Efficient classroom lighting and its environmental consequences in schools in Ho Chi Minh City, Vietnam

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EFFICIENT CLASSROOM LIGHTING AND ITS ENVIRONMENTAL CONSEQUENCES IN SCHOOLS IN HO CHI MINH CITY, VIETNAM

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Abstract

This research examines the current lighting conditions and its thermal comfort consequences in classrooms of secondary schools in Ho Chi Minh City, Vietnam.

Although improving school infrastructure has received a lot of attention recently, there have been several reports on poor visual comfort in the city's school classrooms. Therefore, it is necessary to conduct a full architectural investigation on the current conditions to evaluate how visually comfortable the students and teachers are.

Daylight has always been recommended as the best source of classroom lighting in most of the current design guide-lines. Since Ho Chi Minh City is located within the tropical belt there is a good potential to improve the daylight benefit in the school classrooms, but inappropriate improvement may also lead to worsening thermal comfort conditions. Therefore, the main discussion of this research focuses on the daylight performance of the classrooms and its pertinent consideration on thermal comfort consequences.

The research is structured in three parts.

The first part of this study identifies the major factors that may have significant impact on classroom visual and thermal comfort. It includes an in-depth review of the natural and social settings and the relevant literature.

The second part examines current conditions of a sample of four classrooms, using theoretical methods and analysing data recorded from the site surveys consisting of both site measurements and users comfort questionnaire.

The third part provides a summary of the findings and suggestions.

In light of these discussions, it is revealed that both social and technical factors have significant impact on the development of classroom design. It is found that 55.5% of the students and 37.0% of the teachers are not satisfied with the visual comfort quality and 50.45% of the students and 49.45% of the teachers are not happy about the thermal comfort quality. It is further revealed that the current Vietnamese lighting and thermal comfort codes require revisions; particularly daylight calculation methods used in the codes are not appropriate for Ho Chi Minh City. It is also discovered that the users' preferred visual and thermal comfort conditions may be different from what are predicted by the current codes, and students and teachers have different comfort preferences.

From these findings, this research amends some comfort parameters that may be more appropriate for school classrooms in Ho Chi Minh City. Particularly, it is suggested that school classrooms should have an effective window-to-floor ratio of 10% to have adequate daylight contribution. It is recommended that the neutral thermal comfort temperature be 29.3°C and the width of the comfort zone to be ±2°C.

In summary, this research provides a full review of the current architectural conditions, furthered by an investigation to identify the sources of problems and finally establishes some recommendations that not only contributes to the current literature of classroom lighting but would also useful to other fields of study.

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a	Window width [m]
$A_{ceiling}$	Total ceiling area [m^2]
AD	Area of the Waldram diagram area
A_{floor}	Total floor area [m^2]
A_h	The ratio $h_c/(h_c+h_r)$, and (1-A) is the ratio of $h_r/(h_c+h_r)$
A_r	Total area of all interior surfaces including walls, floor, ceiling, and windows [m^2]
A_w	Total window's net glazed area [m^2]
A_{w1}	Total window's net glazed area in wall 1 [m^2]
A_{w2}	Total window's net glazed area in wall 2 [m^2]
A_{wall1}	Total area of wall 1 [m^2]
A_{wall2}	Total area of wall 2 [m^2]
A_{wall3}	Total area of wall 3 [m^2]
A_{wall4}	Total area of wall 4 [m^2]
$Aw_{unobstructed}$	Unobstructed window area in Waldram diagram [cm^2]
B	Room depth [m]
BCR	Building coverage ratio [%]
C	Constant, expressing the contribution of the diffuse sky illuminance to the buildings and it is more important at higher floors, using in Brotas (2004) equations.
C_{ASHRAE}	ASHRAE Comfort votes
CCT	Correlated colour temperature
$C_{diffuse}$	Ratio of total vertical illuminance on window surface to unobstructed horizontal diffuse sky illuminance, expressed as a decimal
$C_{diffuse}D$	is $C_{diffuse}$ measured in the Dry season, expressed as a decimal
$C_{diffuse}W$	is $C_{diffuse}$ measured in the Wet season, expressed as a decimal
C_e	Coefficient of Utilization
CGI	CIE Glare Index
C_{global}	Ratio of total vertical illuminance on window surface to unobstructed horizontal global sky illuminance, expressed as a decimal
$C_{global}D$	is C_{global} measured in the Dry season, expressed as a decimal
$C_{global}W$	is C_{global} measured in the Wet season, expressed as a decimal
C_h	Heat loss by convection from the surface of the clothed body

C_rb	Ratio of reflected illuminance on window surface coming from external buildings to unobstructed horizontal diffuse sky illuminance, expressed as a decimal
C_{res}	Heat exchange by convection in the respiratory tract
C_rg	Ratio of reflected illuminance on window surface coming from ground, to unobstructed horizontal diffuse sky illuminance, expressed as a decimal
CRI	Colour rendering index
C_{SKY}	Sky index, defined by the ratio between the illuminance at the face of the window and the illuminance on a horizontal plane from an unobstructed sky, expressed as a decimal
C_{sun}	Ratio of direct sunlight on window surface to unobstructed horizontal diffuse sky illuminance, expressed as a decimal
$C_{sun}b$	Ratio of reflected sunlight from buildings to unobstructed horizontal diffuse sky illuminance, expressed as a decimal
$C_{sun}g$	Ratio of reflected sunlight from ground to unobstructed horizontal diffuse sky illuminance, expressed as a decimal
d	Humidity ratio [g/kg]
DGI	Daylight Glare Index
DGP	Daylight Glare Probability
ĐRASTN	*Độ Rọi Ánh Sáng Tự Nhiên*, Vietnamese definition for average daylight factor, expressed as the ratio between the interior illuminance at the working plan and the exterior horizontal illuminance given by the unobstructed sky , similar to *D,* [%]
$ĐRASTN_{Di}$	ĐRASTN at a given interior point contributed by window area *i* , calculated under CIE overcast sky condition [%]
$ĐRASTN_{Du\,i}$	ĐRASTN at a given interior point contributed by window area *i* , calculated under uniform sky condition [%]
$ĐRASTN_{Du}r$	Realistic $ĐRASTN_{Du}$[%]
ĐRASTNr	Realistic *ĐRASTN* [%]
$D_{w,}$ *VDF*	Average daylight factor on the vertical outside window surface [%]
$D_{wr}b$	Vertical daylight factor at the outside of window surface by the external reflected light from buildings [%]
$D_{wr}g$	Vertical daylight factor at the outside of window surface by the external reflected light from ground [%]
D_{ws}	Vertical daylight factor at the outside of window surface by the direct sky component [%]
e	Weighting exponent of the glare index
Eeh	External horizontal illuminance from an unobstructed sky [lux]

$Eeh_{diffuse}$	External diffuse horizontal illuminance from an unobstructed sky [lux]
Eeh_{global}	External global horizontal illuminance from an unobstructed sky [lux]
$Eeh_{uniform}$	External horizontal illuminance from an unobstructed uniform sky [lux]
Eev	External vertical illuminance, measured at mid-height of the outer face of the window surface [lux]
$Eev_{uniform}$	External vertical illuminance receiving from uniform sky , measured at mid-height of the outer face of the window surface [lux]
E_{gh}	Global horizontal illuminance [lux], used in Brotas (2004) equation
E_h	Heat loss by evaporation from the surface of the clothed body
E_{Ho}	Horizontal illuminance from an unobstructed CIE overcast sky [lux]
E_{Hu}	Horizontal illuminance from an unobstructed Uniform Diffused sky of constant luminance [lux]
Eih	Internal horizontal illuminance, measured at working plane 0.8m height from floor [lux]
$EihA$	Internal horizontal illuminance contributed by artificial light, measured at working plane 0.8m height from floor [lux]
$EihD$	Internal horizontal illuminance contributed by daylight, measured at working plane 0.8m height from floor [lux]
$EihD\text{-}D$	Internal horizontal illuminance contributed by daylight in the Dry season, measured at working plane 0.8m height from floor [lux]
$EihD\text{-}W$	Internal horizontal illuminance contributed by daylight in the Wet season, measured at working plane 0.8m height from floor [lux]
Eiv	Internal vertical illuminance, measured on wall at 2m height from floor [lux]
$EivA$	Internal vertical illuminance contributed by artificial light, measured on wall at 2m height from floor [lux]
$EivD$	Internal vertical illuminance contributed by daylight, measured on wall at 2m height from floor [lux]
$EivD\text{-}D$	Internal vertical illuminance contributed by daylight in the Dry season, measured on wall at 2m height from floor [lux]
$EivD\text{-}W$	Internal vertical illuminance contributed by daylight in the Wet season, measured on wall at 2m height from floor[lux]
E_m	Maintenance illuminance [lux]
ERC	Externally reflected component [%]
E_{res}	Heat exchange by evaporation in the respiratory tract
$Esky$	Illuminance of the whole sky [lux]
E_{tv}	Total vertical illuminance [lux], used in Brotas (2004) equations
E_{sun}	Vertical illuminance received at outer window surface from sunlight [lux]

$E_{sun}b$	Vertical illuminance received at outer window surface from sunlight reflected from buildings and trees [lux]
$E_{sun}g$	Vertical illuminance received at outer window surface from sunlight reflected from ground [lux]
ET	Gagge's effective temperature [^{0}C]
ETS	C.G. Webb effective temperature scale [^{0}C]
E_{vo}	Vertical illuminance from an unobstructed CIE overcast sky [lux]
E_{Vu}	Vertical illuminance from an unobstructed Uniform Diffused sky of constant luminance [lux]
$E_{wr}b$	Vertical illuminance received at outer window surface from reflected light coming from buildings and trees [lux]
$E_{wr}g$	Vertical illuminance received at outer window surface from reflected light coming from ground [lux]
E_{ws}	Vertical illuminance received at outer window surface from light coming directly from the sky [lux]
f	Weighting exponent of the glare index
$f(\Phi)$	Complex function of the displacement angle, which can be expressed using the Guth's position index.
FAR	Floor area ratio [%]
FD	Daylight dependency factor
G	Glare index
g	Weighting exponent of the glare index
G_g	Griffiths constant
H	Height of the room, from floor finish to ceiling finish [m]
h_1	Height of the window head, defined as the distance from the head of the window to the working plane (0.8m height) [m]
h_c	Surface heat transfer coefficients of the clothed body by convection [^{0}C]
H_{ob}	Height of the obstructing building, used in Vietnam codes [m]
h_r	Surface heat transfer coefficients of the clothed body by radiation [^{0}C]
I	Room index, expressed as a decimal
I_{De}	Depth index
IRC	Internal reflected component [%]
I_T	Transparency index
k	Coefficient expressing the linear slope, which is dependent of the reflectance of external obstructions, the geometry of the canyon, and the position on the facade, using in Brotas (2004) equation.

K	Maintenance factor (by dirt, cleaning frequency)
K_h	Heat flow by conduction from the surface of the clothed body
K_{hc}	NILP99 correction factor for the hot season in Vietnam, taken K_{hc} =7.965
L	Room length [m]
L	Luminance of the luminous area [cd/m^2], used in URG calculation
L_b	Luminance of the background [cd/m2]
L_1	Distance from the reference point to the window in plan, used in Vietnam codes [m]
$L_{background}$	Background luminance [cd/m2], used in UGR
L_{ob}	Length of the obstructing building, used in Vietnam codes [m]
LPD	Lighting Power Density [w/m^2]
LPW	Luminous efficacy [lm/w]
L_s	Luminance of the glare source [cd/m2]
Lz	Luminance of the sky at the zenith [cd/m^2]
L_θ	Luminance of the sky at angle of elevation θ [cd/m^2]
M	Metabolic rate [met], [w/m^2]
n	NILP99 Ethological correction factor, taken n = 0.92
η	Interior daylight distribution coefficient for light reaching the task plane, dependent on the room shape, position of the window and surface reflectance, expressed as a decimal
n_1	Number of visible grid line in Danhiluc section chart
n_1'	Number of obstructed grid line in Danhiluc section chart
n_2	Number of visible grid line in Danhiluc plan chart
n_2'	Number of obstructed grid line in Danhiluc plan chart
ηcs	Room-Windows index used in Vietnamese codes, defined by room length to room depth
ηcs	Window-Room index, expressed as a decimal
ni	Number of luminaire, used in UGR
OVH	Percentage of class hours when the classroom is overheated [%]
P	Distance from the obstructing building to window, used in Vietnam codes [m]
p	Guth Position index of the glare source, used in UGR
P_{hm}	Partial water pressure at work place [mmHg], used in NIPP99 method
P_i	Atmospheric transparency Index
PMV	Fanger's predicted mean vote
PPD	Predicted Percentage of Dissatisfaction [%]

psDw	Students' preferred vertical daylight factor in both seasons [%]
psDw-D	Students' preferred vertical daylight factor in the Dry season [%]
psDw-W	Students' preferred vertical daylight factor in the Wet season [%]
psEih	Students' preferred interior horizontal illuminance in both seasons [lux]
psEihD	Students' preferred on daylight contribution on interior horizontal illuminance in both seasons [lux]
psEih-D	Students' preferred interior horizontal illuminance in the Dry season [lux]
psEihD-D	Students' preferred on daylight contribution on interior horizontal illuminance in the Dry season [lux]
psEihD-W	Students' preferred on daylight contribution on interior horizontal illuminance in the Wet season [lux]
psEih-W	Students' preferred interior horizontal illuminance in Wet seasons [lux]
psEiv	Students' preferred interior vertical illuminance in both seasons [lux]
psEiv-D	Students' preferred interior vertical illuminance in the Dry season [lux]
psEiv-W	Students' preferred interior vertical illuminance in the Wet seasons [lux]
p_{si}	Position index of the i^{th} part of the glare source, used in URG calculation
ptEih	Teachers' preferred interior horizontal illuminance in both seasons [lux]
ptEihD	Teachers' preferred on daylight contribution on interior horizontal illuminance in both seasons [lux]
ptEih-D	Teachers' preferred interior horizontal illuminance in the Dry season [lux]
ptEihD-D	Teachers' preferred on daylight contribution on interior horizontal illuminance in the Dry season [lux]
ptEihD-W	Teachers' preferred on daylight contribution on interior horizontal illuminance in the Wet season [lux]
ptEih-W	Teachers' preferred interior horizontal illuminance in Wet seasons [lux]
ptEiv	Teachers' preferred interior vertical illuminance in both seasons [lux]
ptEiv-D	Teachers' preferred interior vertical illuminance in the Dry season [lux]
ptEiv-W	Teachers' preferred interior vertical illuminance in the Wet seasons [lux]
$pTneu_{student}$	Predicted students' neutral comfort temperature [^{0}C]
$pTneu_{teacher}$	Predicted teachers' neutral comfort temperature [^{0}C]
Pw	NILP99 Partial water pressure at work place [mmHg]
q	Luminance coefficient, expressed as a decimal
R	External obstruction index, used in Vietnam daylight codes, expressed as a decimal
r_1	Reflectance correction factor by internal reflected light and external reflected light from ground, used in Vietnamese codes, expressed as a decimal

