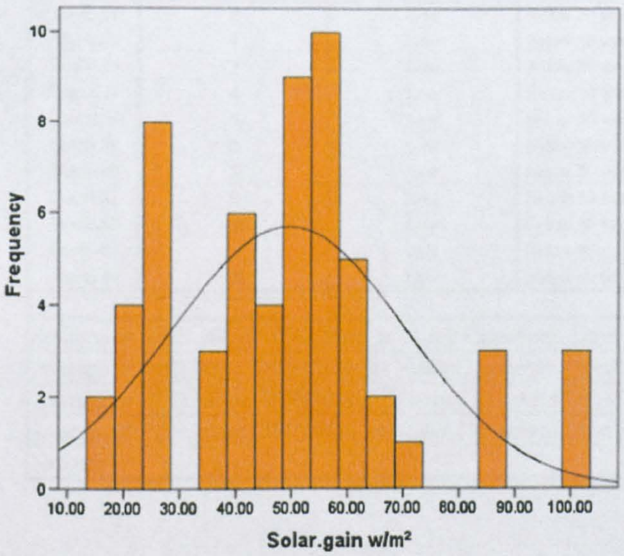
Table 1
Aircraft noise level in each school (Using data derived from Fig. 1).

Schools	Cranford	Grove Rd	STM&M	Orchard	Wellington	Andrew Ewing	Rosary	Heston	Hounslow	Feltham	Pools	Ambler	Norwood	Lady	Hungerford	Colerain	St Gildas	Green Church
Aircraft noise level dB(A) LAeq	66	63	63	63	60	60	57	57	57	<57								
Schools' region	Noisy									Quiet								

$$T_c = 0.33T_{rm} + 18.8 \quad (1)$$

Nicol et al (2009) [8] suggests that the likelihood (P) of overheating (i.e. percentage of dissatisfaction from overheating) in naturally ventilated buildings is related to ΔT. ΔT is the difference between measured temperature in the room and the calculated comfort temperature (T_c). P can be calculated using the formula:

$$P = \frac{e^{(0.4734*\Delta T-2.607)}}{\{1+e^{(0.4734*\Delta T-2.607)}\}} \quad (2)$$



Graph 2. Risk of receiving solar gain in 60 classrooms.

The mean and maximum percentages of dissatisfaction from overheating and the percentage of occasion that indoor temperature exceed 25 °C and 28 °C are calculated for the following groups of classrooms for each day. The result is called 'class-day'.

- Noisy, medium thermal classrooms with the maximum risk of receiving solar gain of above 50 W/m^2 on the perimeter zone.
- Noisy, medium thermal classrooms with the maximum risk of receiving solar gain of below 50 W/m^2 on the perimeter zone.
- Quiet medium thermal classrooms with the maximum risk of receiving solar gain of above 50 W/m^2 on the perimeter zone.
- Quiet medium thermal classrooms with the maximum risk of receiving solar gain of below 50 W/m^2 on the perimeter zone.

Perimeter zone refers to the floor area which is within 6 m on the plan from a window wall.

2.1.4. Fourth step

The 'class-days' that are calculated in the third step are categorised according to the outside temperature and solar irradiance.

2.1.4.1. 'Class-day' division according to the outdoor temperature. The class-days are divided into forty four groups based on the adaptive cooling degree hours which is calculated from adaptive thermal comfort to assess the percentage of dissatisfaction from overheating.

The class-days are divided into forty groups based in fixed cooling degree hours (25 °C) to assess the percentage of occasions that indoor temperature exceed 25 °C and 28 °C.

2.1.4.2. 'Class-day' division according to the solar irradiance. The class-days are divided into two groups (i.e. low and high solar irradiance) according to daily solar irradiance. In this study daily

Table 2
Averages of 'mean and maximum percentages of dissatisfaction from overheating' for noisy and quiet classroom-days based on cooling degree hours, actual daily solar irradiance, risk of receiving solar gain and thermal mass level.

Scenarios	Climate Conditions		Building factors		Ave (PDH.MEAN)			Ave (PDH.MAX)		
	Cooling degree hours	Actual daily irradince	Risk of receiving	Thermal mass	Quiet	Noisy	Comparison	Quiet	Noisy	Comparison
Snario.1	0	High	Above 50 w/m²	Medium	5.87	5.51	Q>N	7.75	7.93	Q<N
Snario.2	1	High	Above 50 w/m²	Medium	4.86	7.11	Q<N	7.65	10.85	Q<N
Snario.3	3	High	Above 50 w/m²	Medium	6.33	10.56	Q<N	11.71	25.75	Q<N
Snario.4	4	High	Above 50 w/m²	Medium	10.75	9.42	Q>N	14.82	14.9	Q<N
Snario.5	5	High	Above 50 w/m²	Medium	6.13	3.9	Q>N	13.26	7.97	Q>N
Snario.6	6	High	Above 50 w/m²	Medium	11.86	10.51	Q>N	20	21.17	Q<N
Snario.7	8	High	Above 50 w/m²	Medium	9.8	8.81	Q>N	14.28	13.69	Q>N
Snario.8	9	High	Above 50 w/m²	Medium	8.72	15.87	Q<N	12.72	24.44	Q<N
Snario.9	14	High	Above 50 w/m²	Medium	–	–	–	20.67	34.42	Q<N
Snario.10	17	High	Above 50 w/m²	Medium	19.75	19.51	Q>N	30.92	33.9	Q<N
Snario.11	22	High	Above 50 w/m²	Medium	18.64	27.83	Q<N	22.52	43	Q<N
Snario.12	0	High	Below 50 w/m²	Medium	5.14	6.43	Q<N	7.32	9.39	Q<N
Snario.13	1	High	Below 50 w/m²	Medium	6	7.19	Q<N	9.27	10.8	Q<N
Snario.14	3	High	Below 50 w/m²	Medium	4.47	7.68	Q<N	6.22	12.29	Q<N
Snario.15	4	High	Below 50 w/m²	Medium	12.52	11.31	Q>N	18.71	17.89	Q>N
Snario.16	5	High	Below 50 w/m²	Medium	4.69	9.3	Q<N	7.97	15.81	Q<N
Snario.17	6	High	Below 50 w/m²	Medium	9.3	19.54	Q<N	11.64	24.91	Q<N
Snario.18	8	High	Below 50 w/m²	Medium	11.67	11.09	Q>N	23.53	17.7	Q>N
Snario.19	9	High	Below 50 w/m²	Medium	4.04	11.94	Q<N	6.47	17.34	Q<N
Snario.20	14	High	Below 50 w/m²	Medium	5.53	18.57	Q<N	5.89	27.02	Q<N
Snario.21	17	High	Below 50 w/m²	Medium	14.68	22.84	Q<N	16.63	29.63	Q<N
Snario.22	22	High	Below 50 w/m²	Medium	10.41	20.12	Q<N	15.47	31.14	Q<N
Snario.23	0	Low	Above 50 w/m²	Medium	3.19	4.56	Q<N	4.27	6.48	Q<N
Snario.24	1	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.25	3	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.26	4	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.27	5	Low	Above 50 w/m²	Medium	12.28	19.83	Q<N	19.08	25.57	Q<N
Snario.28	6	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.29	8	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.30	9	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.31	14	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.32	17	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.33	22	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.34	0	Low	Below 50 w/m²	Medium	3.85	5.34	Q<N	5.52	7.71	Q<N
Snario.35	1	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.36	3	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.37	4	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.38	5	Low	Below 50 w/m²	Medium	7.72	13.26	Q<N	10.51	19.88	Q<N
Snario.39	6	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.40	8	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.41	9	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.42	14	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.43	17	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.44	22	Low	Below 50 w/m²	Medium	–	–	–	–	–	–

Average of PDH.Mean / PDH.Max in 'Noisy.Classroom-Days' is greater than 'Quiet.Classroom-Days'	Q<N
Average of PDH.Mean / PDH.Max in 'Noisy.Classroom-Days' is lower than 'Quiet.Classroom-Days'	Q>N
Average of PDH.Mean / PDH.Max in 'Noisy.Classroom-Days' is equal to 'Quiet.Classroom-Days'	Q=N
Average of PDH.Mean / PDH.Max in 'Noisy.Classroom-Days' and 'Quiet.Classroom-Days' are equal to zero	Q=N=0
No data	–

Table 3
Comparison of the averages of 'mean percentage of dissatisfaction from overheating' for 'Noisy.Classrooms-Days' with 'Quiet.Classrooms-Days' with the Paired Samples Test.

Paired samples test									
		Paired differences					t	df	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean	95% Confidence interval of the difference				
					Lower	Upper			
Pair 1	N.PHD.Mean–Q.PHD.Mean	3.59320	4.43422	.88684	1.76284	5.42356	4.052	24	.000

solar irradiance in June and July varied from 0.80 KWh/m^2 to 8.25 KWh/m^2. The distribution of these data is tested and it is found out that they are normally distributed. The mean and median of these data are 4.96 KWh/m^2. For this reason, days are divided into two groups of high and low according to their corresponding daily irradiance level on horizontal surfaces.

2.1.5. *Fifth step*

In this step:

Firstly an average is taken of the mean and maximum percentage of dissatisfaction from overheating for the 'noisy class-days' and for the 'quiet class-days' which have already been categorised based on building factors (i.e. thermal mass level, solar gain) and climate condition (i.e. outside temperature and solar irradiance). The results are summerised in Table 2.

Secondly an average is taken of the percentage of occasion the indoor temperature exceed 25 °C and 28 °C for the for the 'noisy class-days' and for the 'quiet class-days' which have already been categorised based on building factors (i.e. thermal mass level, solar gain) and climate condition (i.e. outside temperature and solar irradiance). The results are summerised in Table 5.

The impact of internal gain is considered constant as the number of students and their activities and also the number and types of equipment in use are almost the same.

2.2. *Results*

In Table 2, the percentage of dissatisfaction from overheating (mean and maximum) which are calculated for each 'class-days' with the same building factors and climate conditions of noisy class-days are compared with quiet class-days. This comparison is carried out using the T test.

In Table 5, the percentage of occasion that indoor temperature exceed 25 °C and 28 °C which are calculated for each 'class-days' with the same building factors and climate conditions of noisy class-days are compared with quiet class-days. This comparison is carried out by T test.

T test is carried out between the averages of mean and maximum 'percentages of dissatisfaction from overheating' for noisy classroom-days and quiet classroom-days. As can be seen from Tables 3 and 4, they are significantly different ($p < 0.05$) with a difference of 3.59% and 6.41% for mean and maximum percentage of dissatisfaction from overheating respectively. It is suggested that aircraft noise is a predictor for the percentage of dissatisfaction from overheating and consequently indoor temperature.

T test is carried out between the averages of 'percentages of occasions that indoor temperature exceeds 25 °C and 28 °C' for noisy classroom-days and quiet classroom-days. As can be seen from Tables 6 and 7, they are significantly different ($p < 0.05$) with a difference of 15.69% and 9.76% for the percentages of occasions that indoor temperature exceeds 25 °C and 28 °C respectively. It is suggested that aircraft noise is a predictor for percentage of occasions that indoor temperature exceeds 25 °C and 28 °C and consequently indoor temperature.

The result of the above study are summarised in the following table.

As can be seen from Table 8, in all of the techniques of assessing indoor temperature, aircraft noise is a predictor. As the result, it can suggested that high level of aircraft noise plays an important role in indoor temperature as it reduces the buildings' potential for having natural ventilation.

A subjective survey is also carried out in order to test the result that is achieved from the objective survey. In this survey teachers were asked to rate different environmental noise sources (e.g. aircraft, lorries, cars etc.) and thermal comfort.

Regression analysis is carried out between teachers' perception toward environmental noise and thermal comfort in low and medium thermal mass schools. The result of this regression shows that the aircraft noise is the only predictor for thermal comfort in both low thermal mass schools ($p < 0.05$, $r = 0.323$) and medium thermal mass schools ($p < 0.05$, $r = 0.343$) based on self-assessment through questionnaires. In the questionnaires teachers were requested to rate thermal comfort and different noise sources level from 1 to 7 as follows:

Noise from Cars	Too little	1	2	3	4	5	6	7	Too much
Noise from Aircraft	Too little	1	2	3	4	5	6	7	Too much
Noise from Lorries	Too little	1	2	3	4	5	6	7	Too much
Noise from Buses	Too little	1	2	3	4	5	6	7	Too much
Noise from Railway	Too little	1	2	3	4	5	6	7	Too much
Noise from Other	Too little	1	2	3	4	5	6	7	Too much
Thermal comfort	Uncomfortable	1	2	3	4	5	6	7	Comfortable

Graphs 3 and 4 show this relationship separately as thermal mass level is one of the factors that has an impact on the indoor temperature. The teachers' perceptions were elicited through a questionnaire.