Ra	CIE Colour rendering index
R_b	Area-weighted average reflectance of the interior surfaces (walls, floor and ceiling) in the half of the room remote from the window, expressed as a decimal.
R_h	Heat loss by radiation from the surface of the clothed body
RH	Relative humidity [%]
RH_{ADav}	Mean daily relative humidity of the afternoon shift in the Dry season. It is the average value of all the readings recorded by all the data loggers from 13h00 to 16h30 daily during the Dry season visit [%].
RH_{AWav}	Mean daily relative humidity of the afternoon shift in the Wet season. It is the average value of all the readings recorded by all the data loggers from 13h00 to 16h30 daily during the Dry season visit [%].
RH_M	Relative humidity deviation between the Dry and the Wet season [%].
RH_{MDav}	Mean daily relative humidity of the morning shift in the Dry season. It is the average value of all the readings recorded by all the data loggers from 8h00 to 11h30 daily during the Dry season visit [%].
RH_{MWav}	Mean daily relative humidity of the morning shift in the Wet season. It is the average value of all the readings recorded by all the data loggers from 8h00 to 11h30 daily during the Wet season visit [%].
Ro	Window-to-floor ratio, defined as the ratio of total window net area to total floor area [%]
Ro_1	Effective window-to-floor ratio, defined as the ratio of total window net area to total floor area, without considerations of overhangs, sunlight is included [%]
Ro_2	Effective window-to-floor ratio, defined as the ratio of total window net area to total floor area, with considerations of overhangs, sunlight is excluded [%]
R_{wall1}	Window-to-wall ratio, defined as the ratio of total window net area on wall 1 to total area of wall 1 [%]
R_{wall2}	Window-to-wall ratio, defined as the ratio of total window net area on wall 2 to total area of wall 2 [%]
Scs	Total floor area used in Vietnamese codes, similar to *(A)* in BRE daylight factor formula [m^2]
$SET*$	Standard effective temperature [^oC]
SF	Sky Factor [%]
SFr	Realistic Sky Factor [%]
S_h	Body heat storage
SN	Predicted thermal sensation index by NILP99 method
Ss	Total window's net glazed area used in Vietnamese codes, similar to A_w in BRE daylight factor formula [m^2]

$T.iD$	Air temperature in the Dry season [^{0}C]
$T.iW$	Air temperature in the Wet season [^{0}C]
T_{ADdav}	Mean daily afternoon shift temperature in Dry season. It is the mean value of all the classroom monitored indoor temperature values collected by the data loggers every 10 minutes from 13h00 to 16h30 daily during the Dry season survey [^{0}C]
T_{ai}	Indoor air temperature [^{0}C]
T_{AWav}	Mean daily temperature of the afternoon shift in the Wet season. It is the average value of all the readings recorded by all the data loggers from 13h00 to 16h30 daily during the Dry season visit [^{0}C]
$T_{classhour}$	Total class hours [hrs]
T_{comf}	ASHRAE: 55 neutral comfort temperature [^{0}C]
T_{comf20}	ASHRAE: 55 typical 20year neutral comfort temperature [^{0}C]
t_d	Dry bulb temperature [^{0}C]
T_{eff}	C.G. Webb effective temperature [^{0}C]
Tg	Globe temperature [^{0}C]
t_k	NILP99 Dry air temperature in workplace [^{0}C]
TM	Temperature deviation between the Dry and the Wet season [^{0}C]
T_{MDav}	Mean daily temperature of the morning shift in the Dry season. It is the average value of all the readings recorded by all the data loggers from 8h00 to 11h30 daily during the Dry season visit [^{0}C].
T_{MWav}	Mean daily temperature of the morning shift in the Wet season. It is the average value of all the readings recorded by all the data loggers from 8h00 to 11h30 daily during the Wet season visit [^{0}C].
$Tneu$	Predicted neutral comfort temperature [^{0}C]
$Tneu_{max}$	Upper limit of $Tneu$ [^{0}C]
$Tneu_{min}$	Lower limit of $Tneu$ [^{0}C]
T_{om}	ASHRAE: 55 monthly mean outdoor temperature [^{0}C]
T_{om20}	ASHRAE: 55 typical 20 year monthly mean outdoor temperature [^{0}C]
T_{op}	Nicol and Humpreys 's operative temperature [^{0}C]
T_{ovh}	Total hours when the classroom is overheated [hrs]
t_r	Mean radiant temperature of internal surfaces [^{0}C]
T_r	Mean radian temperature [^{0}C]
t_w	Wet bulb temperature [^{0}C]
UGR	Unified Glare Rating Index

v	Air velocity [m/s]
VCP	Visual Comfort Percentage [%]
VSA	Vertical shading angle [^{0}]
W	Rate of performance of external work
W_{index}	Window properties index, expressed as a decimal
z	Sky-wall azimuth in Waldram diagram [^{0}]
Z_1	Obstructing building index calculated in plan, used in Vietnam codes, expressed as a decimal
Z_2	Obstructing building index calculated in section, used in Vietnam codes, expressed as a decimal
γ_0	Altitude angle in Waldram diagram [^{0}]
γ_{shade}	Shading angle by overhang, measured at mid-height of window outer surface[^{0}]
ε_b	Direct sky component under CIE overcast sky, defined in Danhiluc chart [%]
$\varepsilon_{b\text{-}uniform}$	Direct sky component received from the unobstructed uniform sky, defined in Danhiluc chart [%]
ε_{ch}	External reflected component, defined in Danhiluc chart [%]
θ	Angle of visible sky measured in section through the window [^{0}]
Θ_{ed-1}	EN:15251 daily mean external temperature for the previous day [^{0}C]
Θ_{ed-2}	EN:15251 daily mean external temperature for the day before and so on [^{0}C]
θ_H	Upper angle of visible sky in altitude [^{0}]
Θ_{imax}	EN:15251 upper comfort temperature limit [^{0}C]
Θ_{imin}	EN:15251 lower comfort temperature limit [^{0}C]
θ_L	Lower angle of visible sky in altitude [^{0}]
Θ_o	EN:15251 operative temperature [^{0}C]
Θ_{rm}	EN:15251 running mean temperature [^{0}C]
Θ_{rm-1}	EN:15251 running mean temperature for previous day [^{0}C]
θ_{sky}	Angle of elevation [^{0}]
ρ	Area-weighted average reflectance of the interior surfaces, expressed as a decimal
$\rho_{ceiling}$	Reflectance factor of the ceiling, expressed as a decimal
ρ_{floor}	Reflectance factor of the floor, expressed as a decimal
$\rho_{furniture}$	Reflectance factor of the furniture, expressed as a decimal
ρ_{wall1}	Reflectance factor of wall 1, expressed as a decimal
ρ_{wall2}	Reflectance factor of wall 2, expressed as a decimal
ρ_{wall3}	Reflectance factor of wall 3, expressed as a decimal

ρ_{wall4}	Reflectance factor of wall 4, expressed as a decimal
τ	Diffuse transmittance of the glazing, including the effects of dirt, expressed as a decimal
τ_1	Glazing transmittance index used in Vietnamese codes, expressed as a decimal
τ_2	Window frame index used in Vietnamese codes, expressed as a decimal
τ_3	Roof structural index for roof windows, used in Vietnamese codes, for side windows it is given $\tau_3 = 1$
τ_4	Shading device index used in Vietnamese codes, expressed as a decimal
τ_5	Protection screen index for roof windows used in Vietnamese codes, expressed as a decimal
τcs	Window transmittance index used in Vietnamese codes, $\tau cs = \tau 1 . \tau 2 . \tau 3 . \tau 4 . \tau 5$, expressed as a decimal
τ_r	Realistic glazing transmittance index , expressed as a decimal
Φ_L	Left angle of visible sky in azimuth [^{0}]
Φ_R	Right angle of visible sky in azimuth [^{0}]
Ω	Window per floor ratio scaling factor, expressed as a decimal
ω	Size of the luminous area [sr] , used in UGR
Ωs	Solid angle subtended by the source, modified for the effect of the position of the observer in relation to the source, used in DGI calculation [sr]
ω_s	Solid angle subtended by glare source [sr], used in DGI
$\overline{D}$	Average daylight factor on all interior surfaces [%]
$\overline{D}_{BRE}$	BRE Average daylight factor on reference plane, measured at 0.8m height from floor [%]
$\overline{TD}$	Average total daylight factor [%]
$\sum H$	Zuilen- Korenkov condition index [%]

List of Abbreviations

DET	Department for Education and Training
DOET	District Office for Education and Training
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BRE	Building Research Establishment
BRE ADF	Average Daylight Factor method developed by the Building Research Establishment
CIBSE	The Chartered Institution of Building Services Engineers, UK
CIE	Commission International de l'Eclairage
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
HCMC	Ho Chi Minh City
ICT	Information and Communication Technology
ISO	International Organization for Standardization
MoC	Ministry of Construction
MoH	Ministry of Health
MoST	Ministry of Science and Technology
NILP	Vietnam National Institute for Labour Protection
SCATS	Smart Controls and Thermal Comfort
SPSS	Statistical Package for the Social Sciences
U.S	United States of America
UK	United Kingdom
VND	Vietnam Dong, Vietnamese currency

Chapter 1

Introduction

1.1 Rationale

Education has had an important role in the history of Vietnamese development. It has been defined as the strategic key for the success of the country's long term sustainable growth. Since 1990, the government has allocated as much as 20% of all state budget expenditures towards education, and improving the school infrastructure has been set as one of the priority tasks (MPI, 2008).

However, recent surveys have indicated that the quality of the existing school environment is poor; particularly visual comfort quality in a classroom has been reported as below expectation (VEEPL, 2008).

Results from a study initiated in 2005 by the Vietnamese Ministry of Health shows that over 50% of the students in Ho Chi Minh City (HCMC in short) have problems related to eyes, particularly short-sightedness (SGGP, 2006). This has been further corroborated by another study that reveals that 43% of students feel that their classrooms are not adequately lit and 68% are unsatisfied with the visual comfort (VEEPL, 2008). This report was followed by another that has revealed that 50-53% of the classrooms in the city, mostly in secondary schools, are poorly lit (SGTT, 2009).

These reports raise both statistical as well as health and safety concerns but they have not been furthered by any full architectural investigation. Furthermore, a review of the available design literature suggests that there is very limited study done in this field and most of the available literature is derived from studies conducted in temperate climates. The only existing classroom lighting design guidelines that could be considered useful are the national codes (VEEPL, 2008). Therefore, it is necessary to conduct architectural research on this issue, because it will not only help to examine the current conditions and identify the problems. This may also lead to deriving meaningful findings that could be added to the existing limited literature on classroom lighting in HCMC.

1.2 Aims

This research will try to answer a simple question that other surveys have addressed: *"Are people visually comfortable in the classrooms?"*, but it will look at the issue from an architectural perspective rather than from a statistical perspective.

Most of the current codes and design guidelines, including Vietnamese codes, recommend that daylight should be the main source of classroom illumination. Furthermore, researchers have found that students studying in day lit classrooms have better academic performance (Heschong, 1999). Therefore, daylight is regarded as the foundation as well as an inspiration for any improvement on classroom lighting design. Hence, to identify the roots of the current problems, daylight performance in classrooms should be the central focus of this research.

Since Vietnam is located within the tropical belt, there is high availability of natural light and thus there is a lot of potential to improve the daylight benefit in classroom. However, it should be noted that tropical daylight provides both opportunities and threats because any inappropriate enhancement of day lit spaces may also increase solar gain, leading to worsening thermal comfort and poor energy efficiency. Furthermore the complexity of an urban context like HCMC is also a challenge for the success of any daylight design strategy. Hence, besides looking at improving the daylight benefit in classrooms, this research would also look further into the thermal comfort consequences. Thus the research question of this study should be extended to:

"Are people visually and thermally comfortable in the classroom?"

Architecturally, this may seem to be a very general research question, but it leads to a comprehensive answer that has value beyond this particular case study of school classrooms in HCMC. This is because the results obtained in the process of finding this answer could be useful in other circumstances, for instance for other building types or other countries with similar climate and culture.

It is found that there are many external factors, both technical and social, that have significant influences on the internal comfort quality of the classroom environment. Moreover, it is difficult to evaluate "people comfort" using just numeric measurements. Finding an answer for this question is not a straightforward process hence it is important to step back, take a broader look and examine the issues from various perspectives. It is suggested that initially the investigation consist of two steps:

- Review of factors that may have major architectural impact on the visual comfort quality of school classrooms, particularly within the relevant context of HCMC.
- Evaluate the visual and thermal comfort quality of sample classrooms in HCMC.

In light of this initial investigation, several important findings have been revealed. The first finding is that both natural and social factors play a significant role in the design development of classroom. The second and most critical finding is that the current Vietnamese classroom lighting codes, particularly the daylight code, although well- established, are conflicting and inappropriate for HCMC. These inappropriate codes may partly contribute to the fact that classrooms in HCMC hardly achieve these standards and have been found to be in poor condition. The evidence obtained suggests that only 44.5% of the students and 63.0% of the teachers are visually comfortable and 50.45% of the students and 49.45% of the teachers are thermally comfortable. Furthermore, the results from the comfort questionnaire suggest that the users' comfort preferences are different to what are predicted by the codes and students and teachers have different comfort preferences. From these findings the initial research question leads to another question:

What can be done to improve the classroom visual and thermal comfort quality?

The current Vietnamese daylight code has been found to be inappropriate for HCMC and has been identified as the most critical problem. The results from site measurements and the comfort questionnaires help to establish some visual and thermal comfort parameters and these are perhaps more appropriate for HCMC school classrooms.

It may be too ambitious to rewrite the codes due to the constraints of available time and resources of this research as well as the size of the samples examined. Perhaps it would be helpful to establish a simple design indicator, such as the effective window-to-floor ratio. Apart from fulfilling the main aim which is conducting an extensive investigation on the current lighting and its thermal comfort consequences of school classrooms in HCMC, this research also aims to provide meaningful contributions to the existing literature on classroom lighting and thermal comfort, which may also be useful for other cases and other fields of study.

1.3 Research structure

In light of the research question and aims set above, the body of this research should address the three important goals which are as follows:

- Review factors that may have major architectural impact on the visual comfort quality of school classrooms, particularly within the relevant context of HCMC.
- Providing an evaluation of the classroom lighting and its thermal comfort consequences. Identifying potential conflicts and problems.
- Establishing a simple design indicator. Providing suggestions for improving current conditions and establishing initial literature for developing classroom lighting design guideline for secondary schools in HCMC.

Accordingly, the research is therefore structured into three parts addressing the goals set above.

Part I: The overview of background of classroom lighting.

It should be noted that the background of classroom lighting is a very comprehensive subject that involves many factors both technical and social, and thus this overview should be addressed from many perspectives. Therefore, part I is divided into three smaller discussions addressing different issues pertaining to this subject:

- The first discussion focuses on reviewing the natural settings, social and cultural settings and national policy. The review of natural settings includes relevant climatic data that have significant impact on classroom lighting and thermal comfort design strategies. The review of the social and cultural settings focuses on the history of social and cultural developments of HCMC city, their major influences on classroom architecture and lighting design strategies, and the role of and expectation for classroom lighting design in the future. The last part of this discussion provides an overview of the educational settings. It looks at how education was established in the city, the current methods of teaching-learning and expectations for classroom lighting and the relevant governmental plans and policies. This discussion forms chapter 2 of this research.

- The second discussion reviews best practices in classroom lighting. Firstly, established theories behind classroom lighting are presented along with the means by which these are tested, calculated or evaluated. This is done on the basis of codes and established lighting researches in Vietnam and other countries with similar climate. Special focus is set on the current Vietnamese classroom daylight code and its method of assessment *(ĐRASTN)*. Some comparisons on the design parameters and applicable domains are also given. This discussion forms chapter 3 of this research.
- The last discussion presents the review of the development of school buildings and comparison of existing school types in HCMC. This is furthered by some initial evaluations on current school designs generated from user comfort survey. This discussion forms chapter 4 of this research.

Part II: *Evaluation of the classroom lighting and its thermal comfort consequences*

This part presents the evaluation of classroom lighting and its thermal comfort consequences for a sample of four secondary school classrooms in HCMC. It consists of three main discussions:

- The first discussion is the evaluation and analysis of the daylight performance, which is the main mechanism of classroom illumination. This part forms chapter 5 of this research.
- The second discussion focuses on the evaluation of visual comfort in the light of current literature. This part also looks at the results from site measurements and the user comfort surveys. This part forms chapter 6 of this research

- The third discussion presents the evaluation of the thermal comfort conditions in the same approach. This part forms chapter 7 of this research.

Part III Establishing a simple design indicator and providing suggestions.

This part provides the summary of conflicts and findings presented in previous chapters in the light of current literature and the real conditions in HCMC. A simple design indicator, which is effective window-to-floor ratio, is proposed. Furthermore, critical recommendations and suggestions for visual and thermal comfort criteria which are more appropriate for HCMC school classrooms are given. Suggestions for future researches are also presented. All of these issues are summarized in chapter 8.

1.4 Methodology

Analytical approach is the main technique used in this research. Discussions are in the format of analysis of data, using appropriate literature to explain the phenomena and then to establish hypothesis. Each analysis, however, may employ different approaches, methods and techniques, quantitatively and qualitatively, whichever may be most suitable to the context.

In the first step, data on current classroom lighting conditions are obtained using different methods:

- Climatic data are provided by the local meteorological station.
- Social and cultural backgrounds are obtained from official sources, established databases and previous studies.
- Specific information about real operational conditions is obtained from field work on four chosen secondary schools in HCMC.

The field work consists of three main surveys:

- The first survey provides documentation of the site context, e.g. technical measurements, photography, note taking on school operations, users' behaviours and some site experiments to obtain further data (e.g. defining glazing's transmittance factor). All the information is then transferred into analyzable digital formats (e.g. AutoCAD, Excel).
- The second survey involves site measurements. It consists of two major measurements: continuous environmental monitoring by data loggers and instantaneous measurements by handheld devices. In each school,

environmental data loggers are installed in one classroom for several days. These data loggers consist of three photocells recording illuminance level, three temperature loggers, three humidity loggers and one carbon dioxide logger. There are also instantaneous measurements on environmental conditions (i.e. illuminance, air temperature and humidity) recorded by portable devices. These measurements are supplementary to the monitoring by data loggers. For instance, they provide further information on other positions or help obtain further information on glazing, reflectance and transmittance. Two visits were organized - one in the Wet season of 2007 (September –November) and one in the Dry season of 2008 (February-April). These measurements provide critical data for the main analysis.

- The third survey is the user comfort survey in questionnaire format. The participants are students and teachers from the four schools where the site measurements are taken and they include users of the classrooms where the monitoring devices are installed. The questionnaire is constructed to purposely collect data of users' responses, their satisfaction, their expectations and preferences of the environmental performance of the classroom. The questionnaire is modelled after a similar survey done previously (e.g. the Smart Controls and Thermal Comfort, aka SCATS project) and prepared in two formats with minor differences: one for the students and one for the teachers. The comfort survey corresponds to the two site visits for site measurements. The results are analyzed using statistical analysis software (i.e. Statistical Package for the Social Sciences, aka SPSS).

Further details of the field work are given in appendix A.

In the second step, most of the scientific and technical data and information are analyzed by quantitative methods based on analytical calculations, established literature and computerized stimulations (i.e. Dialux, WebHDR and Evalglare). Data mining and analysis of the users' comfort survey requires some qualitative techniques using social science and statistical theories and is done with the aid of SPSS software.

The research structure and process chart are illustrated in figure 1.1.

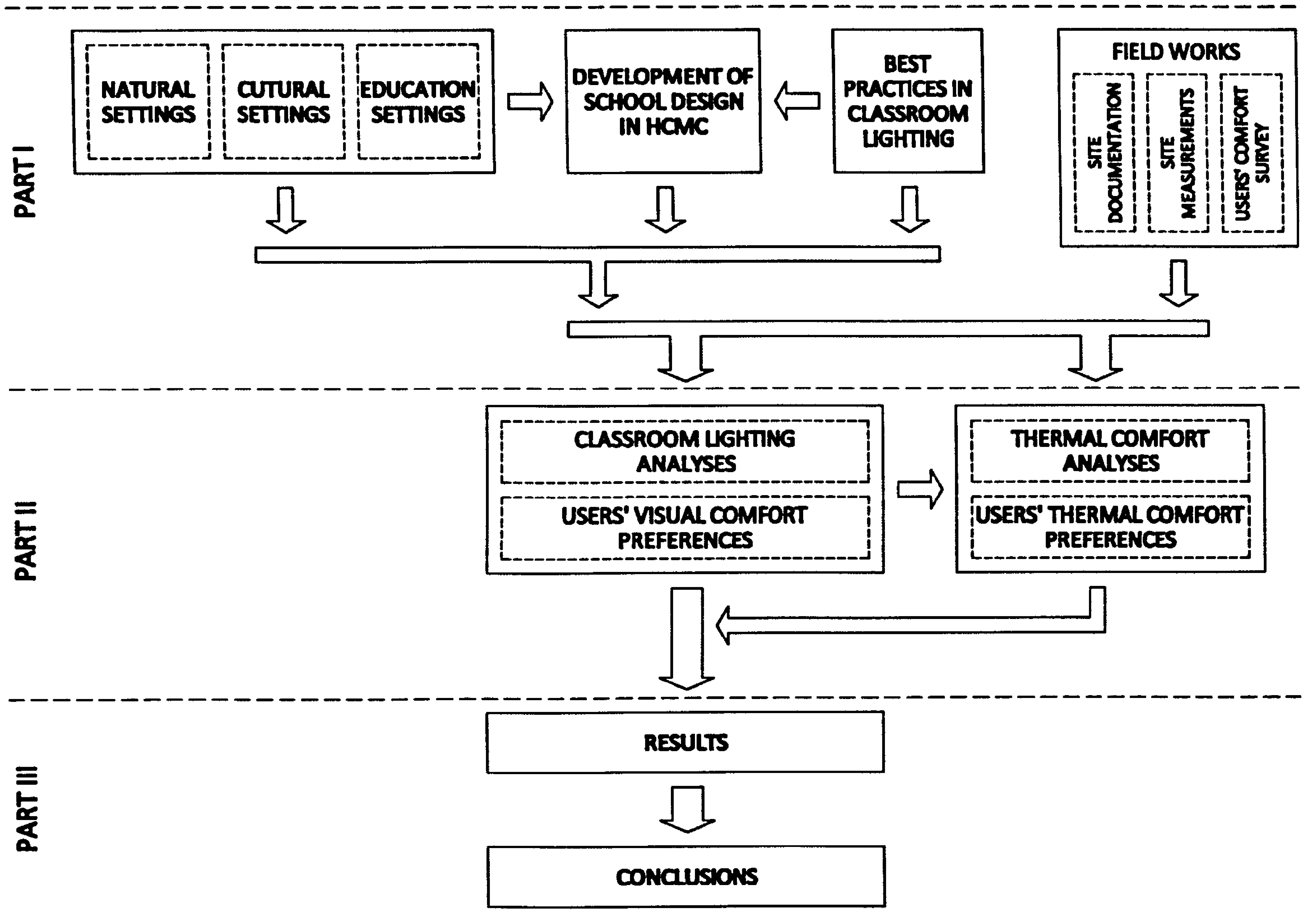


Figure 1.1 Research structure and process chart

Chapter 2

Review of Ho Chi Minh City Education Settings

2.1 Introduction

This chapter aims to provide an overview of the current education settings of HCMC. First, a brief review on the natural setting of the city including geography, topography and climate is given. The second part focuses on reviewing the social settings that have had significant impact on the development of education. This includes a brief review of the history of the city, the cultural and social backgrounds, and plans and policies set by the government. The last part of this chapter reviews the teaching and learning methods and focuses on establishing general expectations for classroom lighting. This part also provides some suggestions on future trends and on the development of classroom lighting design.

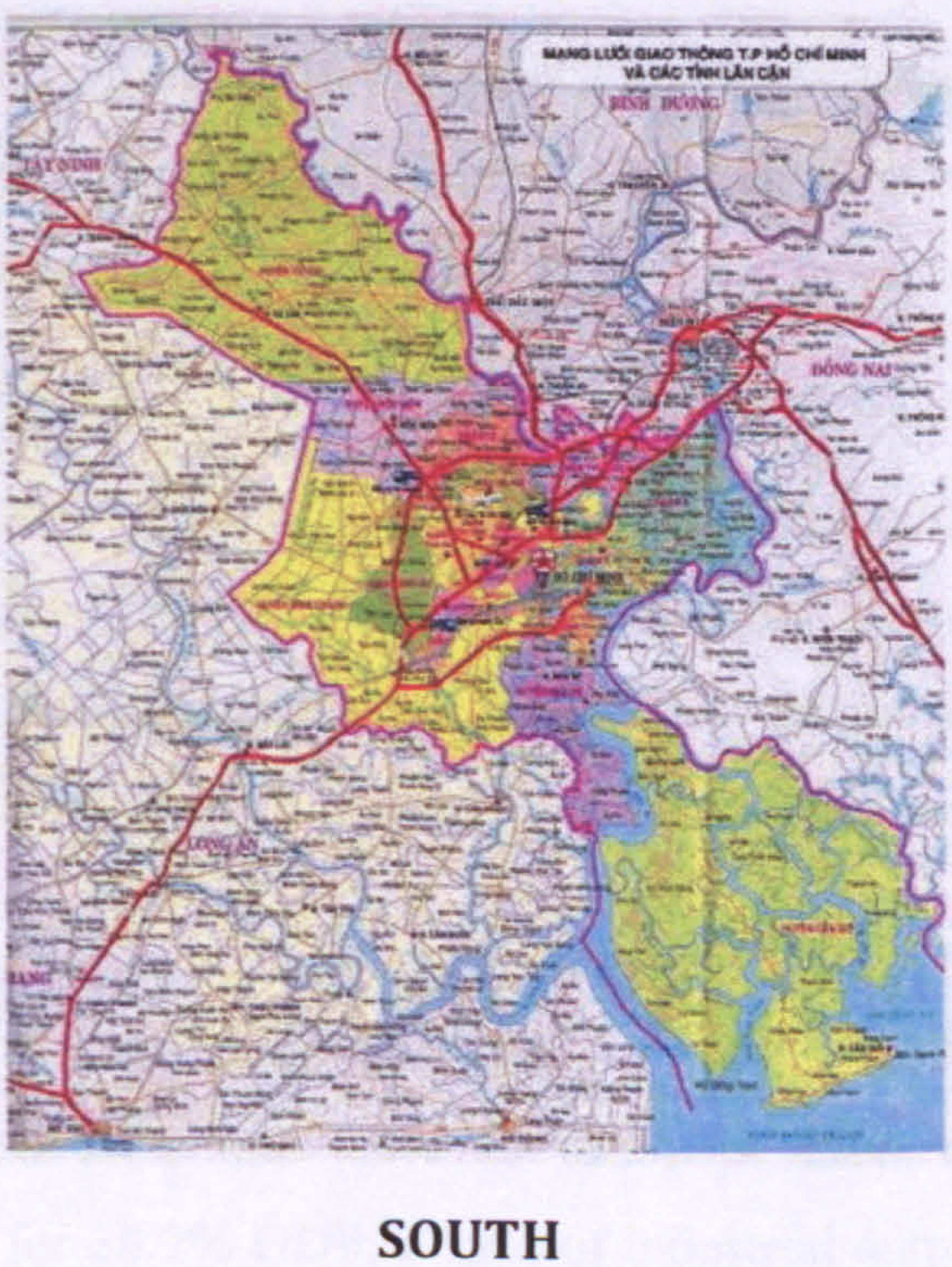
2.2. General background of HCMC

Ho Chi Minh City (or HCMC in short), commonly known as Saigon, is located at the heart of the Southern part of Vietnam, between the northern edge of the Mekong River Delta and the South- East region of volcanic red soil, approximately 1730km south of the capital Hanoi. The position of HCMC within the South East Asia region and within the country regions is illustrated in figure 2.1.

Figure 2.1 The location map of HCMC and its regional position. (NationalOnlineProject, 1998)

NORTH
10°38' N

WEST
106°22' E



EAST
106°54' E

SOUTH
10°10' N

Figure 2.2 The borders and administrative map of HCMC (not to scale). (HCMC, 2009)

Figure 2.3 HCMC is the country's most populous metropolitan city and is the centre of industry, economy and culture nowadays. (AAPhoto, 2010)

As of 2009, the city occupies an area of 2,095.239 km^2, providing living space for 7,123,340 people (HCMC, 2009;Vietnam, 2009). The metropolitan area is divided into twenty-four administrative districts populated by more than nine million people. The population density is 3,401people /km^2. In the city centre, the density can be very high, up to 47,000 people/km^2, making it the most populous metropolitan area in Vietnam and in Indochina (HCMC, 2009).