Table 4
Comparison of the averages of 'maximum percentage of dissatisfaction from overheating' for 'Noisy.Classrooms-Days' with 'Quiet.Classrooms-Days' with Paired Samples Test.

Paired samples test									
		Paired differences					t	df	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean	95% Confidence interval of the difference				
					Lower	Upper			
Pair 1	N.PHD.MAX–Q.PHD.MAX	6.41462	7.36607	1.44460	3.43940	9.38983	4.440	25	.000

Table 5
Averages of 'percentages of occasions that that indoor temperature exceeds 25 °C and 28 °C' for noisy and quiet classroom-days based on cooling degree hours, solar irradiance and risk of receiving solar gain and thermal mass.

Scenarios	Climate Conditions		Building factors		Ave (PGR.25°C)			Ave (PGR.28°C)		
	Cooling degree hours	Actual daily irradince	Risk of receiving	Thermal mass	Quiet	Noisy	Comparison	Quiet	Noisy	Comparison
Snario.1	0	High	Above 50 w/m²	Medium	16.38	9.44	Q>N	1.73	0.307	Q>N
Snario.2	1	High	Above 50 w/m²	Medium	48.43	33.67	Q>N	2.26	0	Q>N
Snario.3	2	High	Above 50 w/m²	Medium	11.975	32.143	Q<N	0.21	0	Q>N
Snario.4	3	High	Above 50 w/m²	Medium	27.311	60.714	Q<N	0.42	3.57	Q<N
Snario.5	6	High	Above 50 w/m²	Medium	53.061	40	Q>N	0	0	Q=N
Snario.6	7	High	Above 50 w/m²	Medium	67.857	98.214	Q<N	1.05	5.35	Q<N
Snario.7	8	High	Above 50 w/m²	Medium	85.714	89.286	Q<N	5.88	3.57	Q>N
Snario.8	15	High	Above 50 w/m²	Medium	80.67	100	Q<N	2.52	21.42	Q<N
Snario.9	21	High	Above 50 w/m²	Medium	97.89	100	Q<N	41.17	42.85	Q<N
Snario.10	24	High	Above 50 w/m²	Medium	96.21	100	Q<N	28.99	71.42	Q<N
Snario.11	0	High	Below 50 w/m²	Medium	8.54	16.49	Q<N	0	0.22	Q<N
Snario.12	1	High	Below 50 w/m²	Medium	58.25	52.38	Q>N	0	0.264	Q<N
Snario.13	2	High	Below 50 w/m²	Medium	0	25	Q<N	0	0	Q=N
Snario.14	3	High	Below 50 w/m²	Medium	0	38.095	Q<N	0	0	Q=N
Snario.15	6	High	Below 50 w/m²	Medium	51.78	47.95	Q>N	1.78	2.72	Q<N
Snario.16	7	High	Below 50 w/m²	Medium	50	85.71	Q<N	0	0	Q=N
Snario.17	8	High	Below 50 w/m²	Medium	96.42	100	Q<N	0	42.85	Q<N
Snario.18	15	High	Below 50 w/m²	Medium	0	100	Q<N	0	14.28	Q<N
Snario.19	21	High	Below 50 w/m²	Medium	100	100	Q=N	0	66.66	Q<N
Snario.20	24	High	Below 50 w/m²	Medium	89.28	100	Q<N	0	33.33	Q<N
Snario.21	0	Low	Above 50 w/m²	Medium	1.44	3.41	Q<N	0	0	Q=N
Snario.22	1	Low	Above 50 w/m²	Medium	8.82	3.57	Q>N	0	0	Q=N
Snario.23	2	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.24	3	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.25	6	Low	Above 50 w/m²	Medium	88.65	100	Q<N	3.78	25	Q<N
Snario.26	7	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.27	8	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.28	15	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.29	21	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.30	24	Low	Above 50 w/m²	Medium	–	–	–	–	–	–
Snario.31	0	Low	Below 50 w/m²	Medium	3.01	8.98	Q<N	0	0	Q=N
Snario.32	1	Low	Below 50 w/m²	Medium	0	88.09	Q<N	0	0	Q=N
Snario.33	2	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.34	3	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.35	6	Low	Below 50 w/m²	Medium	78.57	95.23	Q<N	0	0	Q=N
Snario.36	7	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.37	8	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.38	15	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.39	21	Low	Below 50 w/m²	Medium	–	–	–	–	–	–
Snario.40	24	Low	Below 50 w/m²	Medium	–	–	–	–	–	–

Average of PGR.25°C / PGR.28°C in 'Noisy.Classroom-Days' is greater than 'Quiet.Classroom-Days'	Q<N
Average of PGR.25°C / PGR.28°C in 'Noisy.Classroom-Days' is lower than 'Quiet.Classroom-Days'	Q>N
Average of PGR.25°C / PGR.28°C in 'Noisy.Classroom-Days' is equal to 'Quiet.Classroom-Days'	Q=N
Average of PGR.25°C / PGR.28°C in 'Noisy.Classroom-Days' and 'Quiet.Classroom-Days' are equal to zero	Q=N=0
No data	–

As can be seen from Graphs 3 and 4, the teachers who reported higher levels of aircraft noise, also reported lower levels of thermal comfort and vice versa. This subjective study confirms the objective survey that claims aircraft noise is a predictor for thermal comfort.

It should be noted that the schools in this study were chosen in such a way as to be a considerable distance from main roads and construction sites. For this reason, the ones located within a close distance to Heathrow Airport only suffer from aircraft noise and those located at a far distance to Heathrow Airport do not suffer from any kinds of environmental noises. This means that other environmental noise sources do not act as a predictor of thermal comfort. To determine that whether there is any relationship between other environmental noises with thermal comfort, further research will be needed.

In order to have a better understanding of how the level of aircraft noise has an impact on thermal comfort, the teachers' perceptions towards thermal comfort and aircraft noise are compared with the schools location on the noise contour map of above 57 dBA. Regression analysis is carried out between 'thermal comfort perception' with 'aircraft perception and school's location

Table 6
Comparison of the average of 'percentages of occasions that indoor temperature exceeds 25 °C' in noisy and quiet Classroom-Days with Paired Sample Test.

Paired samples test									
		Paired differences					t	df	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean	95% Confidence interval of the difference				
					Lower	Upper			
Pair 1	N.PGR.25–Q.PGR.25	15.69669	27.35299	5.36436	4.64858	26.74481	2.926	25	.007

Table 7
Comparison of the average of 'percentages of occasions that indoor temperature exceeds 28 °C' in noisy and quiet Classroom-Days with Paired Sample Test.

Paired samples test									
		Paired differences					t	df	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean	95% Confidence interval of the difference				
					Lower	Upper			
Pair 1	N.PGR.28–Q.PGR.28	9.76084	18.10293	3.62059	2.28832	17.23336	2.696	24	.013

on the noise contour'. According to this regression, there is a significant relation between 'aircraft noise perception' with the schools' location on the noise counter map ($p < 0.05$ and $r = 0.316$) and also there is a significant relation between 'thermal comfort perception' with the schools' location on the noise counter map ($p < 0.05$ and $r = 0.337$).

Graph 5 shows the relation between the schools' location on the aircraft noise contour map with the teachers' perception toward aircraft noise and thermal comfort. As can be seen from this graph, the schools located on the higher aircraft noise contour experience lower thermal comfort and vice versa.

This suggests that not only do the schools located in noisy regions have a higher risk of experiencing overheating in comparison to those located in the quiet regions due to the aircraft noise but also the schools located in the noisy region suffer from different levels of overheating according to their location on the noise contour map. In other words, distance of the schools' building from Heathrow airport and the impact of aircraft noise on classrooms' background noise level have an impact on the level of thermal comfort. The high level of aircraft noise plays an important role in dissatisfaction from overheating as it reduces the buildings' potential for having natural ventilation.

3. Impact of high aircraft noise on speech intelligibility

3.1. Methodology

Building Bulletin 93 [12] is a UK guideline written by the Department for Education and Skills for acoustic design of schools. In this guideline, the proposed standards for background noise is difficult to achieve in naturally ventilated schools as the indoor background noise levels are added to significant levels of external

Table 8
Summary of different ways of looking at indoor temperature.

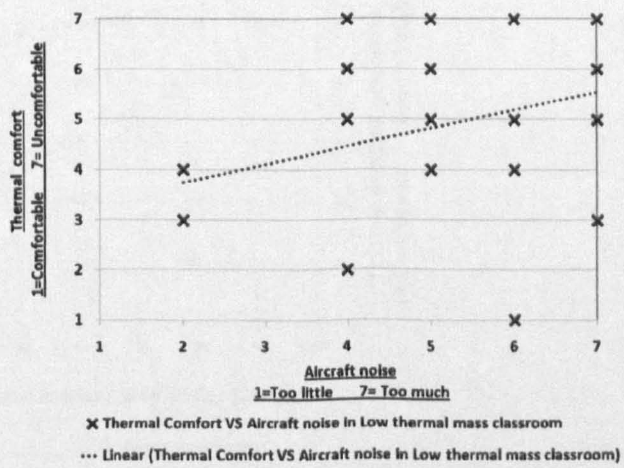
Different techniques of looking at indoor temperature		Impact of aircraft on indoor temperature
Explanation	Code	
Average mean percentage of dissatisfaction from overheating	(Mean.PDH)	√
Average maximum percentage of dissatisfaction from overheating	(Max.PDH)	√
Average percentage of occasion that indoor temperature exceeds 25 °C	(GR.25 °C)	√
Average percentage of occasion that indoor temperature exceeds 28 °C	(GR.28 °C)	√

noise [13]. Thus, additional guidance is provided to facilitate the use of natural ventilation by Building Bulletin 101 [9]. The BB101 is a UK guideline which is written by the Department for Education and Skills for the ventilation design of school buildings. According to this guideline, the indoor ambient noise level should not exceed 35 dB in classrooms if there is a minimum supply of fresh air that is equal to or greater than 3l/s per person provided. The indoor ambient noise level can be increased by 5 dB (reaching to 40 dB) if a ventilation rate of higher than 8l/s per person is required, for example during overheating on hot summer days when it may be necessary to open all the windows.

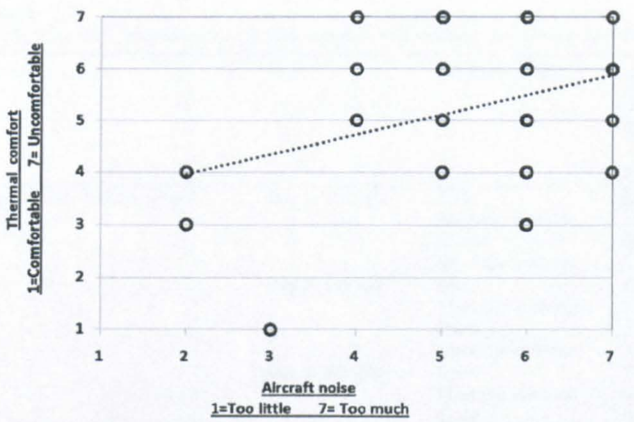
Generally aircraft noise has a negative impact on an occupant's speech intelligibility and it impairs communication and also annoys them causes them to lose their ability to concentrate.

The nature of aircraft noise is intermittent rather than steady. Various guidelines are proposed regarding the impact of aircraft noise on speech intelligibility which is summarised in Table 9. In these guidelines different benchmarks are set for the SIL, L_{max}, SEL, Leq and LA1 of the aircraft noise. Furthermore Shield [14] also took L_{max} as the main factor to estimate the annoyance level.

To study that how the aircraft noise has an impact on speech intelligibility, 30 min noise measurements were carried out when the schools were unoccupied, both when the windows are open



Graph 3. Relationship b05, between aircraft noise level and indoor temperature and thermal comfort on low thermal mass school ($p < 0.05$, $r = 0.323$).



Graph 4. Relationship between aircraft noise level and indoor temperature and thermal comfort on medium thermal mass school ($p < 0.05$, $r = 0.343$).

and closed. These measurements were carried out with Symphonie acquisition system. These measurements were carried out in 1 m height toward the back of classrooms. A windshield was used on the microphone which was calibrated before and after the measurement period.