Nestled between two terrains, HCMC is intertwined with natural forest, vast plains, long coast and hundreds of rivers and canals. The Saigon River winds around the city and connects it with the South China Sea (called East Sea in Vietnam). Its natural advantageous strategic location in the maritime crossroad makes it an important seaport of the region.

HCMC is the country's most important economic centre. Although it accounts for just 0.6% of the land area and 7.5% of the population of Vietnam, HCMC nevertheless accounts for 20.2% GDP, 27.9% of industrial output and 34.9% of FDI projects in this country (HCMC, 2009). The city has a strong cultural and social diversity. This diversity developed due to its mixed population background and through the different layers of the city's history.

2.3 The Natural Setting

2.3.1. Topography

HCMC is located in a transitional region between the South Eastern and Mekong Delta regions. Most of the city is flat land; with the average elevation between 5 to 10 metres (62 ft) above sea level. In general the city topography is higher in the North-West, and lower in the South-East. There are three types of terrain. The low hill terrain lies in the Northern-North Eastern area of the Cu Chi District where the average height is between 10 to 25 metres. The highest point at Long Binh Hill in District 9th is 32 metres. The flat land terrain forms most of the city centre where the average height is 5 to 10 meters. The low land terrain lies in the South – South Western, near the coastal area and here the average height is 0.5 to 2 meters.

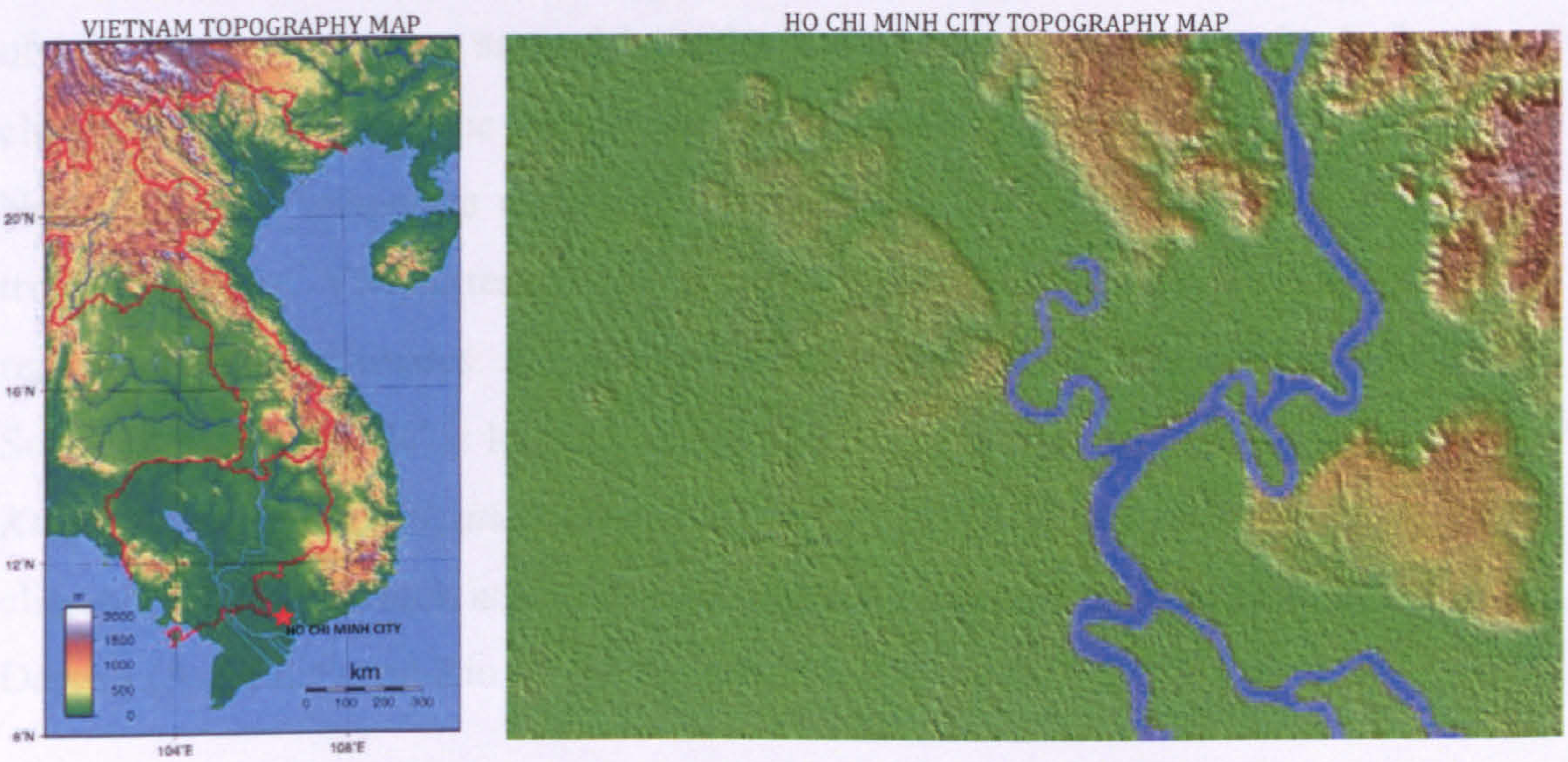


Figure 2.4 Vietnam's topography map (Left). The topography map of HCMC showing most of the city as flat with the low land lying along the river (Right) (Vietnam Travel, 2008)

Figure 2.5 The extensive waterway network is a vital part of the city landscape (NTT, 2003)

HCMC has an extensive system of about 9,120km of rivers and canals. The biggest rivers are Dong Nai River and the Saigon River, which meet each other in the South of the city to form the Nha Be River, an important waterway from the city harbour to the sea. The city centre lies along the Saigon River, forming part of the city centre landscape. These rivers are connected to a large network of canals that are a major part of the city drainage system and the water way, and are a typical characteristic of the city. In the past, some of the canals such as Ben Nghe, Thi Nghe and Lo Gom were vital for the city trading. Overall, the metropolitan area extends across a vast area with similar topography. This can be considered as an advantage when designing buildings as they can have similar design parameters.

2.3.2. The Climate Overview

Vietnam's climate is classified as tropical monsoon climate. The geographical area of Vietnam extends over several latitudes and types of topographical relief so local climate differences can be seen, especially between the North and the South. The North enjoys a temperate monsoon climate, while the South has a hot and humid tropical climate. Vietnamese building codes categorize the country into five small regional building climates: A1, A2, and A3 for the Northern areas; B4 and B5 for the Southern areas. HCMC is located within zone B5, the tropical belt. According to the *Köppen climate classification* (Peel et al, 2007) , HCMC has a tropical wet and dry climate (zone A_w), which is similar to Bangkok (Thailand), Manila (The Philippines), Darwin (Australia) and Rio de Janeiro (Brazil) (see figure 2.7 and figure 2.8).

A year is divided into two distinct seasons: the Wet and the Dry. The Wet season usually begins in May and ends in late November. The Dry season lasts from December to April. The season names are derived from the fact that in the Dry season the sun shines most of the time; while it often rains during the Wet season. However, in the Wet season there are also some sunny intervals, mostly seen in the morning. Therefore, the overall impression is that of a dominant sunny climate.

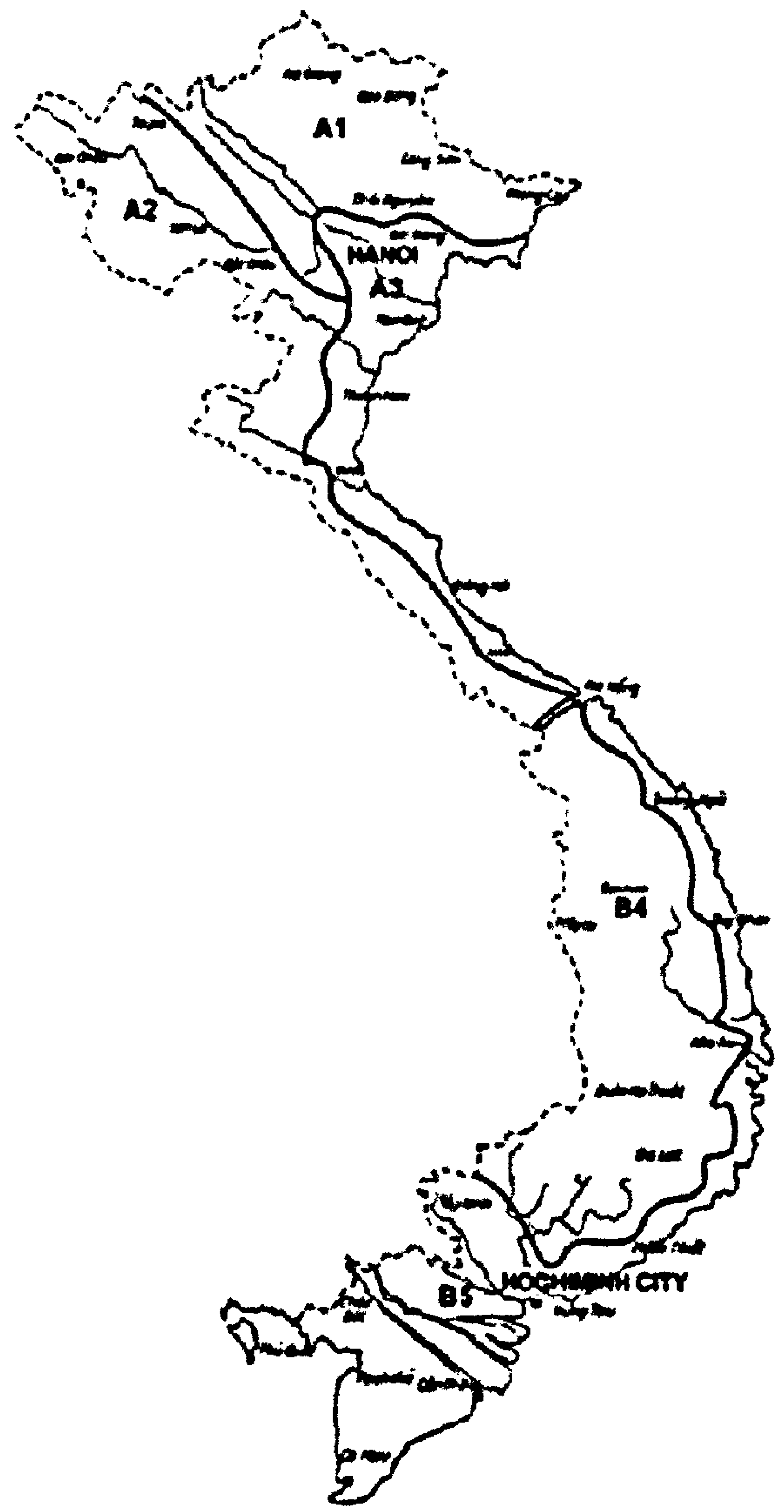


Figure 2.6. Vietnam climate building zones: HCMC is located within zone B5. (TCXDVN:306, 2004)

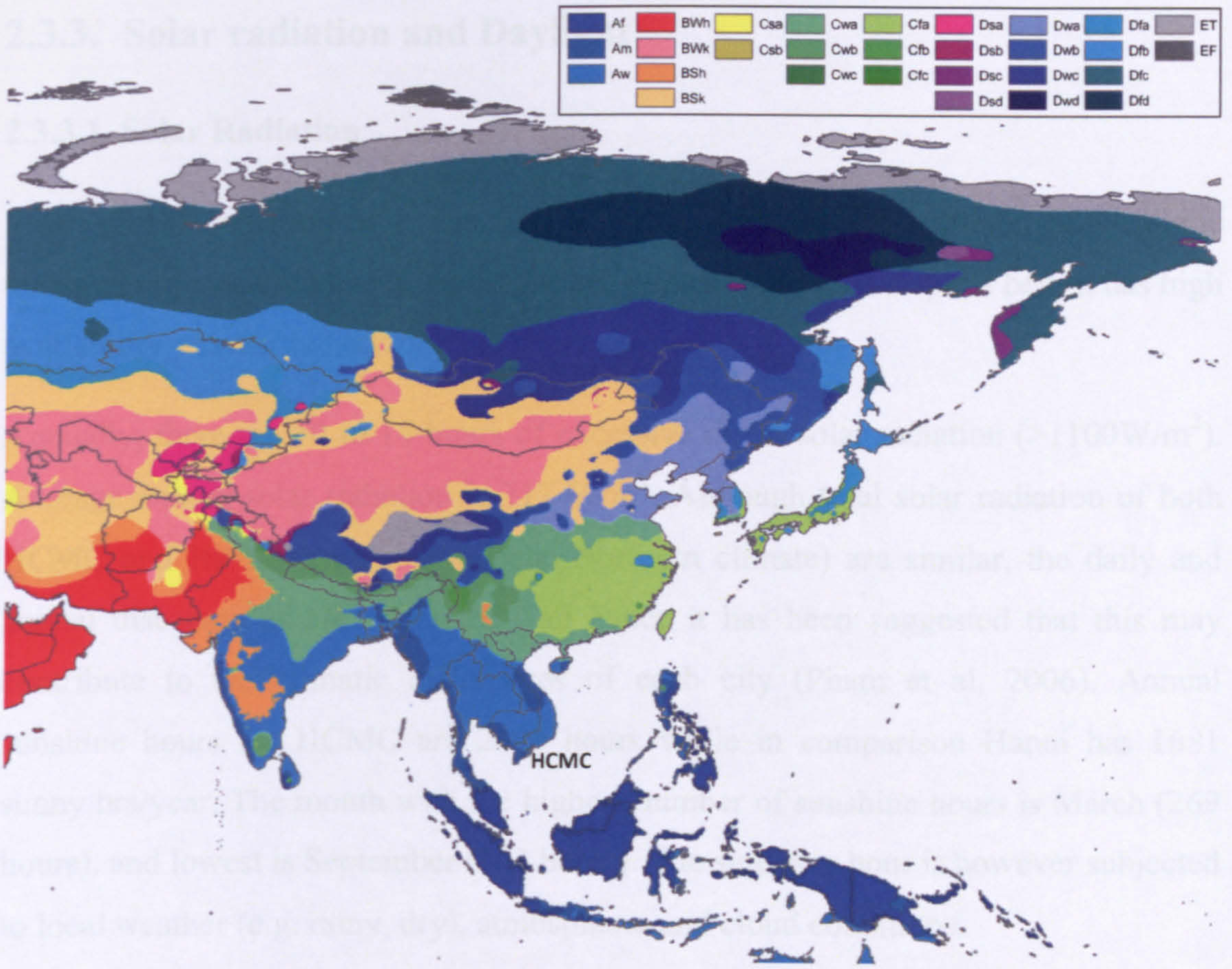


Figure 2.7 Regional map of Köppen-Geiger climate classification showing HCMC climate located within group Aw (tropical wet and dry climate) (Peel et al,2007).

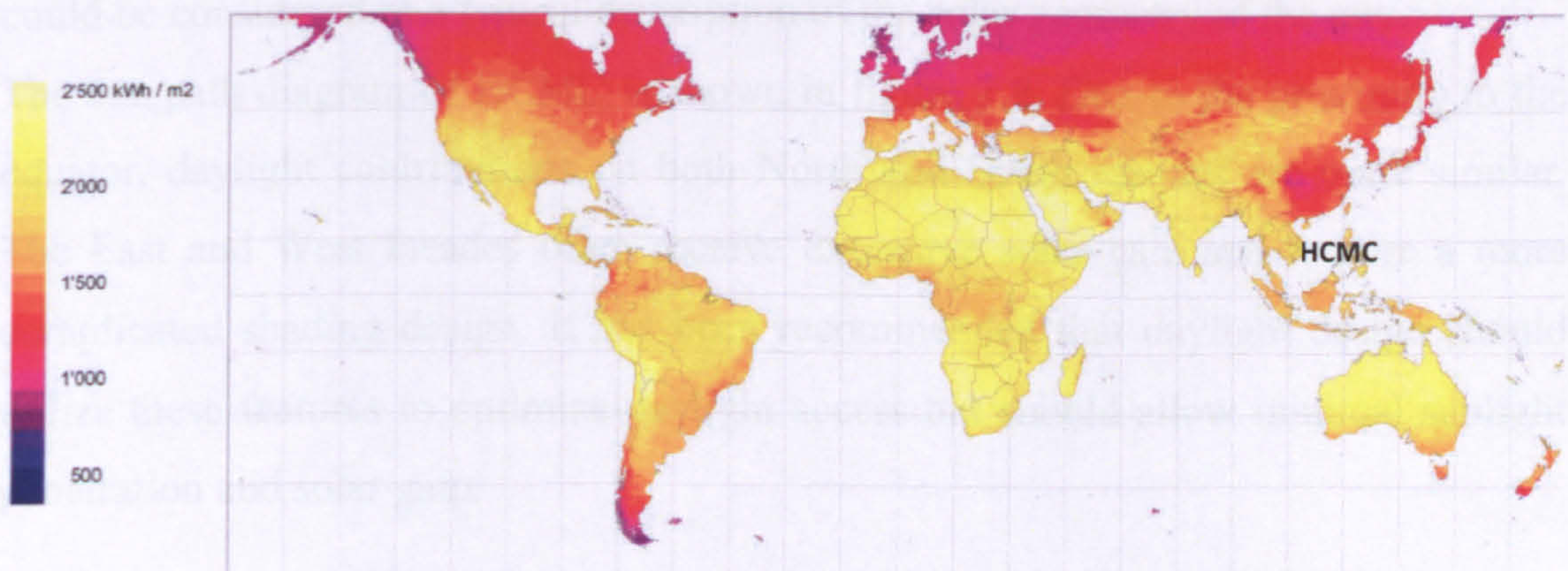


Figure 2.8 Map of Yearly sum of Global Horizontal Irradiance (Meteonorm , 2010)

2.3.3. Solar radiation and Daylight

2.3.3.1. Solar Radiation

Solar global radiation is a function of solar altitude, site altitude, atmospheric transparency and cloudiness. As HCMC is located within the tropical belt, it has high availability of solar radiation.

Annually, there are 10 to 14 hours of excessive direct solar radiation (>1100W/m^2). Average annual solar radiation is 717 W/m^2. Although total solar radiation of both HCMC and Ha Noi (representing the Northern climate) are similar, the daily and annual distributions are different. And hence it has been suggested that this may contribute to the climatic differences of each city (Pham et al, 2006). Annual sunshine hours for HCMC are 2497 hours while in comparison Hanoi has 1681 sunny hrs/year. The month with the highest number of sunshine hours is March (269 hours), and lowest is September (163 hours). The sunshine hour is however subjected to local weather (e.g. rainy, dry), atmospheric and cloud conditions.

2.3.3.2. Solar geometry

Because HCMC is relatively close to the equator, the equatorial solar conditions could be considered as a typical description of the solar geometry of the city.

The sun path diagram of HCMC is shown in figure 2.9. Due to the proximity to the equator, daylight contributions on both North and South facades are quite similar. The East and West facades often receive excessive solar gain and require a more complicated shading design. It has been recommended that daylight design should utilize these features to optimize daylight access but should allow minimal sunlight penetration and solar gain.

Table 2.1 Annual solar radiation [W/m²] of HCMC and Hanoi.

MONTH	HOUR 06h00	07h00	08h00	09h00	10h00	11h00	12h00	13h00	14h00	15h00	16h00	17h00	18h00	*Average*
HO CHI MINH CITY														
1	0	310	555.9	787.9	967.8	1081.3	1120	1081.3	967.8	787.9	555.9	310	0	*739*
2	0	220.1	506.2	753.3	943.2	1062.6	1103.4	1062.6	943.2	753.3	560.2	220.1	0	*711*
3	0	199	467.7	709.8	898.3	1017.6	1058.4	1017.6	898.3	709.8	467.7	199	0	*669*
4	12.1	226	484.9	719	901.9	1017.9	1057.5	1017.9	901.9	719	484.9	226	12.1	*678*
5	34.3	226.5	522.3	750	927.2	1039.2	1077.5	1039.2	927.2	750	522.3	266.5	34.3	*707*
6	51.1	296.1	552.4	777.9	952.4	1062.6	1100.2	1062.6	952.4	777.9	552.4	296.1	51.1	*733*
7	39.2	279.4	538	766.7	944.1	1056.2	1094.5	1056.2	944.1	766.7	538	279.4	39.2	*722*
8	13.5	229.5	488.5	722.3	904.9	1020.6	1060.2	1020.6	904.9	722.3	488.5	229.5	13.5	*681*
9	0	220.3	498	744.1	934.8	1055.1	1096.2	1055.1	934.8	744.1	489	220.3	0	*699*
10	0	217.6	503.2	750.4	940.3	1059.8	1100.6	1056.8	940.3	750.4	503.2	217.6	0	*703*
11	0	287.7	545	779.1	960	1074	1113	1074	960	779.1	545	287.7	0	*730*
12	0	419.6	573.6	792.9	966.3	1076.2	1113.8	1076.2	966	792.9	573.6	419.6	0	*752*
HANOI														
1	0	52.1	265	475.6	642.2	748.3	764.6	748.3	642.2	475.6	265.5	52.1	0	*456*
2	0	77.2	277.7	480.7	645.2	751.1	767.5	751.1	645.2	480.7	277.7	77.2	0	*463*
3	0	95.3	275.1	460.5	624	713.9	748.5	713.9	614	460.5	275.1	95.3	0	*448*
4	9.1	125.2	298.9	474.5	619.8	714.6	747.5	714.6	619.8	474.5	298.9	125.2	9.1	*458*
5	30.8	182.8	375.7	561.3	711.3	808.1	841.4	808.1	711.3	561.3	375.7	182.6	30.8	*537*
6	45.3	211.9	412	600.4	751.2	848	881.4	848	751.2	600.4	412	211.9	45.3	*573*
7	37	203.2	407.1	599.7	754	853	853	853	754	599.7	407.1	203.2	37	*569*
8	14.5	185.3	370.1	567.7	727.1	829	865	829.7	727.1	567.7	370.1	165.3	14.5	*543*
9	0	131.7	349.9	560.9	730	838.6	875.9	838.6	730.1	560.9	349.9	131.7	0	*536*
10	0	108.9	345.2	567.4	742.6	853.9	892	853.9	742.6	567.4	345.2	108.9	0	*541*
11	0	68.5	303.5	522.5	693.6	801.9	838.9	801.9	693	522.5	303.5	68.5	0	*498*
12	0	47.5	275.4	489.8	657.1	762.9	799.1	762.9	657.1	469.8	275.4	47.5	0	*467*

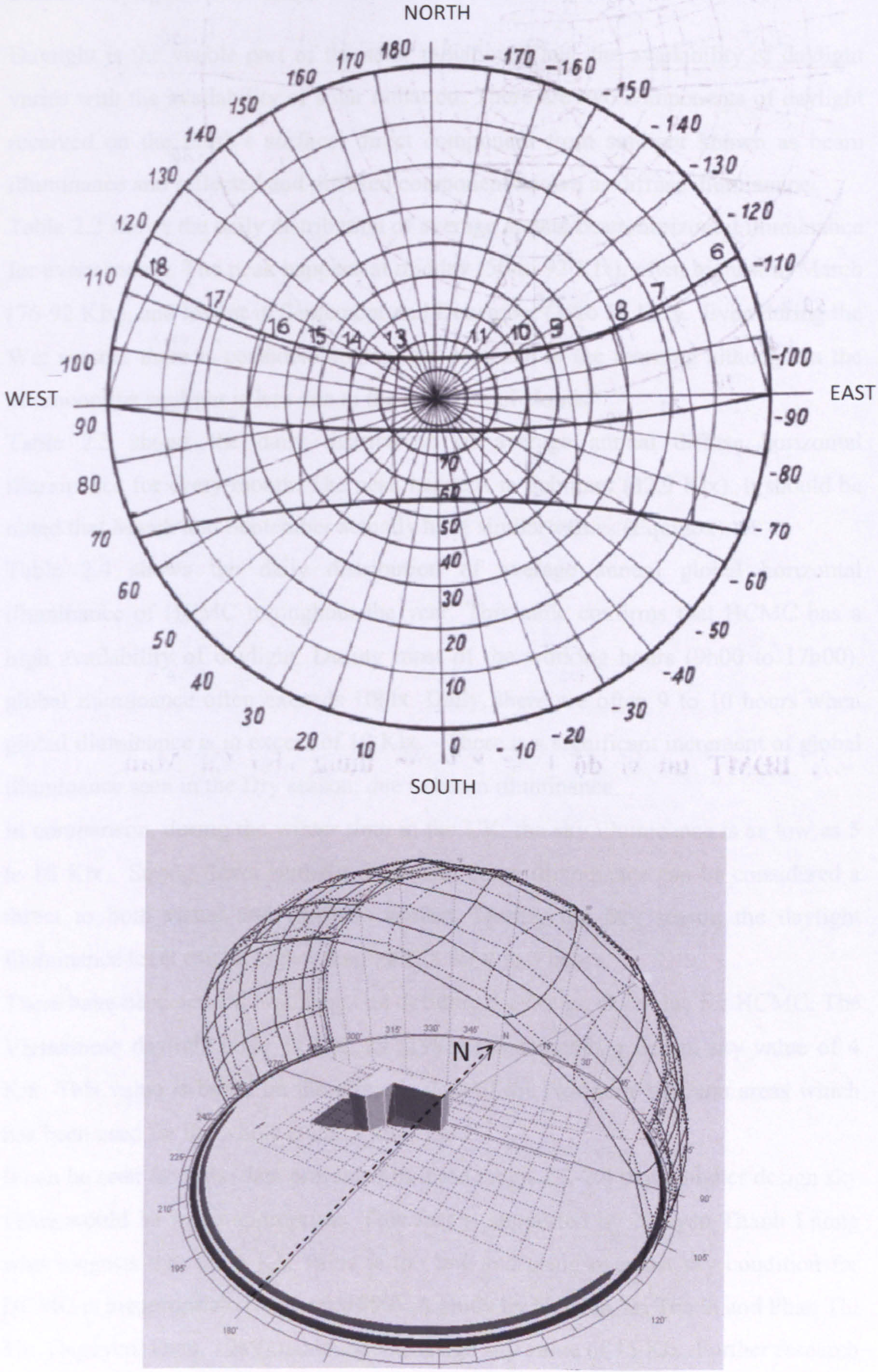


Figure 2.9 Sun path Diagram of HCMC (at 11°N). (Pham et al, 2006)

2.3.3.3. Daylight availability

Daylight is the visible part of the solar radiation. Thus, the availability of daylight varies with the availability of solar radiation. There are two components of daylight received on the Earth's surface: direct component from sunlight known as beam illuminance and reflected and diffused component known as diffuse illuminance.

Table 2.2 shows the daily distribution of average annual beam horizontal illuminance for every month. The peak happens at midday (50 to 92 Klx), often highest in March (76-92 Klx), and lowest in September and December (39to 55 Klx). Even during the Wet season, there is considerable sunlight presence in the morning although in the afternoon the sunlight is less due to the presence of clouds.

Table 2.3 shows the daily distribution of average annual diffuse horizontal illuminance for every month. The peak happens in February (32.9 Klx). It should be noted that March and September actually have similar values (Equinox).

Table 2.4 shows the daily distribution of average annual global horizontal illuminance of HCMC throughout the year. This table confirms that HCMC has a high availability of daylight. During most of the working hours (9h00 to 17h00), global illuminance often exceeds 10klx. Daily, there are often 9 to 10 hours when global illuminance is in excess of 10 Klx. There is a significant increment of global illuminance seen in the Dry season, due to beam illuminance.

In comparison, during the winter time in the UK, the sky illuminance is as low as 5 to 10 Klx. Strong direct sunlight present in beam illuminance can be considered a threat to both visual and thermal comfort. During the Dry season the daylight illuminance level can be higher than 50 Klx for 4 to 5 hours.

There have been several arguments on defining the design sky value for HCMC. The Vietnamese daylight code TCVN: 29 (1991) recommends a design sky value of 4 Klx. This value is based on the climatic data of the Northern Vietnam areas which has been used for the whole country after 1975.

It can be seen from the data presented in these tables 2.2-2.4 that a higher design sky value would be more appropriate. This fact is supported by Nguyen Thanh Luong who suggests that the 5 Klx value is too low and using overcast sky condition for HCMC is inappropriate (Nguyen, 1990). A study by Nguyen Tri Thanh and Phan Thi Thi, (Nguyen, Phan, 1989) recommends design sky value of 15 Klx. Further research needs to be done to define an appropriate sky model and a design sky value.