3.2. Results

In Table 10, the classrooms' aircraft noises against the criteria set for speech intelligibility in two situations (window closed and opened) are shown in order to show that how the acoustic difficulties arise in the schools located under the Heathrow flight path.

Based on Tables 10, it can be suggested that leaving the windows open almost always causes problems according to all criteria. According to these guidelines, the speech intelligibility is improved if windows are closed. The extent of the improvement varies depending on what guideline is referred to.

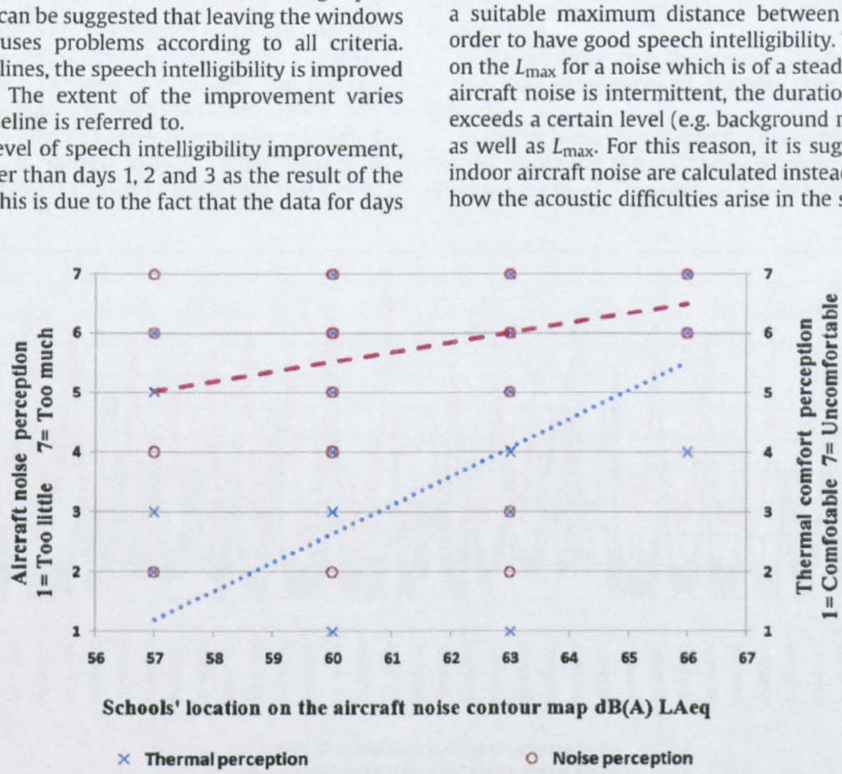
As can be seen, the level of speech intelligibility improvement, on days 4 and 5 are better than days 1, 2 and 3 as the result of the windows being closed. This is due to the fact that the data for days 1–3 are related to the Grove Road primary schools which are located directly under the flight path and an airplane passes directly over the building. This school is located on the 63 dB(A) noise contour . The data for days 4–5 are related to the Andrew Ewing primary school which is located parallel to the flight path and is located on the 60 dB(A) noise contour. In this study the impact of aircraft noise was assessed using the existing criteria (Tables 9 and 10).

Table 9
Indoor Noise level criteria in order to have good speech intelligibility.

Criteria	Benchmark	Proposed by
SIL maximum sound level in the frequency range of 500–20000 HZ	SIL < 45 dBA 90% of sentences intelligibility	Sharp et al., 1984 [15]
L_{max}	L_{max} < 50 dBA 90% of the words would be understood	Lind et al., 1998 [16]
SEL Sound exposure level	SEL < 60 dBA 95% of intelligibility	Bradley (n.d.) [17] cited in interference with speech communication
Leq	Leq < 40 dBA	ANSI123 [18]
LA1, 30 min	LA1 < 55 dBA	UKDFES [17]

In order to have a better understanding about how the window closure has an impact on aircraft noise level inside classroom, the maximum level of aircraft noise while the classroom was unoccupied and windows were open and closed are compared with recommended L_{max} as an example (Graph 6). As it can be seen by closing the window the L_{max} is decreased to 55 dB (on average) but it still does not meet the recommended criteria which is 50 dB.

It should be noted that both the level of disturbing noise (e.g. aircraft noise) and the distance between speaker and listener have a significant impact on speech intelligibility. BS 8233 recommends a suitable maximum distance between speaker and listener in order to have good speech intelligibility. This distance is set based on the L_{max} for a noise which is of a steady nature. As the nature of aircraft noise is intermittent, the duration of indoor aircraft noise exceeds a certain level (e.g. background noise level) are important as well as L_{max}. For this reason, it is suggested the L10 and L5 of indoor aircraft noise are calculated instead of L_{max} in order to show how the acoustic difficulties arise in the schools located under the



Graph 5. The relation between schools' location on aircraft noise.

Table 10
A study of aircraft noise based on different criteria when windows are opened and closed in Grove Road and Andrew Ewing Primary School.

Schools	Days	Windows' status	Criteria and recommended benchmark					
			SIL		L_{max}	SEL	Leq	LA1
			45 dB		50 dB	60 dB	40 dB	55 dB
			L_{max} for 500 HZ	L_{max} for 2000 HZ	L_{max}			
Grove Road Primary School	Day 1: 2nd July	Open	62	60	69	84	53	64
		Meet the criterion	×	×	×	×	×	×
		Closed	60	54	65	74	44	55
		Meet the criterion	×	×	×	×	×	√
	Day 2: 3rd July	Open	64	76	79	89	56	69
		Meet the criterion	×	×	×	×	×	×
		Close	57	59	68	73	41	53
		Meet the criterion	×	×	×	×	×	√
	Day 3: 4th July	Open	70	62	75	88	55	68
		Meet the criterion	×	×	×	×	×	×
		Close	61	63	70	76	44	53
		Meet the criterion	×	×	×	×	×	√
Andrew Ewing Primary School	Day 4:8th July	Open	66	51	70	81	49	61
		Meet the criterion	×	×	×	×	×	×
		Close	43	37	56	68	36	47
		Meet the criterion	√	√	×	×	√	√
	Day 5: 14th July	Open	56	50	63	76	46	54
		Meet the criterion	×	×	×	×	×	√
		Close	47	41	53	70	41	48
		Meet the criterion	×	√	×	×	×	√
Meet the criterion			√					
Do not meet the criterion			×					

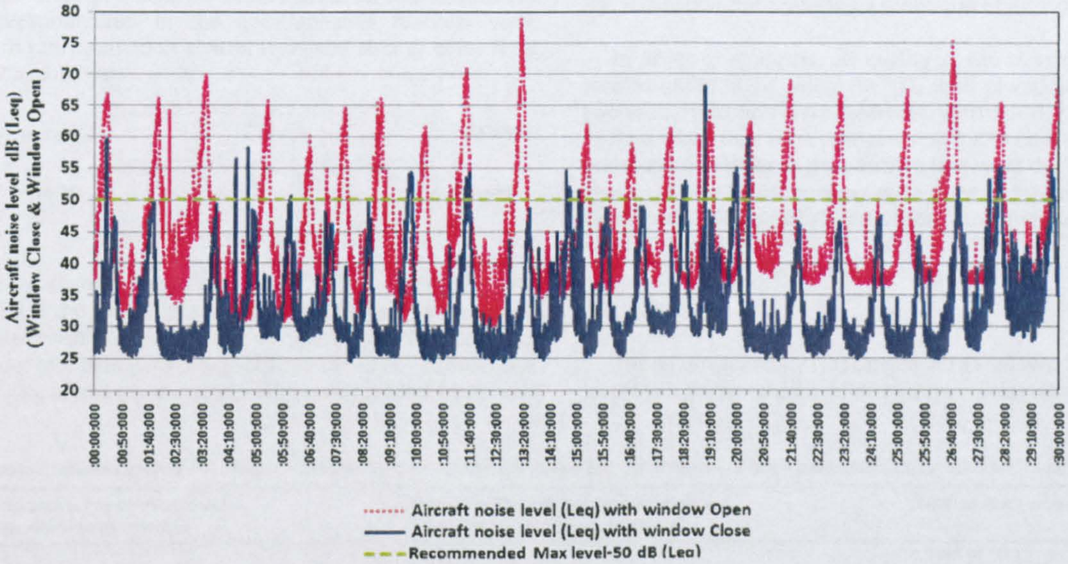
Heathrow flight path. Based on this calculation, the 10% and 5% of high level of aircraft noise are calculated in order to estimate the percentage of occasions that communication would fail due to the aircraft noise.

Aircrafts pass over the schools which have close distances to Heathrow airport every 90 s. The Table 11 shows the maximum suitable distances between speaker (with the normal voice) and listener based on BS 8233 [19] (which is adapted for L5 and L10) and the percentage of occasions that communications would be failed. For example, if the distance between the speaker and listener (in the situation that the window is open) becomes higher than 0.7 m, out of 90 s when an aircraft passes over a school building 4.5 s of communication is missed out. In other words, if pronouncing each word lasts for 1 s, it can be concluded that nearly five words will be missed out of 90 words which causes a negative impact on speech intelligibility.

Furthermore, if the distance between speaker (with the normal voice) and listener becomes higher than 1.32 m, then 9 s out of 90 s is missed out; this creates a more critical situation as nine out of 90 words will be missed out. In the situation that the window is closed, this amount is increased to 2.7 and 4.7 respectively.

In the condition that the speaker raises his/her voice by up to 5 dBA the recommended distance can be increased as per Table 12.

As can be seen, the suitable distance between speaker (with the normal voice) and listener varies between 0.7 m and 1.3 m when windows are open. This amount can be increased to from 1.6 to 2.3



Graph 6. Comparison between the level of aircraft noise inside the classroom when window is open and closed with the recommended maximum level.

Table 11
Maximum distance between speaker and listener when windows are opened and closed and the durations of failed communication (speaker uses normal voice).

Maximum distance between speaker and listener when windows are 'opened'	Maximum distance between speaker and listener when windows are 'closed'	Duration that communication is failed
0.7	2.7	4.5 out of 90 s
1.3	4.7	9.0 out of 90 s

if the speaker raises his or her voice by up to 5 dBA. As it can be seen from the Figs. 2–4 the best condition in which the speech intelligibility is provided (while the windows are opened and aircrafts fly over the school) is when the teacher sits on a chair at the centre, students sit around him/her and the teacher raises his/her voice. In this condition, teacher speech intelligibility is provided even for the students, who sit in the second and third rows.

As it was observed several times in the classrooms of Grove Road and Andrew Ewing primary schools, teachers invited students to sit on the floor during lecturing activities and they themselves sat on the chair during most of the lecturing activities in order to improve speech intelligibility.

It should be noted that if the teacher wants to stand or students want to sit at their desks, the speech intelligibility will be impaired even further and students will start to miss at least 4.5 s (or more) out of 90 s depending on their distance from the teacher as their distance exceeds the maximum distance between speaker and listener [Table 11 (teachers with normal voice) and Table 12 (teachers with raised voice)]. In this situation, in order to improve speech intelligibility, classroom windows should be kept closed. This accords with the occupants of the school located under the flight paths tending to close the windows most of the time. Although closing windows tends to improve the speech intelligibility, it reduces the buildings' potential for having natural ventilation as the only means of ventilation in these schools are through windows.

In addition, in the situation that it is crucial to leave the windows open, the distance between speaker and listener should be at a minimum otherwise the listener starts to miss out some parts of the communication which has an impact on speech intelligibility.

The results of the subjective study tended to confirm this analysis. The regression analysis of perceived ventilation control level with aircraft noise confirmed that there is a small but significant negative relationship between ventilation control level and aircraft noise level ($p < 0.05$, $r = 0.275$) based on self-assessment through questionnaires. In the questionnaires teachers were requested to rate ventilation control level and aircraft noise level from 1 to 7 as follows:

Ventilation	No Control	1	2	3	4	5	6	7	Full Control
Aircraft	Too little	1	2	3	4	5	6	7	Too much

The only available ventilation system in the classrooms that were studied is the natural ventilation (i.e. window) as they were all naturally ventilated. Although occupants of the buildings located under the flight path physically had the ability to open and close windows, access to natural ventilation was limited by aircraft noise suggesting there would be a lack of sufficient ventilation and overheating and poor indoor air quality will occur.

4. Impact of not opening windows due to noise on indoor air quality

4.1. Methodology

CO_2 is produced by occupants' breathing and the amount of CO_2 produced depends on the number of occupants, their weight and activity level (weight and activity have an impacts on the number of inhalations and exhalations by occupants). Also each exhalation has a certain amount of CO_2. The volume of the room also has an impact on CO_2 concentration. Ventilation helps to remove the CO_2 by providing fresh air. In general, the higher the CO_2 level, the lower the air quality.

In BB101, CO_2 concentration has been chosen as the key performance indicator for assessment of indoor air quality. BB101 proposed two sets of criteria to assess air quality inside a classroom. One of these sets is according to classrooms' CO_2 level and the other is according to the classrooms' ventilation rate.

a) The BB101 criteria according to classrooms' CO_2 level:

1. The average concentration of CO_2 should not exceed 1500 ppm during occupied hours.
2. The maximum concentration of CO_2 should not exceed 5000 ppm during a teaching day.
3. At any occupied time the occupants should be able to reduce the concentration of CO_2 to 1000 ppm.

b) The BB101 criteria according to classrooms' ventilation rate:

1. A minimum of 3 l/s per person
2. A minimum daily average of 5 l/s per person
3. A capability of achieving a minimum of 8 l/s per person

In order to study the air quality of the classrooms which are located under flight paths, the CO_2 level of various classrooms of two primary schools were measured, with a device called Telair, for 11 days when they were occupied and for 13 days when they were unoccupied in order to have an idea that what the background CO_2 levels are. The measurements were done in 1–2 m intervals for 7 classrooms. In some classrooms more than one measurement was done.

4.2. Results

The air quality study was carried out as follows: The average CO_2 level in all classrooms on different days was less than the 1500 ppm

Table 12
Maximum distance between speaker and listener when windows are opened and closed and the durations of failed communication (speaker with a raised voice).

Maximum distance between speaker and listener when windows are 'opened'	Maximum distance between speaker and listener when windows are 'closed'	Duration that communication is failed
1.6	5.99	4.5 out of 90 s
2.4	8.00	9.0 out of 90 s

Table 13
Summary of classrooms indoor air quality against BB101 air quality guideline based on CO_2.

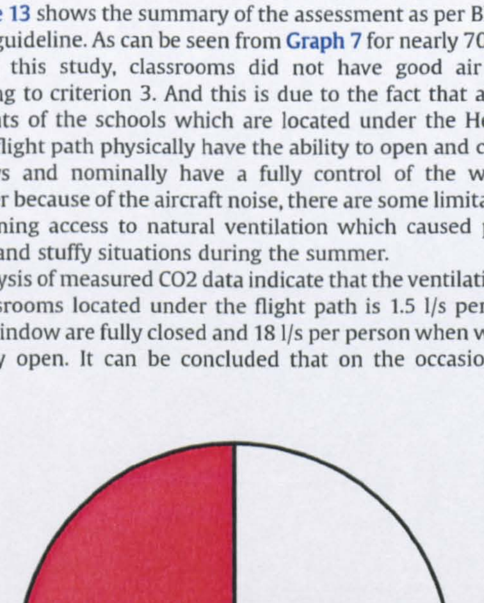
Classroom	School	Date	First criterion	Second criterion	Third criterion	Result
Y2	Grove Road	24, June	✓	✓	✓	Pass
Y4	Grove Road	25, June	✓	✓	×	Fail
Y3	Grove Road	26, June	✓	✓	×	Fail
Y6	Grove Road	27, June	✓	✓	×	Fail
Y6	Grove Road	30, June	✓	✓	×	Fail
Y4	Grove Road	1, July	✓	✓	×	Fail
Y4	Grove Road	2, July	✓	✓	✓	Pass
Y4	Andrew Ewing	7, July	✓	✓	×	Fail
Y2	Grove Road	10, July	✓	✓	×	Fail
Y2	Grove Road	11, July	✓	✓	×	Fail
Y6	Andrew Ewing	14, July	✓	✓	✓	Pass
Y3	Andrew Ewing	15, July	✓	✓	✓	Pass

which means that classrooms meet the first criterion for having good air quality. The maximum CO_2 level in all classrooms on different days was less than the 5000 ppm which means that classrooms meet the second criterion for having good air quality. However the ability to reduce the level to 1000 ppm was not possible because of aircraft noise.

As the result of assessing the indoor CO_2 in different classroom against the third BB101 criterion, it can be concluded that in some situations windows are closed and occupants are not able to open the classrooms' windows because of aircraft noise. Therefore, all the classrooms in all session do not meet the 3rd BB101 criterion.

Table 13 shows the summary of the assessment as per BB101 air quality guideline. As can be seen from Graph 7 for nearly 70% of the days in this study, classrooms did not have good air quality according to criterion 3. And this is due to the fact that although occupants of the schools which are located under the Heathrow airport flight path physically have the ability to open and close the windows and nominally have a fully control of the windows. However because of the aircraft noise, there are some limitations to maintaining access to natural ventilation which caused poor air quality and stuffy situations during the summer.

Analysis of measured CO2 data indicate that the ventilation level for classrooms located under the flight path is 1.5 l/s per person when window are fully closed and 18 l/s per person when windows are fully open. It can be concluded that on the occasion when



Graph 7. Share of the days according to classrooms' air quality.[14]

classrooms' windows are fully closed, the classrooms' ventilation rate fails to meet the BB101 air quality guidelines based on ventilation rate criteria and consequently classrooms suffer from poor air quality. The subjective results confirm this. The regression analysis of air quality with aircraft noise confirmed that there is a significant relationship between air quality and aircraft noise ($p < 0.05$, $r = 0.255$) based on self-assessment through questionnaires.

In the questionnaires teachers were requested to rate air quality and aircraft noise level from 1 to 7 as follows:

Aircraft	Too little	1	2	3	4	5	6	7	Too much
Air quality	Fresh	1	2	3	4	5	6	7	Stuffy

The result confirms that the higher the level of aircraft noise, the lower will be the air quality level. On the other word, teachers who scored a higher level of aircraft noise, also scored a stuffier situation and vice versa.

5. Conclusions

The overriding conclusion of this study is that natural ventilation through windows is not sufficient for keeping indoor temperatures at a comfortable level and for providing fresh air for schools which are located under flight paths. Due to global warming, according to the current set of UK climate scenarios, it is predicted that average temperature during summers will increase by 7 °C by the end of this century. This will have a significant impact on overheating in free-running schools. In addition, the lack of ventilation will add to this problem.

It can be concluded that the free-running primary schools which are located under the flight paths with only windows as a means of natural ventilation have a higher likelihood of experiencing poor air quality and overheating during summer terms. This is what architects should consider in order to provide better environmental conditions for primary school children.

As control of ventilation is one of the method of controlling overheating, it is possible to reduce the overheating risk by controlling solar gain, internal gain, design layout and by the use of heavy thermal mass material instead of low and medium ones. Night time ventilation could be a solution for thermal comfort purposes. Ventilation shafts may be adapted as a suitable means of ventilation for both purposes of thermal comfort and fresh air.

Acknowledgment

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Using an inappropriate thermal benchmark leads to overheating in UK primary schools

Azadeh Montazami[1], Fergus Nicol[2]

1) Coventry University, United Kingdom
2) London metropolitan University, UK

Abstract:

Schools' buildings can have a significant impact on students and teachers' health and performance through their internal environment such as noise level, indoor temperature, air quality and light. Providing good environmental conditions for schools has always been critical. The two main reasons are: firstly of the conflict between comfort factors (thermal, lighting, acoustic comfort and air quality) as they are interrelated and secondly the use of relaxed thermal, air quality, acoustic and lighting benchmarks. In this study, the current thermal benchmark, which is used to design and refurbish the UK school classrooms, is assessed in order to evaluate the extent to which it is lenient and whether it represents the occupants' feelings.

Keywords: Overheating, School classrooms, Fixed thermal benchmark, Adaptive thermal benchmark

1. Introduction:

School buildings can have a significant impact on students and teachers' health and performance through their internal environment such as noise level, indoor temperature, air quality and light. According to Heath et al. (2000), there has always been concern regarding the indoor environment of schools due to shortage of funding for school buildings, because poor environments have a greater impact on children than on adults, and because the length of time that children spend at school is higher than the time they spend at home. For this reason, considerations of environmental and comfort factors have always had a specific position in any building design guidelines. Despite this, schools have failed to provide optimum environmental conditions from the Victorian era up until now.

The summary of conflict between comfort factors in each era is reviewed in the Background section. The conflict between comfort factors can be one of the main reasons for poor environmental conditions in school classrooms as a result of the lack of designer concentration in the first stages of design. The other reason for poor environmental conditions may be due to use of the lenient benchmarks which is the topic of this study.

In this study, the current thermal benchmark, which is used to design and refurbish the UK school classrooms, is assessed in order to evaluate the extent to which it is too lenient and whether it adequately represents the occupants' feelings. It should be noted that the schools which were built during different periods are still being utilised in London. For this reason, a range of schools from Victorian to modern have been examined.

2. Background:

The background study is carried out in two parts. The first part concentrates on the conflicts which are observed in schools built in different priods in the UK, and the second part concentres on different overheating benchmarks.

2.1. Conflict between comfort factors

As far as the comfort factors requirements are concerned, the history of the UK school construction is divided into five time periods the Victorian, Open air, Post World War II, Post-oil crisis and PCP (Primary Capital Programme) / BSF (Building School for Future) schemes. It should be noted that the schools which were built during the different periods mentioned above are still being utilised in London. In each era of school construction, there are various kinds of conflict between comfort factors. In the following list different types of conflict between comforts factors in each period are summarised:

a. Victorian schools mainly refer to the schools that were built before 1920 with heavy thermal mass material (Châtelet, n.d). On the one hand, Victorian schools have the privilege of having stack ventilation due to sash windows and high ceilings and consequently the ability to maintain indoor air quality and thermal comfort during summer. On the other hand, the occupants of these schools suffer from high reverberation times and consequently a higher level of noise due to their high ceilings. As a result, the type of conflict that is observed in Victorian schools is the conflict between acoustic comfort and 'air quality/ thermal comfort' in summer.

b. Open air schools mainly refer to the schools built in the early part of the 20th century, when there was concern over the spread of tuberculosis. These schools at the time of their construction were thermally comfortable during summer but not winter. These schools had the benefit of cross ventilation, as large windows and doors could be fully opened to maintain indoor temperature and to remove excessive heat during cooling seasons (summer). Although these schools had the benefit of a high level luminance, good level of natural light and thermal comfort during summer, a large amount of heat was lost during winter due to their large openings. As a result, the type of conflict observed in open air schools is, the conflict between 'thermal comfort' and 'lighting comfort' in winter and also, the conflict between thermal comfort in winter and summer. These schools were modified by covering up one side of the classrooms using glass enclosure in order to improve environmental conditions. With this modification, classrooms have had a lower risk of heat loss during winter; however, they have had a higher risk of experiencing overheating during summer as the benefit of cross ventilation was reduced to a single sided ventilation (conflict between thermal comfort in winter and summer).

c. Post-war schools mainly refer to the schools built as a result of the baby boom after the destruction caused by World War II and the growing need for the schools at the beginning of fifties (1945 -1970) [Woolner, 2010]. On the one hand, the post-war classroom had a high level of natural light due to the large windows but, on the other hand, these classrooms produce excessive glare and receive a high amount of solar gain that causes overheating during summer and cold due to heat loss during winter.

This is the conflict between lighting level and thermal comfort in post war primary school classrooms. It should be noted that the poor thermal comfort is not only related to the large windows but also to the lightweight construction materials used in these buildings.

d. Post- oil crisis schools refer to the schools that are constructed due to two phenomena i.e. the energy crisis in the 1970s and the sick building syndrome. As a result, the open-plan space school concept was introduced in the United State, in 1970 and the idea spread to Europe and especially to the UK (Bennet et al, 1980). Open-plan schools had the privilege of having cross ventilation to maintain classrooms' indoor temperature and air quality during summer but they were highly noisy and were not acoustically comfortable. As a result, there was a conflict between acoustic comfort and 'thermal comfort / air quality' in these kinds of schools. Therefore, the open plan classrooms were converted to cellular classrooms to overcome the acoustic problem. As a result of this conversion, classrooms lost their opportunity for having cross ventilation in summer (Conflict between acoustic comfort and 'thermal comfort and air quality').

e. BSF & PCP schools mainly refer to the schools built under the Primary Capital Programme (PCP) and Building Schools for the Future (BSF) schemes which were announced for primary and secondary schools in 2003 & 2006 respectively. The PCP and BSF programmes were the first wave of school construction / refurbishment since the huge Victorian and post-war building programmes. Although the main principle of constructing these schools is to provide comfortable environments, these schools still fail to provide comfortable environment in some cases due to the conflict between comfort factors. Mumvic et al. (2009) study the winter indoor air quality, thermal comfort and acoustic performance of a newly built secondary school in England following BSF investment. Based on this research, complex interactions between thermal comfort, ventilation and acoustic comfort are studied. Two types of conflict are shown in the research. Firstly, conflict between acoustic comfort and air quality: Schools in this research are equipped with mechanical ventilation to maintain indoor air quality. The noise level measured inside the classrooms when occupants were engaged with a quiet test exceeded 50dB (A), which is far above the requirement proposed by BB93. This is a result of the noise produced by the mechanical ventilation. This shows one kind of conflict between air quality and acoustic comfort. Secondly, conflict between air quality and thermal comfort: the mechanical ventilation installed to provide good air quality, in this situation should provide 8 l/s per person fresh air but produces cold droughts that have a negative impact on thermal comfort. Hence it can be seen that although the school has recently been built based on the BSF programme, it does not provide a comfortable environment as the comfort factors conflict and interact with each other.