Table 2.2 Annual beam horizontal illuminance [Klx]

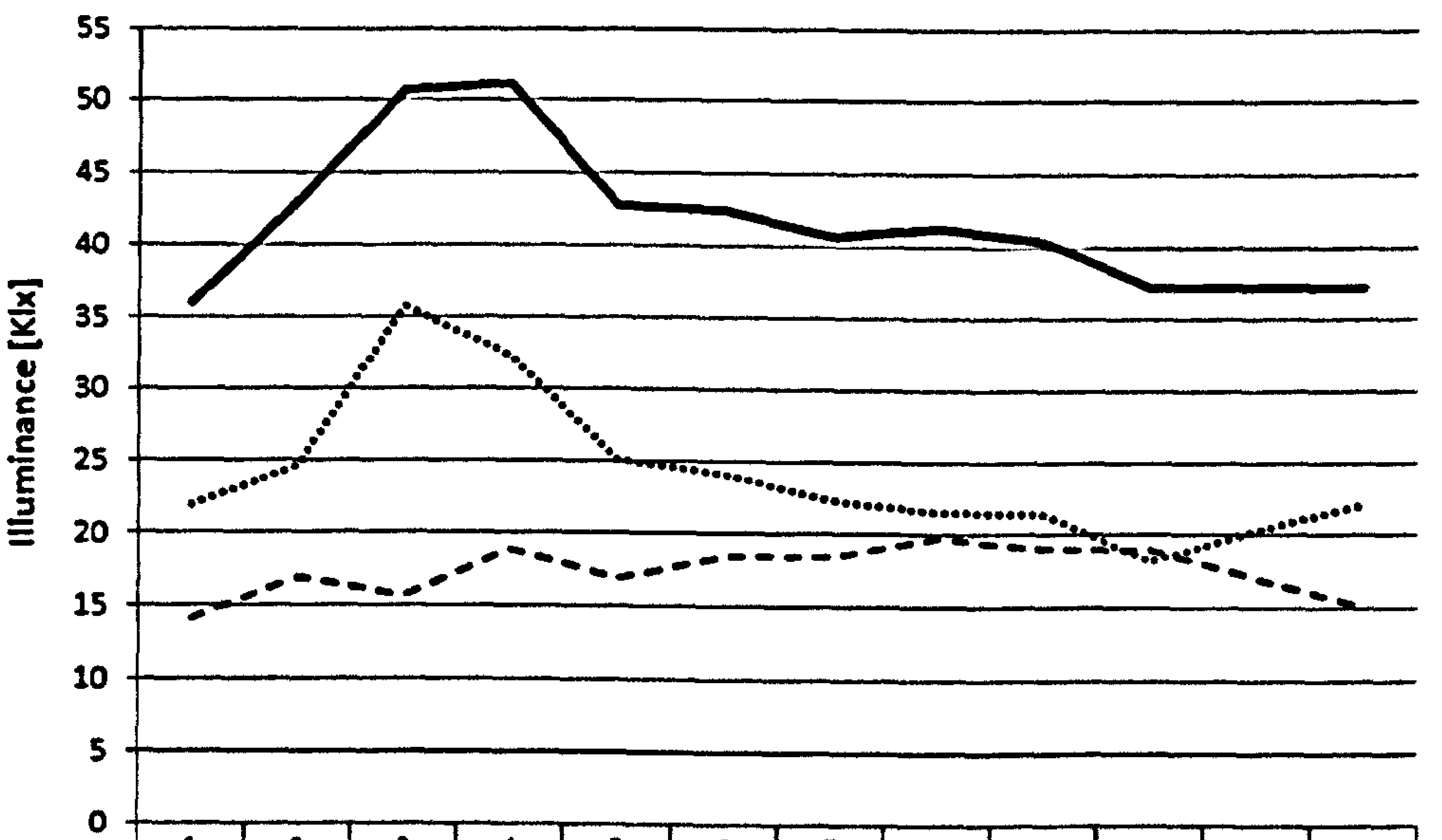
MONTH	BEAM ILLUMINANCE [Klx] HOUR													
	06h00	07h00	08h00	09h00	10h00	11h00	12h00	13h00	14h00	15h00	16h00	17h00	18h00	*Average*
	HO CHI MINH CITY													
1	0.0	1.4	5.9	18.7	39.9	55.7	63.2	50.0	28.5	16.0	4.0	0.9	0.0	*21.9*
2	0.0	1.6	6.3	20.9	37.6	55.5	65.4	58.1	42.6	23.8	6.0	1.6	0.0	*24.6*
3	0.2	0.7	7.9	26.4	52.8	75.6	92.4	86.4	76.9	32.1	11.3	2.0	0.0	*35.7*
4	0.7	1.5	9.2	30.4	58.1	75.7	76.6	75.2	51.8	30.2	8.7	1.7	0.0	*32.3*
5	0.9	2.9	12.2	26.9	46.8	52.6	65.5	57.3	37.0	18.1	4.8	0.8	0.2	*25.1*
6	0.7	2.7	9.6	25.9	42.3	54.1	61.8	58.5	35.3	16.9	5.5	0.1	0.3	*24.1*
7	0.0	1.6	9.8	21.0	42.1	54.2	58.9	48.0	32.5	14.0	5.0	2.3	0.2	*22.3*
8	0.0	1.4	8.1	22.5	39.6	49.0	55.1	49.9	32.8	16.2	4.8	0.5	0.1	*21.5*
9	0.0	1.7	11.5	21.0	43.0	52.2	54.8	50.9	27.3	13.1	1.3	1.2	0.0	*21.4*
10	0.0	1.5	9.4	23.5	37.4	48.9	46.2	33.8	22.9	10.9	1.6	0.4	0.0	*18.2*
11	0.0	3.5	13.2	23.8	48.7	51.8	49.4	38.7	22.4	9.2	2.5	0.4	0.0	*20.3*
12	0.0	11.2	23.8	42.1	52.6	54.8	41.4	28.3	17.8	10.2	3.8	1.0	0.0	*22.1*

Table 2.3 Annual diffuse horizontal illuminance [Klx]

MONTH	DIFFUSE ILLUMINANCE [Klx] HOUR													
	06h00	07h00	08h00	09h00	10h00	11h00	12h00	13h00	14h00	15h00	16h00	17h00	18h00	*Average*
	HO CHI MINH CITY													
1	1.0	5.7	10.9	16.7	21.4	23.0	24.1	23.9	23.0	17.1	11.1	5.7	0.0	*14.1*
2	1.8	6.2	13.0	20.1	27.7	32.9	25.8	24.0	27.8	19.8	14.0	6.3	0.8	*16.9*
3	2.3	7.5	14.2	21.1	25.1	18.3	29.1	25.7	22.0	17.7	12.7	6.8	1.4	*15.7*
4	3.0	10.0	18.9	24.7	29.2	31.6	33.6	29.8	24.7	18.5	12.9	6.6	1.3	*18.8*
5	2.5	8.7	15.7	22.5	27.0	28.5	28.7	25.6	22.8	17.3	12.4	6.3	1.5	*16.9*
6	3.8	10.0	16.7	23.1	27.7	30.8	31.5	28.5	23.8	19.4	13.6	7.8	2.5	*18.4*
7	3.5	9.0	16.4	24.9	28.3	30.8	29.7	27.4	25.5	21.5	13.9	6.3	2.0	*18.4*
8	2.9	9.7	17.7	24.0	30.7	34.0	34.1	31.6	28.1	21.7	13.7	7.3	1.5	*19.8*
9	3.3	10.0	16.7	25.3	30.0	32.3	33.2	29.4	24.8	20.5	15.4	5.4	1.0	*19.0*
10	2.4	10.4	19.0	25.2	31.3	34.0	35.3	29.2	24.5	18.4	11.5	5.2	0.8	*19.0*
11	1.8	9.1	15.4	26.4	24.6	30.6	30.6	27.0	23.1	18.2	9.7	4.1	0.0	*17.0*
12	1.5	7.1	12.5	18.4	24.5	27.7	28.3	25.7	21.0	15.8	9.3	4.9	0.0	*15.1*

Table 2.4 Annual global horizontal Illuminance [Klx]

MONTH	GLOBAL ILLUMINANCE [Klx] — HOUR 06h00	07h00	08h00	09h00	10h00	11h00	12h00	13h00	14h00	15h00	16h00	17h00	18h00	*Average*
HO CHI MINH CITY														
1	1.0	7.1	16.8	35.4	61.3	78.7	87.3	73.9	51.6	33.1	15.1	6.6	0.0	*36.0*
2	1.8	7.8	19.3	41.0	65.5	88.4	101.2	92.1	70.4	43.6	20.0	7.9	0.8	*43.1*
3	2.5	8.2	22.1	47.5	77.9	103.9	121.5	112.1	79.1	49.8	24.0	8.8	1.4	*50.7*
4	3.7	11.5	28.1	55.1	87.3	107.3	110.2	105.1	76.5	48.7	21.6	8.3	1.3	*51.1*
5	3.4	11.6	27.9	49.4	73.8	91.1	94.2	82.9	59.8	35.4	17.2	7.1	1.7	*42.7*
6	4.5	12.7	26.3	49.0	70.0	84.9	93.3	87.0	59.1	35.3	19.1	7.9	2.5	*42.4*
7	3.5	10.6	26.2	45.9	70.4	85.0	88.6	75.4	58.0	35.5	18.9	8.6	2.3	*40.7*
8	2.9	11.1	25.8	46.5	70.3	83.0	89.2	81.5	60.9	37.9	18.5	7.8	1.6	*41.3*
9	3.3	11.7	28.2	46.3	73.0	84.5	88.0	80.3	52.1	33.5	16.7	6.6	1.0	*40.4*
10	2.4	11.9	28.4	48.7	68.7	82.9	81.5	63.0	47.4	29.3	13.1	5.6	0.8	*37.2*
11	1.8	12.6	28.6	50.2	73.3	82.4	80.0	65.7	45.5	27.4	12.2	4.5	0.0	*37.2*
12	1.5	18.3	36.3	60.5	77.1	82.5	69.7	54.0	38.8	26.0	13.1	5.9	0.0	*37.2*



	1	2	3	4	5	6	7	8	9	10	11	12
Beam Illuminance [Klx]	21.9	24.6	35.7	32.3	25.1	24.1	22.3	21.5	21.4	18.2	20.3	22.1
Diffuse Illuminance [Klx]	14.1	16.9	15.7	18.8	16.9	18.4	18.4	19.8	19.0	19.0	17.0	15.1
Global Illuminance [Klx]	36.0	43.1	50.7	51.1	42.7	42.4	40.7	41.3	40.4	37.2	37.2	37.2

Month

Figure 2.10 The annual beam, diffuse, and global horizontal Illuminance [Klx] of HCMC.

2.3.4. Sky conditions and Nebulosity

Solar radiation's properties and intensity change on entering Earth's atmosphere. In general, the Earth's atmosphere absorbs, blocks and redirects part of the solar radiation spectrum depending on the wavelengths. There are two factors that have a significant impact on the solar radiation: the distance travelled by sunlight which is a function of latitude and the properties of the Earth's atmosphere which varies from place to place. Similarly many factors contribute to local atmospheric properties, e.g. the presence of water vapour, topography and air pollution. Climatic research of daylight should study carefully the two important factors of sky conditions: atmospheric transparency and nebulosity.

2.3.4.1. Atmospheric transparency

Atmospheric transparency index, P_i, is often used to evaluate the impact of the atmosphere on solar radiation. It measures the percentage of solar radiation reaching the Earth's surface. P_i values for HCMC are shown in figure 2.13. It is lowest during the Dry season and highest in the Wet season.

As mentioned before HCMC has a tropical climate with a high level of humidity. This means that level of water vapour in the atmosphere is high and this would scatter and diffuse a lot of daylight. Apart from this, the city's extensive system of river and canals should also be considered. The *Relative Humidity* level *RH* [%] remains fairly constant over time varying within the range of 70 to 80%. Therefore, it can be suggested that the impact of water vapour on daylight properties does not change much over the year.

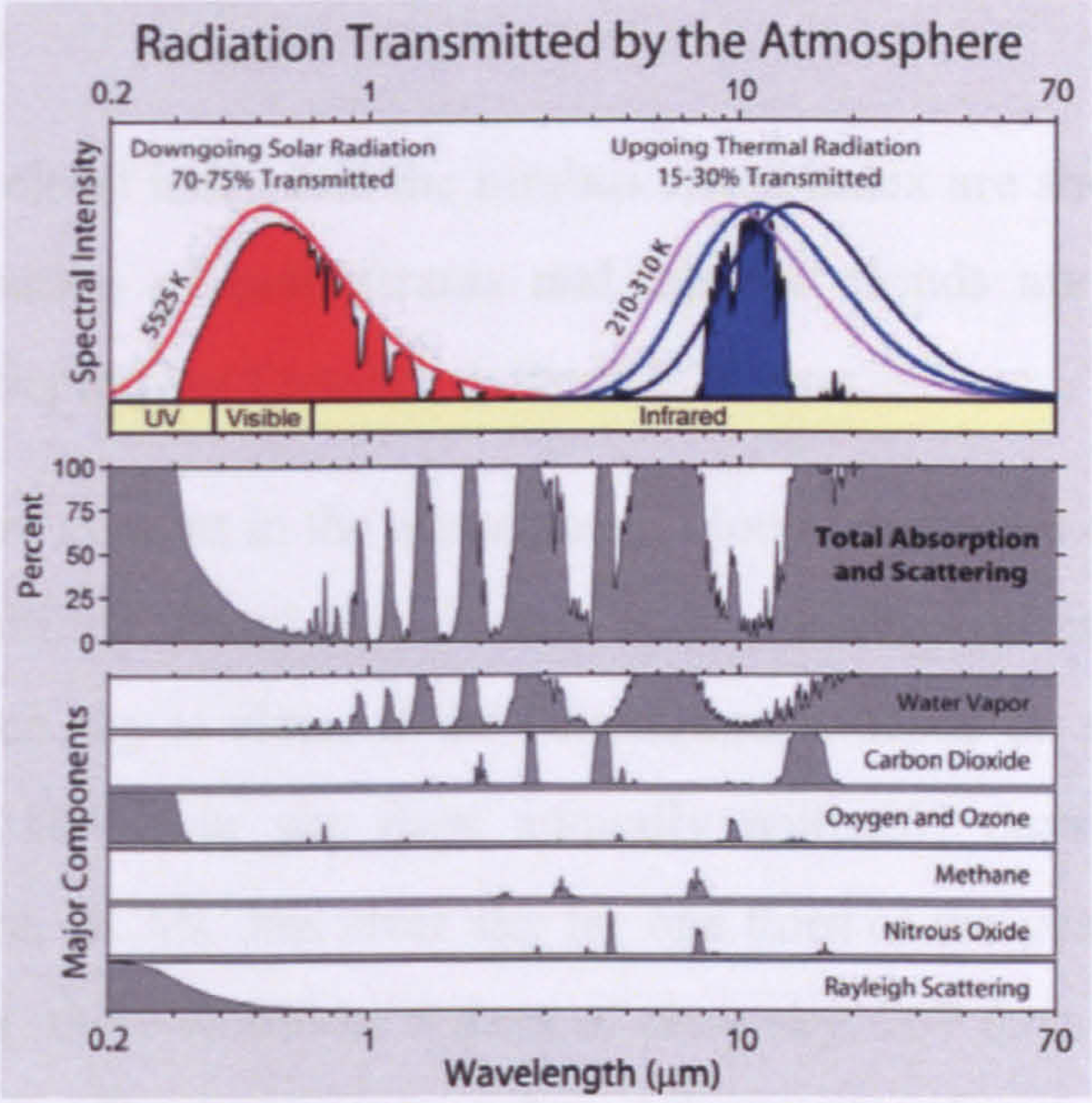


Figure 2.11 Radiation transmitted by the atmosphere. (Rohde, 2007)