As explained above, each type of school has its own type of conflict between comfort factors that lead classrooms to experience poor environmental condition, Another type of conflict that is investigated by Montazami et al. (2011) is the conflict between acoustic comfort and 'thermal comfort / air quality' in the schools located around Heathrow Airport. This conflict is not limited to a particular era and occurs in any naturally ventilated school which is located under the Heathrow Airport flight path. Based on this research, it is observed that the occupants of schools which are located under Heathrow Airport Flight path keep the windows shut in order to provide acoustic comfort while they lose their chance to have natural ventilation. This leads the classroom to suffer from overheating and poor air quality.

As is observed, one of the main reasons of poor environmental conditions is due to the conflict between comfort factors. The other reason may be due to the use of relaxed comfort benchmarks which is the topic of this study. For this reason, in the next part, a complete literature review is carried out regarding the overheating guidelines which have been in place for a number of years.

2.2. Overheating guidelines for UK classroom

Generally, the overheating guidelines follow one of the two adopted approaches: Adaptive and Fixed.

2.2.1. Fixed approach: The fixed approach is the most popular approach. This approach considers a fixed temperature as a benchmark (comfort temperature) for evaluating overheating in a classroom. The three guidelines that are designed based on the fixed approach are BB87, BB101 and CIBSE that help a designer to assess the overheating occurrence in the UK classroom. Each of these guidelines is explained in detail further below.

2.2.2. Adaptive approach: The adaptive approach is the most recent approach. This approach considers an adaptive temperature as a benchmark (the comfort temperature which can be calculated) for evaluating overheating in a classroom. Based on this approach, temperatures at which the majority of people are comfortable vary with the running-mean of the external temperature which can be calculated. The two guidelines which are designed based on the adaptive approach are the BS guideline which helps a designer to assess the maximum allowable difference from the adaptive comfort temperature and the Nicol guideline that helps to identify the percentage of occupants who suffer from overheating.

In the followings, the guidelines which are designed based fixed and adaptive models are explained in detail:

Fixed model guidelines:

a. **BB87:** According to Building Bulletin 87 (BB87) which was published in 2003 for UK school building, a classroom is defined as overheated when the internal air temperature exceeds 28°C. The guideline allows flexibility of up to 80 occupied hours in a year above this temperature, normally in the non-heating periods of May to September excluding August.

b. **BB101:** These overheating criteria will ensure that the design of future schools is not dictated by a single factor, unlike BB87, but by a combination of factors that will allow a degree of flexibility in the design of the school. These criteria are only applicable for the cooling season for the occupied period (i.e. 9:00-15:30, Monday to Friday from 1st May to 30th September excluding August which is school summer holiday). These criteria are in compliance with Approved Document L2 for summertime overheating for teaching and learning areas and are as follows:

    - There should be no more than 120 hours when the air temperature in the classroom rises above 28°C.

- The average internal to external temperature difference should not exceed 5°C (i.e. the internal air temperature should be no more than 5°C above the external air temperature on an average).
- The internal air temperature when the space is occupied should not exceed 32°C. In order to show that the proposed school will not suffer overheating two of these three criteria must be met.

c. **CIBSE:** Two temperature thresholds have been defined by CIBSE for schools: a lower temperature threshold, which is taken to indicate when occupants will start to feel 'warm' (above 25°C) and higher threshold temperature, which is taken to indicate when occupants will start to feel 'hot' (above 28°C). However, to define a fixed measure of 'overheating' an excess of more than 1% of occupied hours in a year over the higher temperature benchmark is adapted to indicate a failure of the building to control overheating risk (CIBSE Guide A, 2006).

   The formation of an overheating taskforce by CIBSE is in part a recognition that there are problems with the use of a fixed, nationwide threshold temperature and 'hours over' criterion, which are as follows :

   - According to Humphreys and Nicol (Nicol et al, 2009), comfort temperature varies in accordance to outdoor running mean temperature and therefore is not fixed.
   - The CIBSE criteria fail to recognise the severity of overheating which is as important as its occurrence (Nicol et al, 2009).
   - Two criteria were developed by CEN Technical committees in BS EN15251 which considers both discomfort occurrence and severity: cooling degree-hours measure and a weighted measure based on Predicted Percentage Dissatisfaction (PPD). However, the PPD has been argued to be an unreliable indicator in naturally ventilated buildings according to Humphrey and Nichol (Nicol et al, 2009).
   - As overheating evaluation for buildings is based on a fixed threshold depending on the number of occupied hours above threshold, therefore by changing the number of occupied hours, the result can be altered to solve the overheating problem, which is totally unrealistic (Nicol et al, 2009) and deceptive.
   - Based on the fixed temperature threshold, it is debateable whether overheating should be measured over a whole year or a shorter period during a year (Nicol et al, 2009). For example, based on the CIBSE overheating is measured over a whole year and based on BB101 and BB87, it is measured on the duration of cooling seasons (May to September excluding August).

For all above reasons, some other criteria based on adaptive model are presented.

Adaptive model guidelines:

a. **British Standard:** Alternative criteria are presented by British Standard (based on survey of thermal comfort in European buildings and first proposed in CIBSE Guide A (Nicol et al, 2009) for thermal comfort in naturally ventilated building using an adaptive thermal comfort model.

According to these criteria, thermal comfort is not a fixed temperature and varies according to recent climate conditions (e.g. over selected previous days). The criteria link comfort temperature to 'running mean temperature' (Trm). The running mean is calculated from the external temperature over the preceding days, with a weighting taking into account the greater influence of the most recent day, using the formula below where the mean outdoor temperature exceeds 10°C.

$$Tc=0.33Trm + 18.8 \quad (1)$$

The following graph (Graph 3-1.3) shows the comfort temperatures as a function of outdoor temperature (from CIBSE 2006 cited in Nicol et al, 2009):

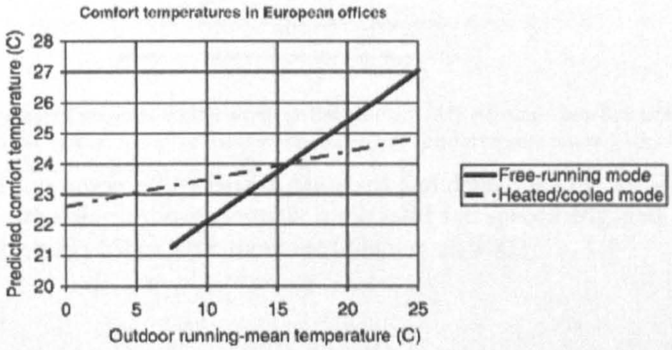

Figure 1: Comfort temperature as a function of outdoor running means temperature (CIBSE, 2006)

British Standard proposes that there is a maximum allowable difference from comfort temperature as it is shown in the following table (Table 1).

Category	Explanation	Suggested acceptable range
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	±2K
II	Normal expectation (for new buildings and renovations)	±3K
III	Moderate expectation (used for existing buildings)	±4K
IV	Values outside the criteria for the above categories (only acceptable for a limited periods)	
Source: British Standards (BSI) (2007e).		

Table 1: Suggested applicability of the categories and their associated acceptable temperature range. (British Standard 2007)

b. **Percentage of discomfort by occupants:** Nicol and Humphreys (cited in Nicol et al, 2009) suggest that occupants' discomfort is related to ΔT by applying a weighting factor which reflects the non-linear relationship between heat discomfort (percentage of overheating by occupant) and departure from the comfort temperature which is observable in the following graph (Figure 2). The percentage of discomfort is be calculated from the following formula (equation 2):

$$P = \frac{e^{(0.4734 \cdot \Delta T - 2.607)}}{\{1 + e^{(0.4734 \cdot \Delta T - 2.607)}\}}$$

In the above formula, ΔT refers to the differences between actual temperature and 'Tc=adaptive thermal comfort'. Tc is related to 'the outdoor running mean temperature' and calculated from the equation Tc=0.33Trm+18.8. 'Trm' refers to the thermal running mean temperature and CEN Standard EN15251 (2009) gives an approximate calculation method (for Trm) using the mean temperature for the last 7 days ($\alpha = 0.8$).

$$Trm = (Tod_{-1} + 0.8\ Tod_{-2} + 0.6\ Tod_{-3} + 0.5\ Tod_{-4} + 0.4\ Tod_{-5} + 0.3\ Tod_{-6} + 0.2\ Tod_{-7})/3.8 \quad (3)$$

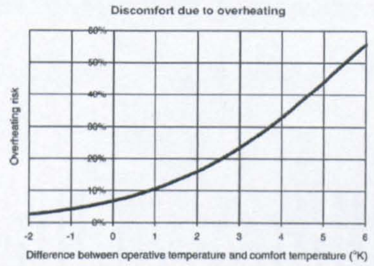

Figure 2: The proportion of subjects voting warm or hot on the ASHRAE scale as a function of the difference between the indoor operative temperature and CEN comfort temperature, (Nicol et al)

This alternative criterion proposed by British Standard and developed by Nicol regarding the percentage of overheating by occupants is only valid for spaces engaged in mainly sedentary activities such as offices, classroom etc (Nicol et al, 2009).

3. Methodology:

This research is carried out objectively and subjectively. All the objective and subjective data are recorded by the author. In the objective survey, indoor temperatures of 139 classrooms from 18 naturally ventilated primary schools in London were recorded every half hour by placing two miniature temperature data loggers called 'I Buttons' in each classroom in June and July of the years 2005, 2007 and 2008 with the accuracy of 0.5 ° C in each classroom. The indoor temperatures were recorded for both occupied and unoccupied durations. In the UK Primary Schools, children attend school from Monday to Friday between 0900 to 1530 hours. The occupied indoor temperature mentioned in this text refers to the recorded temperatures of these classrooms over these durations. Graph 3 shows the average percentage distribution of indoor temperature in all schools in 2005, 2007 and 2008.

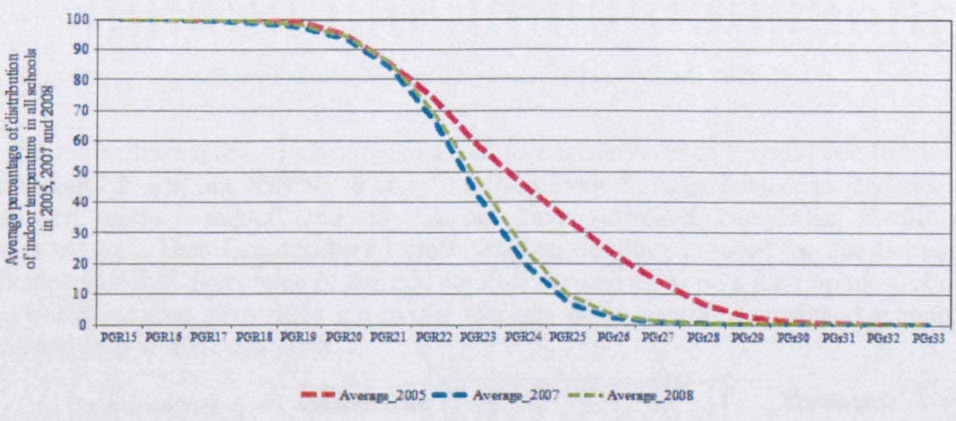

Figure 3: Average percentage distribution of indoor temperature in all schools in 2005, 2007 and 2008.