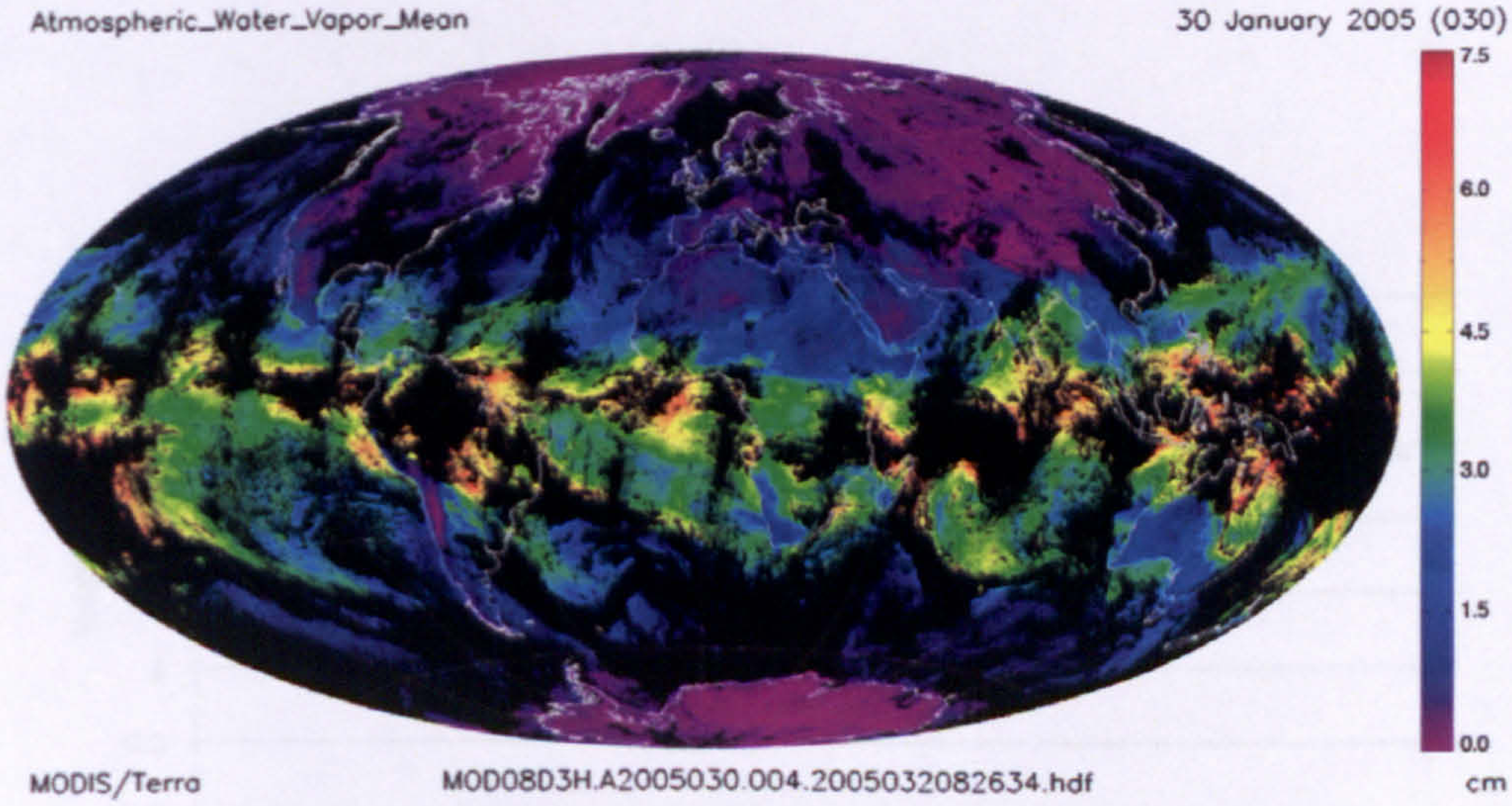


Figure 2.12 World map of mean atmospheric water vapour. (MODIS, 2007)

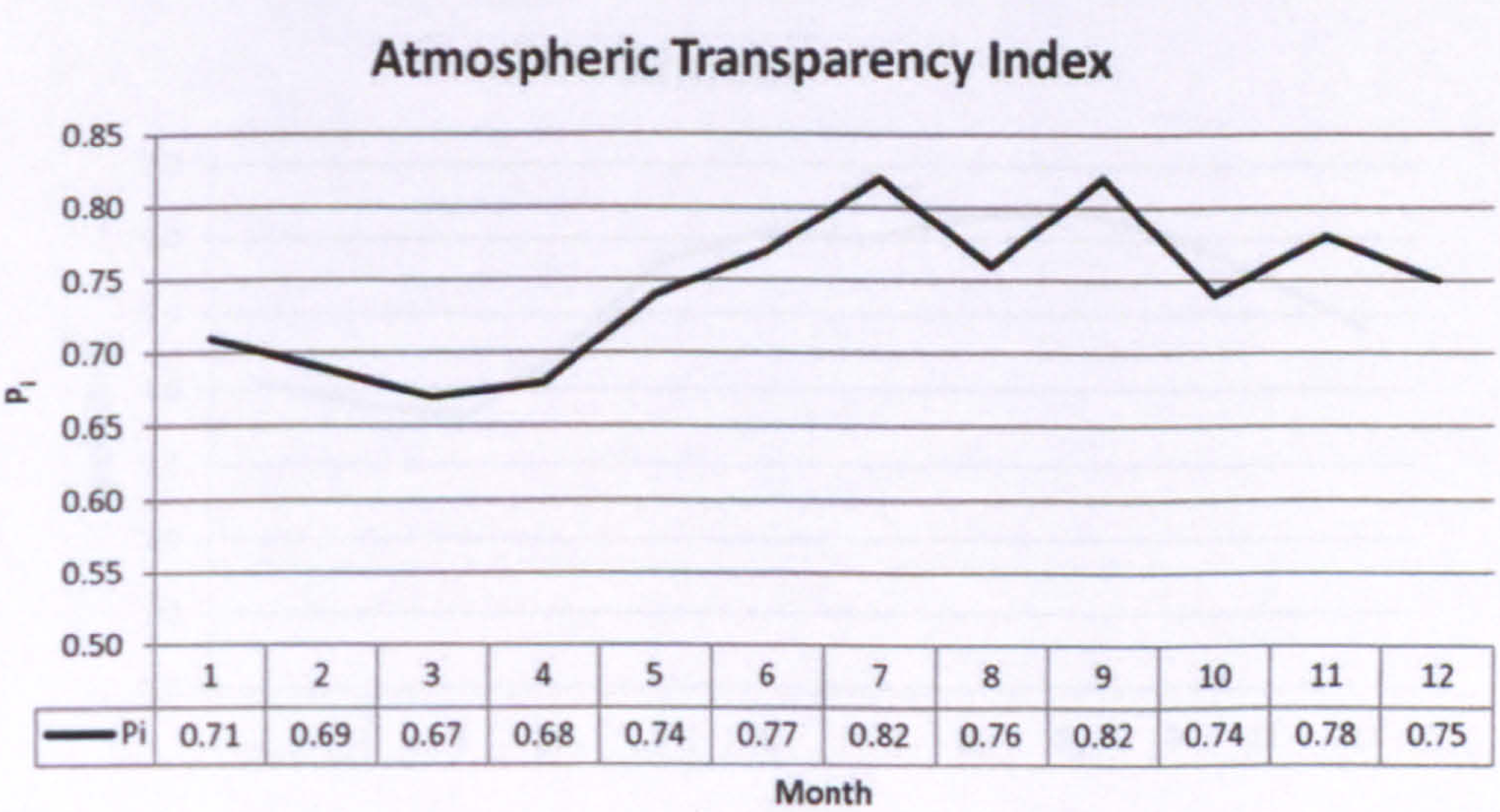


Figure 2.13 The atmospheric Transparency Index of Ho Chi Minh City.

2.3.4.2. Nebulosity

The annual stratus cloud index and the nimbus cloud index are shown in figure 2.14. The annual distribution of both stratus and nimbus clouds are quite similar, the highest appears in September/October in the Wet season.

As with the moisture content in the atmosphere, cloud conditions can have an impact on daylight availability. From this index, it is possible to estimate the annual sunshine hours when sky is clear. If the calculation is based on stratus cloud, there are approximately 104 clear sky days annually with 261 days of average cloud condition. Therefore, HCMC has clear sky for one third of the year. If we look at the nimbus cloud index, there would be 8 days of clear sky, 267 days of half cloudy and 90 days of cloudy sky. Hence it can be inferred that sunny climate dominates HCMC daylight climate.

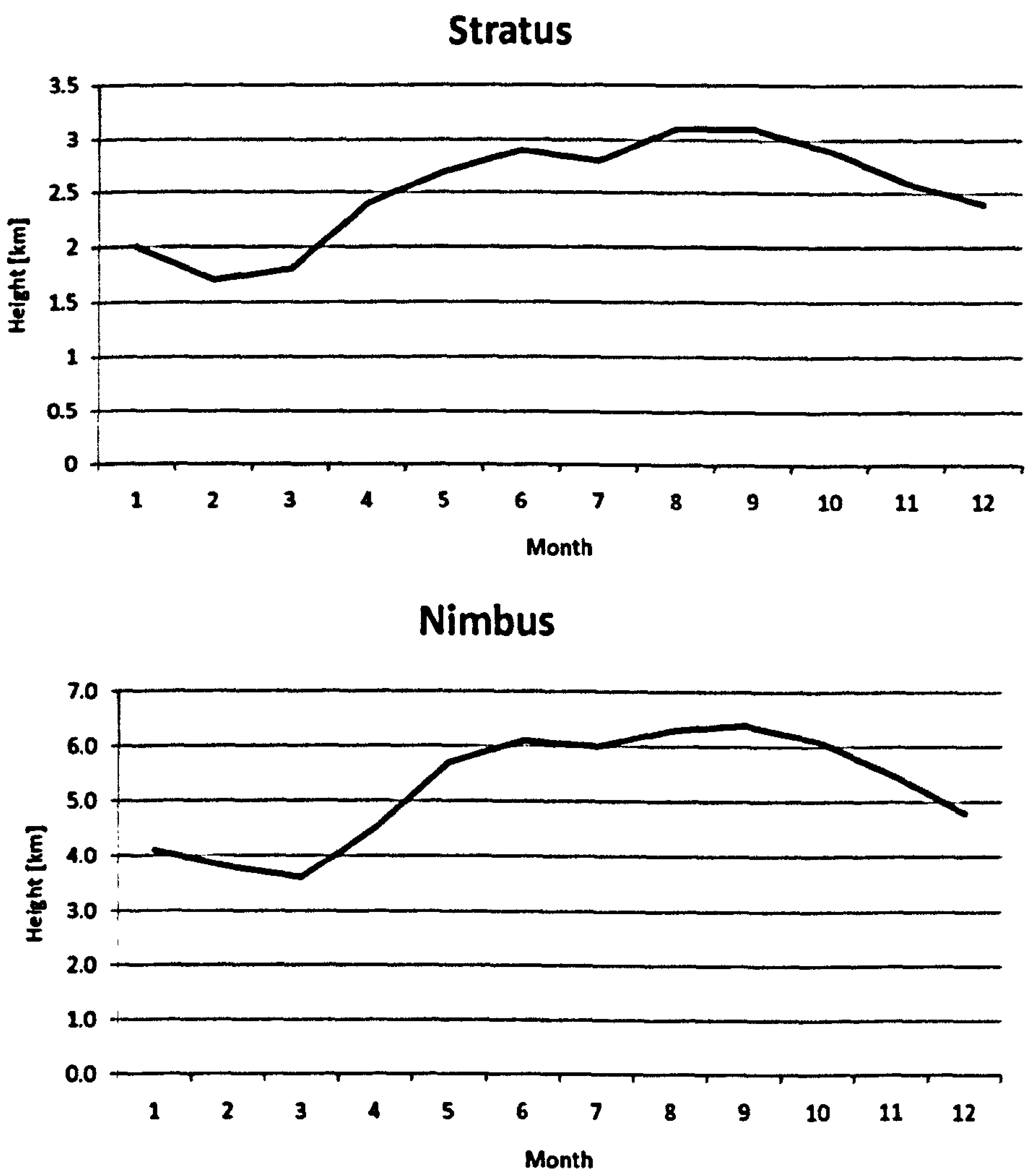


Figure 2.14 The annual distribution of mean stratus (above) and nimbus (below) cloud index.

2.3.4.3. Sunshine hour

The average annual sunshine hours of HCMC are 2497 hours. In comparison, annual sunshine hours in London-UK are 1200 hours, and Hanoi-North Vietnam has 1681 sunshine hours annually. The month with highest sunshine hour is March (269 hours) and the lowest is September (163 hours). In March, the mean daily sunshine hour reaches 7.7 hours; while in September this would be 6.8 hours. However, most of the sunshine hours appear during the working hours (9h00 to 17h00). Annually, there are more than seven months which have mean daily sunshine hours exceeding six hours. In these seven months, the total sum of sunshine hours exceed 1627 hours, while during the other five months there are 870 hours of sun.

Study of the HCMC cloud and sunny indices show that for two thirds of the year (267 days), the sky is intermediately cloudy. Nguyen Thanh Luong suggests that the intermediate sky, a somewhat hazy variant of the clear sky, can be used as sky model in daylight calculation (Nguyen, 1990). The availability of sunlight is frequent and with high intensity. Therefore, using shading devices are likely to be recommended for buildings in HCMC.

Table 2.5 Estimates of sunshine day based on percentage of sunshine hour.