One of the climate factors that have an impact on indoor temperature is outside temperature. For this reason, the outdoor temperatures were collected from the Weather Underground Website (2008) which shows the outdoor temperatures in half hourly intervals. The Heathrow Station was chosen for outdoor temperature. The outdoor temperatures were collected from this website for June and July of 2005, 2007 and 2008. Daily outdoor temperatures for the duration of study are summarised in figures 4 and 5.

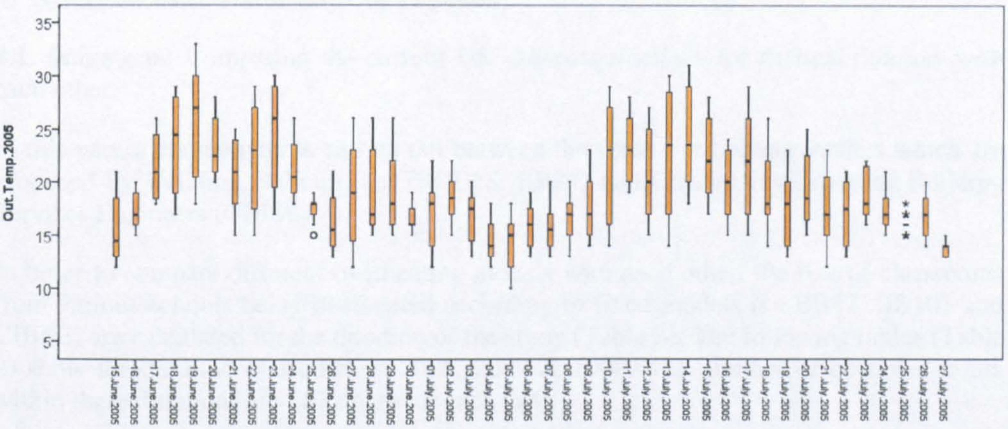

Figure 4: Daily Outdoor temperature in June and July 2005

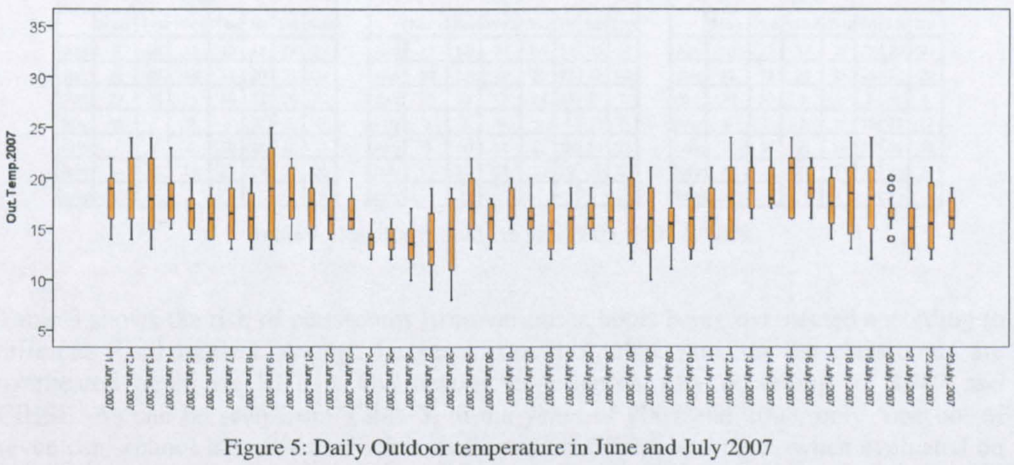

Figure 5: Daily Outdoor temperature in June and July 2007

In the subjective survey, teachers were asked to rate the level of thermal comfort inside classrooms. It was not possible to carry out the survey on large number of students and also the primary school students did not have sufficient knowledge to fill out questionnaires. Therefore, teachers were briefed so that they ensured the questionnaires reflected students' perception of thermal comfort as opposed to own their opinion. Ninety two questionnaires were filled out by the teachers of 15 naturally ventilated schools in June and July of 2007 and 2008.

Thermal comfort	**Uncomfortable**	1	2	3	4	5	6	7	**Comfortable**

This part of the study is carried out in three stages in order to identify the most reliable overheating models. For this reason, firstly the current UK design guidelines for thermal comfort are compared with each other using real data (indoor temperature data) that have been collected from schools. Secondly, the relation between occupants' perception regarding thermal comfort are compared with the adaptive and fixed thermal comfort. Finally, the percentage of dissatisfaction from overheating is calculated for each school as one of the most reliable tools to assess overheating.

4. Analysis and discussion of results:

4.1. Stage one: Comparing the current UK design guidelines for thermal comfort with each other.

In this part, a comparison is carried out between the fixed overheating models which are proposed by Building Bulletin (i.e. BB101& BB87) and Charted Institution of Building Services Engineers (CIBSE).

In order to compare different overheating models with each other, the risk of classrooms from various schools being overheated according to fixed models (i.e.BB87, BB101 and CIBSE) are calculated for the duration of the study (Table 3). The following tables (Table 2) show the duration of studies in 2005, 2007 & 2008. The number of occupied hours within these durations are 202 hours for each year.

2008							
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jun	9	10	11	12	13	14	15
Jun	16	17	18	19	20	21	22
Jun	23	24	25	26	27	28	29
July	30	1	2	3	4	5	6
July	7	8	9	10	11	12	13
July	14	15	16	17	18	19	20
July	21						

2007							
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jun	11	12	13	14	15	16	17
Jun	18	19	20	21	22	23	24
Jun	25	26	27	28	29	30	1
July	2	3	4	5	6	7	8
July	9	10	11	12	13	14	15
July	16	17	18	19	20	21	22
July	23						

2005							
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jun	15	16	17	18	19	20	21
Jun	22	23	24	25	26	27	28
Jun	29	30	1	2	3	4	5
July	6	7	8	9	10	11	12
July	13	14	15	16	17	18	19
July	20	21	22	23	24	25	26
July	27						

Table 2: Duration of study in year 2005, 2007 & 2008

Table 3 shows the risk of classrooms from various schools being overheated according to different fixed models. As can be seen from this table, none of the classrooms are overheated based on BB101. Overheating experiences vary according to BB87 and CIBSE. As can be seen from Table 3, in the years of 2007 and 2008, only 'one out of seventeen' school is overheated when evaluated on CIBSE and none, when evaluated on BB87 and BB101; In 2005, 'six out of eight' schools were overheated when evaluated based on CIBSE and 'one out of eight' when evaluated based on BB87 and none based on BB101.

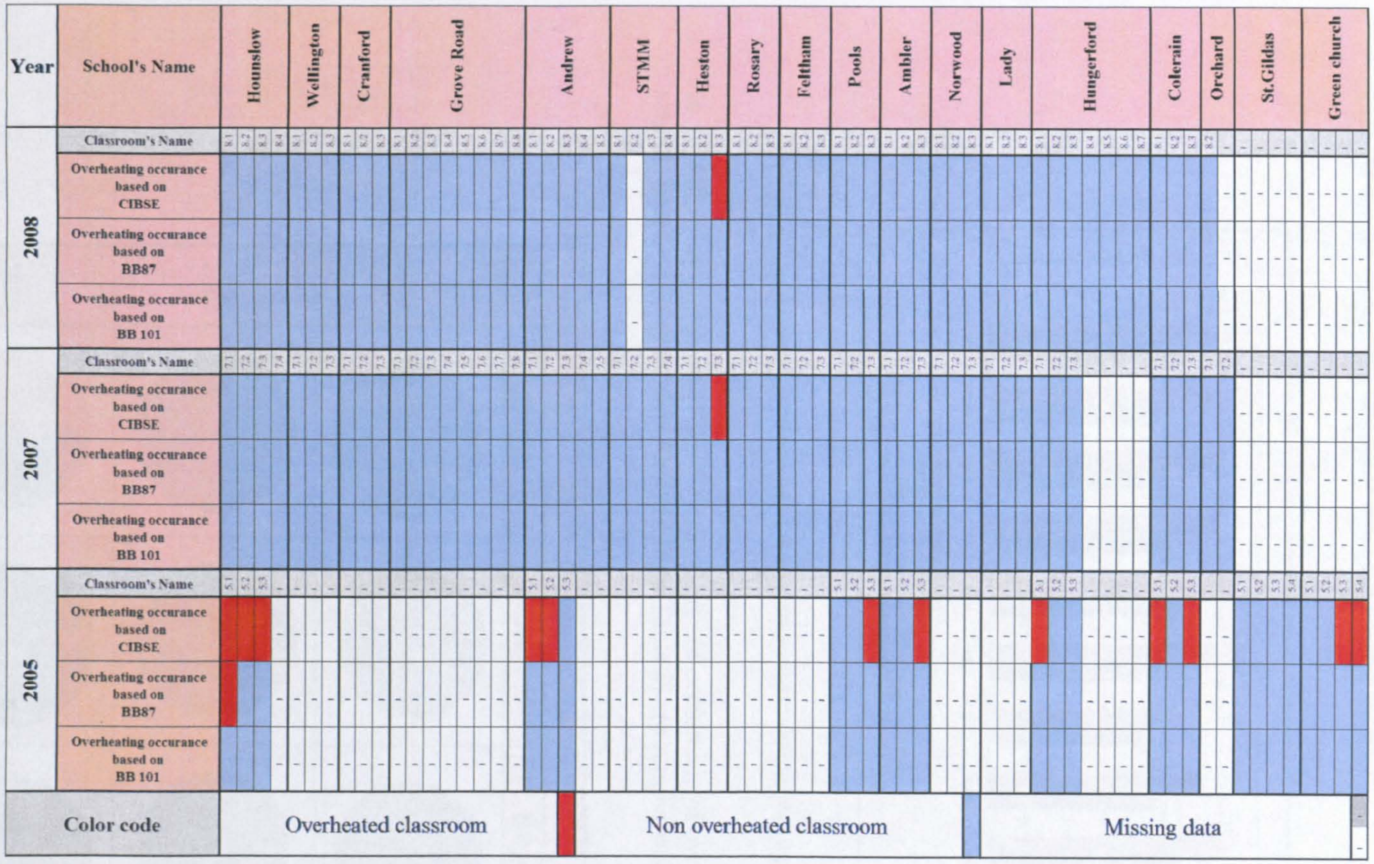

Table 3: Study of the classrooms' indoor temperature based on Fixed models in various schools

The cold summer of 2007and 2008 (when compared with 2005) was the reason for a big gap between occurrence of overheating in 2005 and 2007/2008. Figure 6 shows the average of mean and maximum outside temperature during the months of June and July for the last ten years. As can be seen, 2008 and 2007 were the coldest summers.

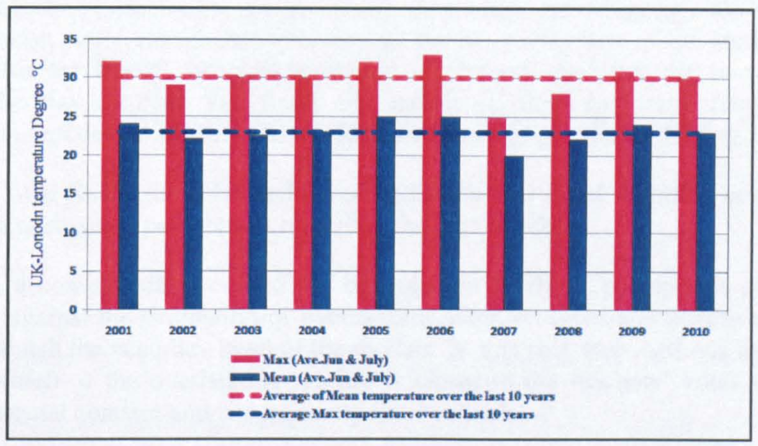

Figure 6: June and July London temperatures during last 10 years

In the following pie-charts (Figure 7), the shares of occurrence of overheating in different schools based on fixed models (derived from Table 3) are summarised.

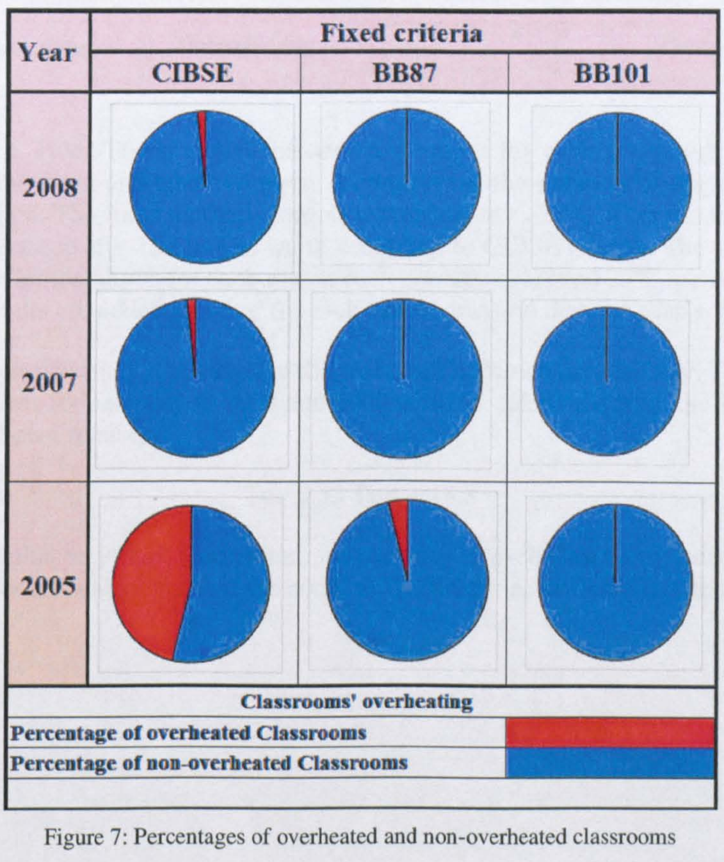

Figure 7: Percentages of overheated and non-overheated classrooms

As a result, the indoor temperature of 139 classrooms were compared with different overheating criterion (based on the fixed model) and concluded that the Building Bulletin criteria (BB101) which is currently used as the design benchmark for schools is the most relaxed criterion. CIBSE is the most stringent one among the fixed models. In fact, BB101 is more insensitive than BB87 and BB87 more than CIBSE.

This could be one of the reasons that the classrooms which are designed/ refurbished based on this criterion could experience overheating. Based on this part of the study, it can be suggested that the BB101 benchmark should be revised. As there are two models for assessing thermal comfort (i.e. fixed and adaptive), the next stage focuses on the assessment the models to identify those which are closer to occupants' feeling.

4.2. Stage two: Study the relation between adaptive and fixed thermal comfort models with schools occupants' perceptions regarding thermal comfort.

In this part, a comparison is carried out between the teachers' perceptions of classroom overheating against the evaluation of overheating based on fixed and adaptive models, in order to establish the accuracy level of the models. In this part, two methods are applied to determine which of the overheating models is closer to the teachers' votes (perception) regarding thermal comfort and consequently more reliable.

<u>4.2.1. First Method: Compare the teachers' votes with overheating dissatisfaction</u>

This section of the research was carried out in the following 3 sections:

a. Section One: Subjective surveys were carried out in 2007 and 2008. In these surveys, the teachers were requested to score their comfort level during summer terms (June & July) on a 7 scale Likert scale for their classroom. One representing comfortable and seven representing uncomfortable.

Thermal comfort	**Uncomfortable**	1	2	3	4	5	6	7	**Comfortable**

b. Section Two: The occupied indoor temperature for each classroom is compared with the fixed and adaptive thermal comfort for the duration of the study in 2007 and 2008. The fixed thermal comfort is considered as 25°C. This is a temperature at which occupants start to feel warm according to CIBSE criteria. The occasions that indoor temperatures for each day in each classroom exceed 25°C are calculated and the results are added together for each classrooms and then for each school.

Furthermore, in this study, the adaptive thermal comfort varies for each day. The adaptive thermal comforts for each day in 2007 and 2008 which is calculated from the following formula are shown in table 4.

$$Tc = 0.33\ Trm + 18.8$$

The occasions that an indoor temperature for each day in each classroom exceeds adaptive thermal comfort are calculated and the result are added for each classroom and then for each school.

Year																																
2008	Day	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon
	Date	09/06/2008	10/06/2008	11/06/2008	12/06/2008	13/06/2008	16/06/2008	17/06/2008	18/06/2008	19/06/2008	20/06/2008	23/06/2008	24/06/2008	25/06/2008	26/06/2008	27/06/2008	30/06/2008	01/07/2008	02/07/2008	03/07/2008	04/07/2008	07/07/2008	08/07/2008	09/07/2008	10/07/2008	11/07/2008	14/07/2008	15/07/2008	16/07/2008	17/07/2008	18/07/2008	21/07/2008
	Mean Tout	21.0	19.2	16.4	13.2	13.4	14.4	16.0	15.4	17.0	15.3	16.7	17.4	17.8	16.4	17.5	17.4	20.3	17.5	16.3	16.4	15.1	16.0	15.1	17.2	16.0	18.4	20.6	17.7	16.4	16.9	16.0
	Trm	16.7	17.5	17.9	17.6	16.7	15.6	15.3	15.5	15.5	15.8	16.3	16.3	16.5	16.8	16.7	17.3	17.4	17.9	17.9	17.5	17.1	16.7	16.6	16.3	16.5	15.9	16.4	17.3	17.3	17.2	16.9
	Tc	24.3	24.6	24.7	24.6	24.3	23.9	23.9	23.9	23.9	24.0	24.2	24.2	24.3	24.3	24.3	24.5	24.5	24.7	24.7	24.6	24.4	24.3	24.3	24.2	24.2	24.1	24.2	24.5	24.5	24.5	24.4
2007	Day	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon
	Date	11/06/2007	12/06/2007	13/06/2007	14/06/2007	15/06/2007	18/06/2007	19/06/2007	20/06/2007	21/06/2007	22/06/2007	25/06/2007	26/06/2007	27/06/2007	28/06/2007	29/06/2007	02/07/2007	03/07/2007	04/07/2007	05/07/2007	06/07/2007	09/07/2007	10/07/2007	11/07/2007	12/07/2007	13/07/2007	16/07/2007	17/07/2007	18/07/2007	19/07/2007	20/07/2007	23/07/2007
	Mean Tout	18.4	18.6	18.2	18.1	17.1	16.0	18.6	18.1	17.0	15.7	13.8	13.5	14.1	14.8	17.3	16.0	15.5	15.5	16.1	16.3	14.8	15.3	16.7	18.3	19.0	19.4	17.4	18.1	17.5	16.8	16.0
	Trm	17.5	17.7	17.9	17.9	18.0	17.2	17.0	17.3	17.5	17.4	16.3	15.8	15.4	15.1	15.0	16.0	16.0	15.9	15.8	15.9	16.1	15.9	15.7	15.9	16.4	17.8	18.1	17.9	18.0	17.9	16.9
	Tc	24.6	24.6	24.7	24.7	24.7	24.5	24.4	24.5	24.6	24.5	24.2	24.0	23.9	23.8	23.8	24.1	24.1	24.0	24.0	24.0	24.1	24.0	24.0	24.1	24.2	24.7	24.8	24.7	24.7	24.7	24.4

Table 4: Mean outside temperature, Mean running temperature and thermal comfort for the duration for duration of the 2007 and 2008 studies

c. Section Three: Two regression analyses were carried out between the results of the above:

- Between the teachers' votes and the percentage of occasions that indoor temperatures exceed fixed thermal comfort (i.e. greater than 25°C) for 2007 & 2008.
- Between the teachers' votes and the percentage of occasion that indoor temperatures exceed adaptive thermal comfort ($Tc = 0.33\ Trm + 18.8$) for 2007 & 2008.

The results show that the teachers' votes on their satisfaction from indoor temperature (comfortable and uncomfortable) have a correlation (R) of 0.64 where the indoor temperatures exceed adaptive thermal comfort while this correlation is reduced to 0.46 when the indoor temperature exceed fixed thermal comfort in the years of 2007 & 2008.

In other words, a regression analysis between the teachers' votes on the indoor temperature with the occurrence of overheating based on different overheating criteria shows that there is a higher relation between teachers' votes with the adaptive thermal comfort than the fixed thermal comfort.

The following graph (Graph 8) shows the correlation between teachers vote and the percentage of occasions that indoor temperatures exceed adaptive and fixed thermal comfort.

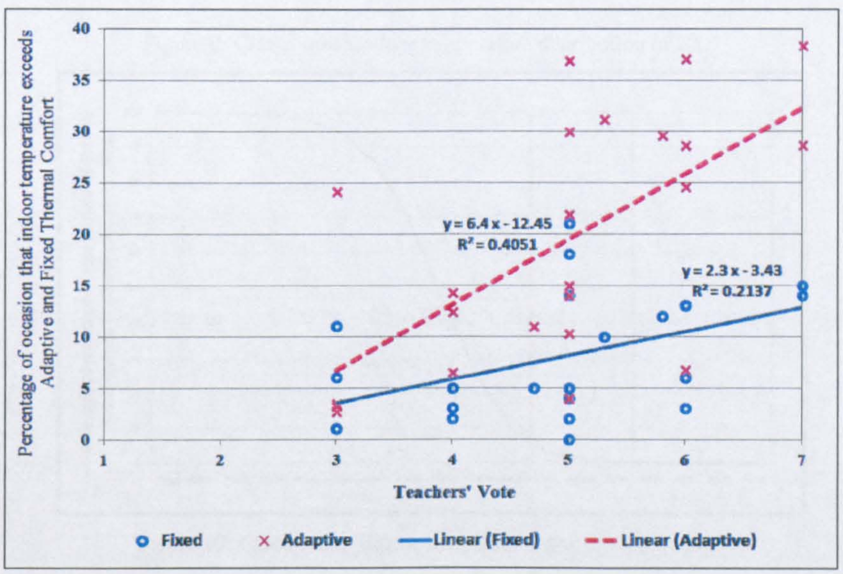

Figure 8: Relation between teachers actual feeling with the occasions that indoor temperature exceeds adaptive and fixed thermal comfort

As it can be seen from Figure 8, there is a higher correlation between the percentage of occasions that exceed adaptive thermal comfort ($R=0.64$, $P<0.05$) than fixed thermal comfort ($R=0.46$, $P<0.5$).

4.2.2. Second Method: Second method: Distribution of indoor temperature

The first method has proven that the adaptive model is a better criterion than the fixed model for assessing overheating in classrooms.

The distribution of indoor temperature is an alternative way to compare the teachers'' votes on overheating with the fixed and adaptive model.

The average distributions of 15 schools' indoor temperatures are shown in the Graph 9 and Graph 10 for the years of 2007 & 2008. As can be seen, only a small portion of the indoor temperatures exceeded 25°C & 28°C.

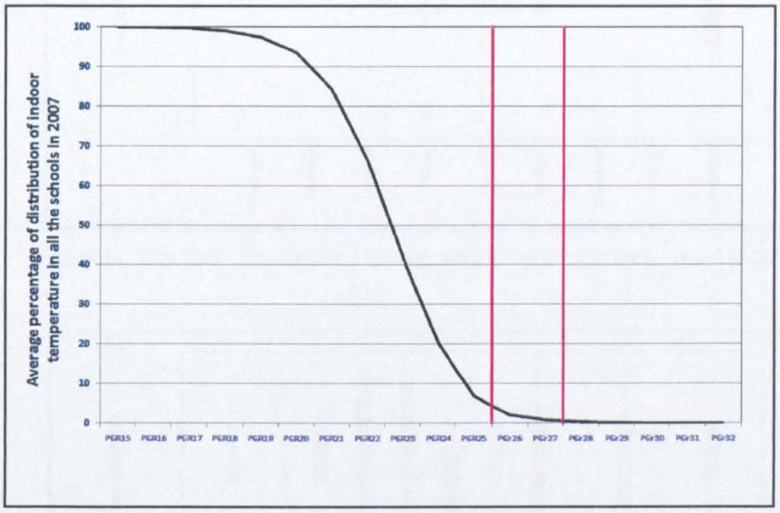

Figure 9: Classrooms' indoor temperature distribution in 2007

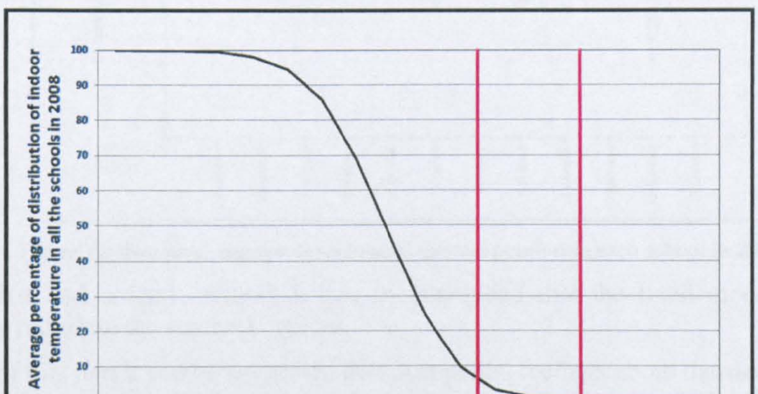

Figure 10: Classrooms' indoor temperature distribution in 2008

As can be seen from Figures 9 and 10, the schools' indoor temperatures rarely exceeded 25°C and hardly exceeded 28°C for the duration of the study. Consequently, the occupants of these schools should not significantly have felt thermally uncomfortable if evaluated on the basis of the fixed model. But the results of the questionnaires on thermal comfort show that the teachers were significantly thermally uncomfortable in June and July of the years 2007 & 2008 (Graph 11 and 12). The teachers' responses which had a tendency towards uncomfortable in 8 out of 9 primary schools is proof of this claim (above scale of 4). This can be seen in the Graph 11 and Graph 12.

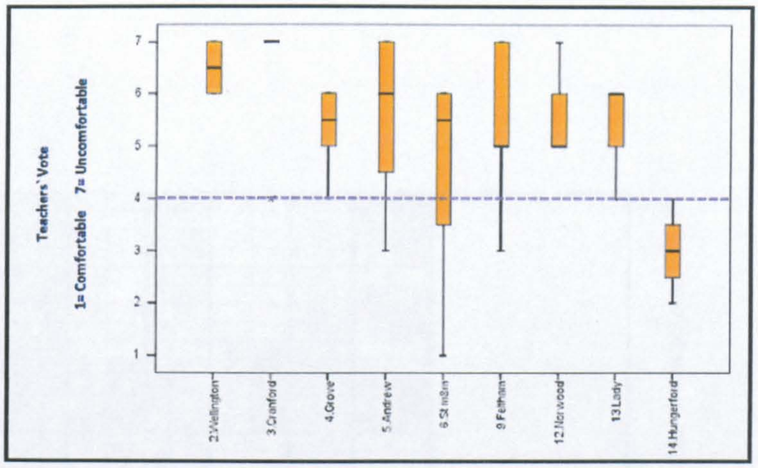

Figure 11: Teachers' comfort level toward thermal comfort in each school in 2007

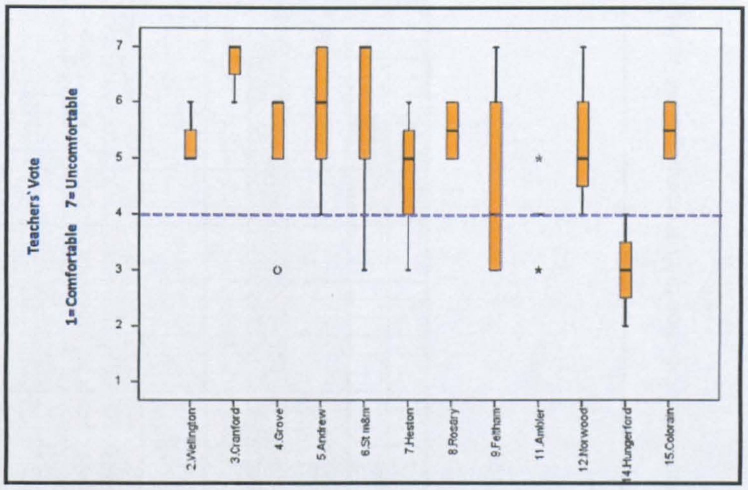

Figure 12: Teachers' comfort level toward thermal comfort in each school in 2008

From the first and second method, it can be concluded that the fixed model does not significantly represent the teachers' voices.

As a result of this part it can be suggested that occupants' feelings about thermal comfort is more related to the adaptive thermal comfort rather than fixed thermal comfort. For this reason it is recommended that thermal comfort benchmarks to be revised based on adaptive model rather than fixed model.

4.3. Stage three: Compare indoor temperature with adaptive model

As it is shown in the first part of the study, the current UK thermal comfort benchmark (BB101) for schools, is the most insensitive one among fixed thermal comfort benchmarks (BB87 and CIBSE). In the second part of this study, it is shown that there is a higher relation between teachers' votes regarding thermal comfort with adaptive thermal comfort rather than fixed thermal comfort. In this part, indoor temperatures are compared with the Nicol criterion which is based on the adaptive model. In his theory, it is possible to calculate the percentage of people who may overheat and the result can be used to categorise classrooms to highly overheated, moderate overheated and low overheated.

Table 5 shows the predicted percentages of occupants who are overheated (thermal dissatisfaction) inside each classroom of various schools based on Nicol formula.

School's Name	2008 Classroom's Name	2008 Mean	2008 Max	2007 Classroom's Name	2007 Mean	2007 Max	2005 Classroom's Name	2005 Mean	2005 Max
Hounslow	8.1	8	41	7.1	7	36	5.1	13	78
	8.2	4	23	7.2	3	18	5.2	12	85
	8.3	4	14	7.3	2	14	5.3	11	73
	8.4	6	30	7.4	4	22	-	-	-
Wellington	8.1	3	15	7.1	2	10	-	-	-
	8.2	5	16	7.2	4	12	-	-	-
	8.3	4	16	7.3	5	20	-	-	-
Cranford	8.1	7	22	7.1	6	26	-	-	-
	8.2	7	25	7.2	5	15	-	-	-
	8.3	6	25	7.3	6	22	-	-	-
Grove Road	8.1	7	19	7.1	6	18	-	-	-
	8.2	8	25	7.2	5	18	-	-	-
	8.3	6	23	7.3	6	22	-	-	-
	8.4	7	25	7.4	5	18	-	-	-
	8.5	6	19	7.5	6	18	-	-	-
	8.6	8	24	7.6	5	15	-	-	-
	8.7	5	15	7.7	6	18	-	-	-
	8.8	4	13	7.8	4	18	-	-	-
Andrew	8.1	3	9	7.1	4	17	5.1	7	46
	8.2	6	14	7.2	4	12	5.2	9	33
	8.3	6	17	7.3	4	20	5.3	8	35
	8.4	12	35	7.4	5	18	-	-	-
	8.5	5	18	7.5	5	24	-	-	-
STMM	8.1	6	15	7.1	6	16	-	-	-
	8.2	-	-	7.2	7	22	-	-	-
	8.3	6	13	7.3	6	17	-	-	-
	8.4	7	15	7.4	5	17	-	-	-
Heston	8.1	4	16	7.1	4	11	-	-	-
	8.2	4	21	7.2	3	10	-	-	-
	8.3	11	74	7.3	9	64	-	-	-
Rosary	8.1	4	15	7.1	3	11	-	-	-
	8.2	4	20	7.2	3	12	-	-	-
	8.3	3	8	7.3	3	29	-	-	-
Feltham	8.1	3	10	7.1	4	10	-	-	-
	8.2	7	26	7.2	6	12	-	-	-
	8.3	3	9	7.3	3	8	-	-	-
Pools	8.1	5	16	7.1	4	12	5.1	7	35
	8.2	6	18	7.2	5	14	5.2	6	31
	8.3	7	21	7.3	5	15	5.3	7	31
Ambler	8.1	5	14	7.1	5	30	5.1	6	31
	8.2	4	14	7.2	5	18	5.2	6	24
	8.3	3	6	7.3	4	10	5.3	10	45
Norwood	8.1	5	22	7.1	4	15	-	-	-
	8.2	5	25	7.2	5	17	-	-	-
	8.3	12	46	7.3	9	42	-	-	-
Lady	8.1	3	6	7.1	3	8	-	-	-
	8.2	7	26	7.2	4	10	-	-	-
	8.3	5	27	7.3	4	11	-	-	-
Hungerford	8.1	4	8	7.1	4	8	5.1	8	37
	8.2	4	16	7.2	4	15	5.2	4	18
	8.3	3	9	7.3	3	6	5.3	5	25
	8.4	3	9	-	-	-	-	-	-
	8.5	3	12	-	-	-	-	-	-
	8.6	2	7	-	-	-	-	-	-
	8.7	4	10	-	-	-	-	-	-
Colerain	8.1	2	14	7.1	3	12	5.1	10	58
	8.2	2	8	7.2	2	47	5.2	5	37
	8.3	5	19	7.3	3	14	5.3	9	49
Orchard	8.2	2	19	7.1	3	15	-	-	-
	-	-	-	7.2	5	39	-	-	-
St.Gildas	-	-	-	-	-	-	5.1	5	29
	-	-	-	-	-	-	5.2	6	35
	-	-	-	-	-	-	5.3	6	35
	-	-	-	-	-	-	5.4	-	-
Green church	-	-	-	-	-	-	5.1	5	18
	-	-	-	-	-	-	5.2	4	39
	-	-	-	-	-	-	5.3	8	54
	-	-	-	-	-	-	5.4	8	48

Color Code	
Highly overheated ≤ 10	red
Moderate overheated 6 ≤ & < 10	orange
Low overheated <6	yellow
Missing data	white

Table 5: Study of the percentages of occupants' dissatisfaction from overheating based on Adaptive model in various schools

As can be seen from Table 5, classrooms are categorised into the following groups, based on the percentage of occupants' dissatisfaction from overheating.

- Highly overheated classrooms refer to the classrooms in which more than 10% of occupants feel overheated.
- Moderate overheated classrooms refer to the classrooms in which 6% to 10% of occupants feel overheated.
- Low overheated classrooms refer to the situation in which less than 6% of occupants feel overheated.

The above is based on normal level of expectation in new or renovated buildings with occupants who are not sensitive and fragile (i.e. disabled, sick, very young children and elderly persons).

In a condition that a classroom is occupied by very sensitive and fragile persons with special requirement like disabled, sick children, high level of expectation is required. In this condition, a classroom is highly overheated if only 6% of occupants feel overheated.

In the pie-charts in Figure 13 the percentage of classrooms that were overheated (in different level of highly, moderate and low) in 2005, 2007 and 2008 is summarised.

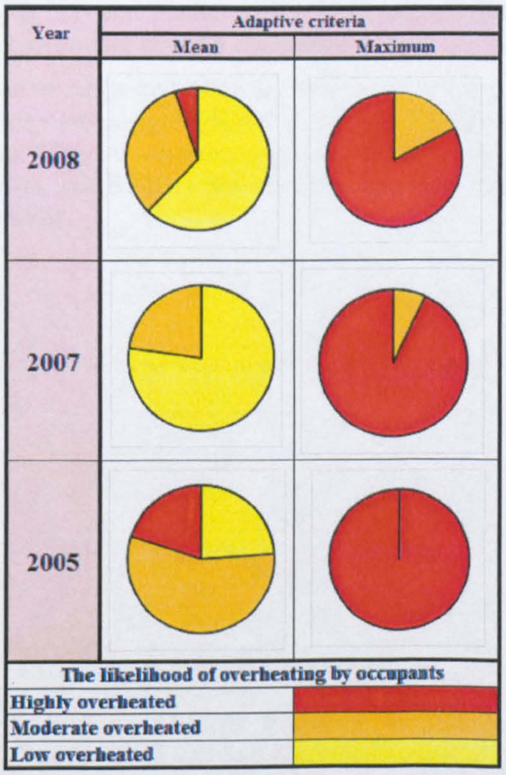

Figure 13: The summary of evaluating classrooms' indoor temperatures based on Adaptive model

As it can be seen in Figure 13 the number of schools (and consequently, their classrooms) which are highly overheated in 2005 is greater than that of 2007 and 2008 (Mean column). In all schools, there is always an occasion when classrooms are highly overheated. These data are based on normal expectations with normal occupant.

5. Conclusion:

As a result of this study, it can be suggested that the two main reasons for poor environmental conditions in UK schools are: firstly the conflict between comfort factors (thermal, lighting, acoustic comfort and air quality) as they are interrelated and secondly, the use of the insensitive thermal, air quality, acoustic and lighting benchmarks for their design.

The Nicol thermal criterion is not only designed based on the adaptive model which has a better relation with occupants' feeling, but also provides detailed information regarding overheating by predicting the percentage of people that may feel overheated and considering the type of occupants inside classroom, while overheating criteria based on fixed model only determine whether the classrooms are overheated or not. As a result, there is a gap between predicting thermal comfort (based on the fixed model) and actual occupants feeling inside a classroom.

Based on this study, it can be suggested that one of the reasons for overheating in UK school buildings is that they are designed based on the least sensitive thermal design criteria (Building Bulletin 101). As a result, it is suggested that the current building design thermal benchmark (i.e.BB101) for the UK primary schools be revised considering the Nicol formula.

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