HO CHI MINH CITY										
MONTH	*no Sun*		*1 to 3 hours*		*3 to 6 hour*		*6 to 9 hours*		*over 9 hours*	
	Day	*%*	*Day*	*%*	*Day*	*%*	*Day*	*%*	*Day*	*%*
1	0.7	2.2	1.8	5.8	5.3	17.1	13.3	42.9	9.9	31.9
2	0.4	1.4	0.7	2.5	3.1	11.1	10.4	37.1	13.4	43.2
3	0.4	1.3	0.7	2.2	3.2	10.3	11.9	38.3	14.8	47.8
4	0.3	1.0	1.2	4.0	5.4	18.0	13.0	40.3	10.1	33.7
5	0.5	1.6	4.2	13.2	9.0	29.0	12.8	41.3	4.5	14.5
6	0.8	3.7	4.8	16.0	9.7	32.3	10.9	36.3	3.8	12.7
7	1.6	5.2	5.5	17.7	10.0	32.3	10.0	32.3	3.9	12.6
8	1.0	3.2	6.4	20.7	9.2	19.7	11.0	35.3	3.4	11.0
9	1.5	5.0	6.5	21.7	10.1	33.7	8.9	29.6	3.0	10.0
10	1.8	5.8	4.7	15.2	9.9	31.9	10.9	35.1	3.7	11.9
11	0.8	2.7	2.8	9.3	7.7	25.7	12.9	43.0	5.8	19.3
12	0.6	1.9	2.4	7.7	5.4	17.4	15.0	48.4	7.6	24.5
Year	10.4		41.7		88.0		141.0		83.9	

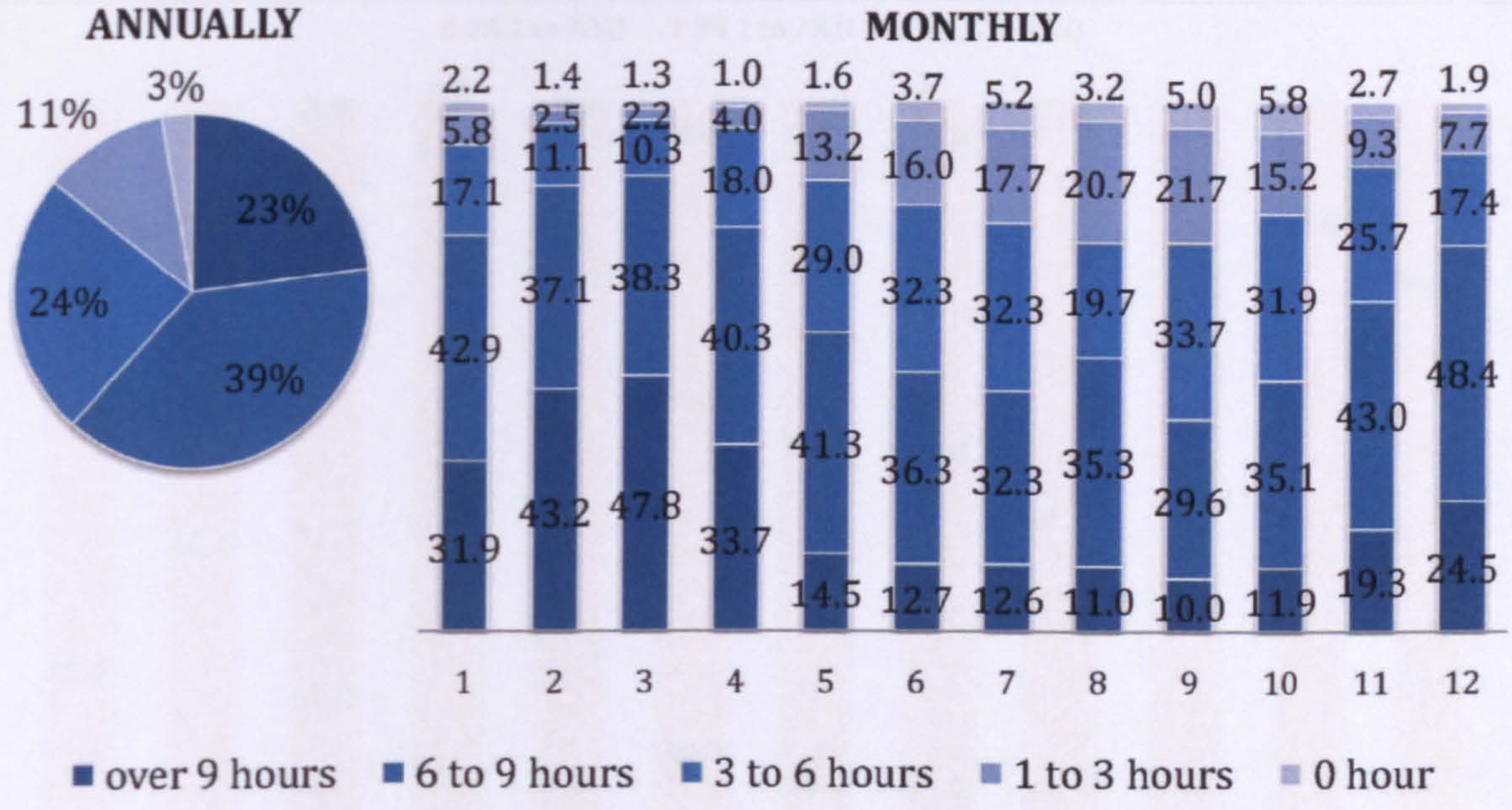


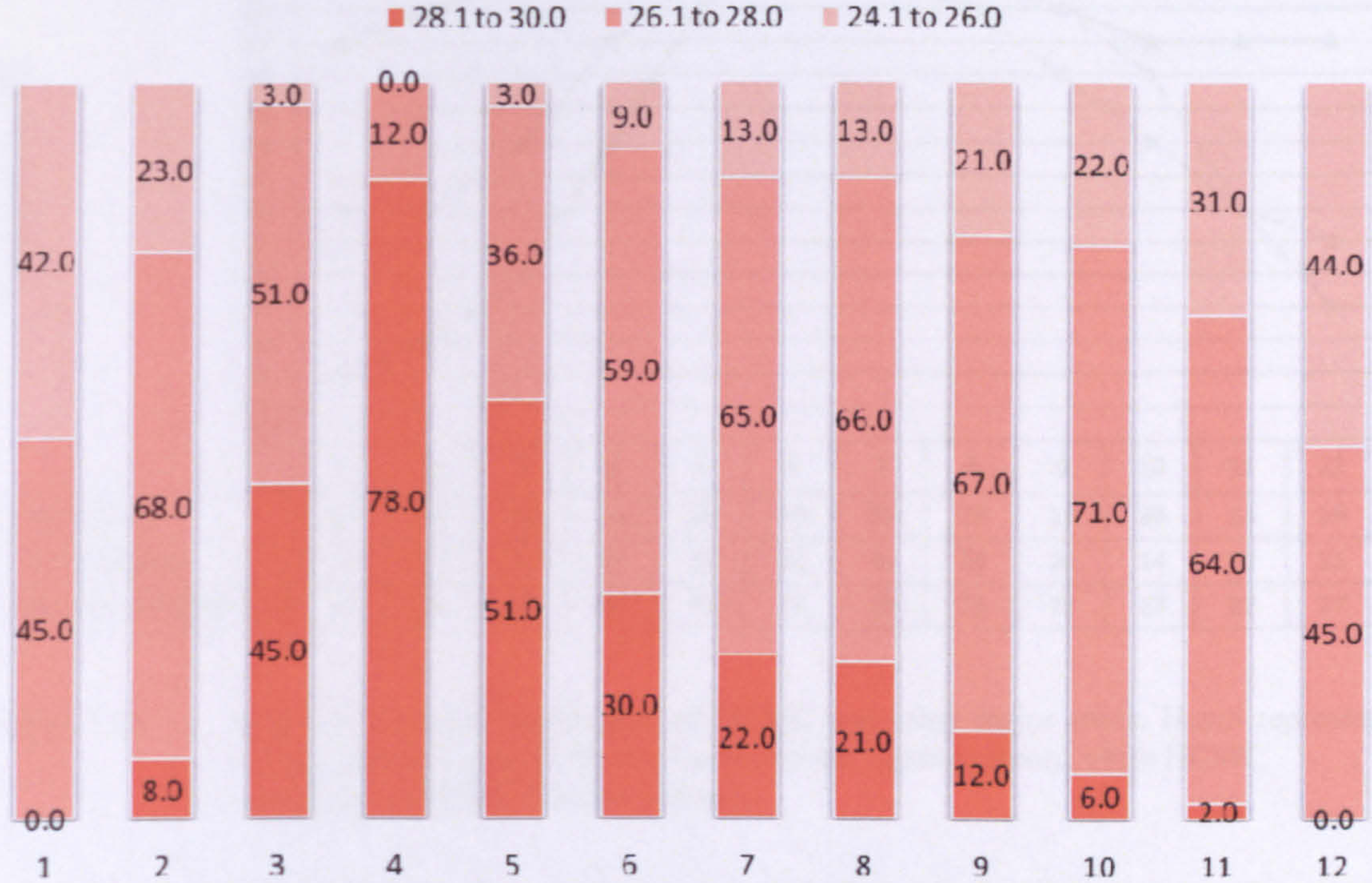
Figure 2.15 Annual frequency of sunshine hours [%] of HCMC.

2.3.5. Temperature

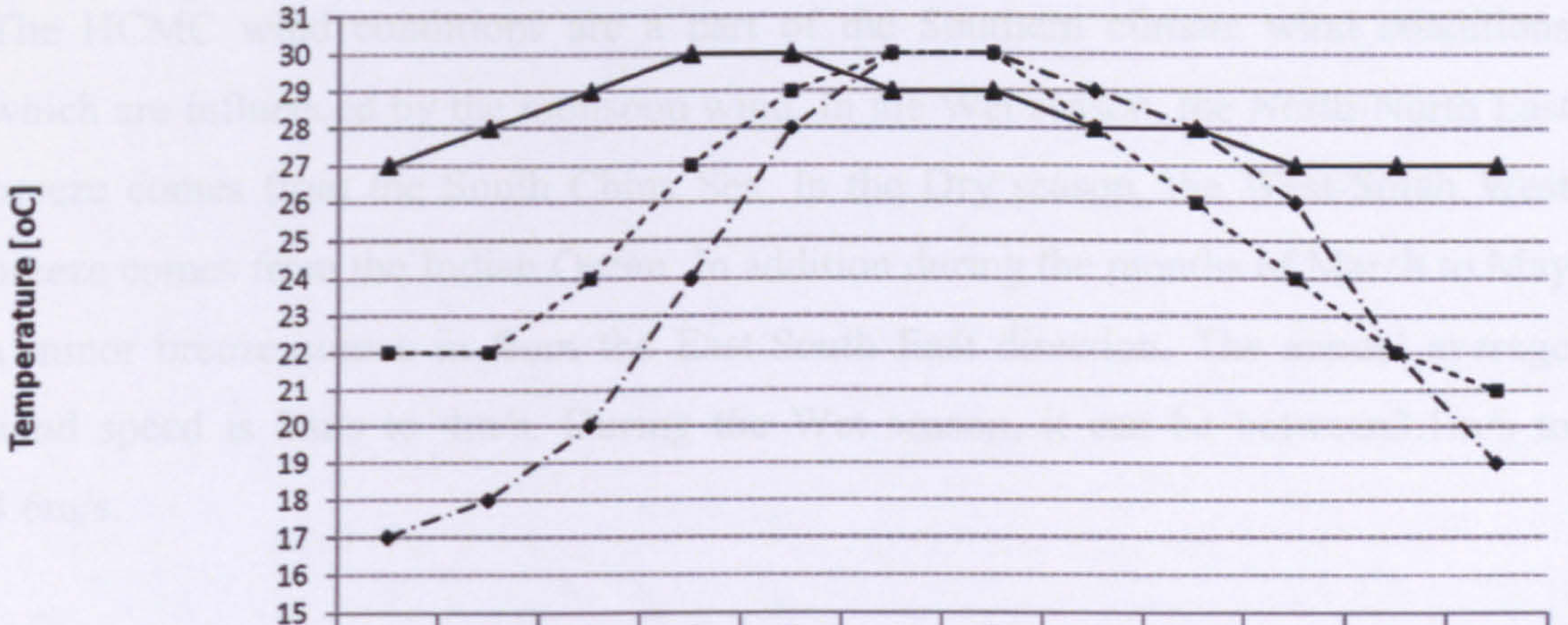
Due to the strong solar radiation and high number of sunshine hours, the average monthly air temperature is quite high (from 25.7°C to 28.8 °C). Daily average temperature is rarely below 20 °C, and it is above 25 °C for 94% of the year. The highest monthly mean air temperature often is recorded in April (34.5°C) and the lowest is recorded in January (21.1°C). The daily mean temperature of the hottest day is from 31.7 °C to 35.6°C. During the Dry season, it varies between 9.2-10.6°C while in the Wet season it varies between 7.2 -8.6°C. Annually, the mean range is around 8.7°C. The range is wider in the Dry season than in the Wet season.

Table 2.6 shows the monthly frequency percentage of temperature range in Ho Chi Minh City. It seems that most of the time, the temperature varies in the range of 26.1 to 28.0°C. For half of March and May and nearly 80% of April, the temperature usually is as high as 28°C.

Table 2.6 Temperature range [°C] and frequency [%] of HCMC.



HO CHI MINH CITY						
MONTH	Temperature range and Frequency					
	24.1 to 26.0 °C		*26.1 to 28 °C*		*28.1 to 30°C*	
	Day	*%*	*Day*	*%*	*Day*	*%*
1	13.0	42.0	14.0	45.0	-	-
2	7.0	23.0	19.0	68.0	2.0	8.0
3	1.0	3.0	16.0	51.0	14.0	45.0
4	-	-	4.0	12.0	23.0	78.0
5	1.0	3.0	11.0	36.0	16.0	51.0
6	3.0	9.0	18.0	59.0	9.0	30.0
7	4.0	13.0	20.0	65.0	7.0	22.0
8	4.0	13.0	21.0	66.0	7.0	21.0
9	6.0	21.0	20.0	67.0	4.0	12.0
10	7.0	22.0	22.0	71.0	2.0	6.0
11	9.0	31.0	19.0	64.0	1.0	2.0
12	14.0	44.0	14.0	45.0	-	-



	1	2	3	4	5	6	7	8	9	10	11	12
HANOI	17	18	20	24	28	30	30	29	28	26	22	19
DANANG	22	22	24	27	29	30	30	28	26	24	22	21
HO CHI MINH CITY	27	28	29	30	30	29	29	28	28	27	27	27

Figure 2.16 Monthly mean air temperature of HCMC and other major cities. Hanoi represents the Northern climate; Da Nang represents the Central region, while HCMC represents the typical Southern climate.

2.3.6. Wind Conditions

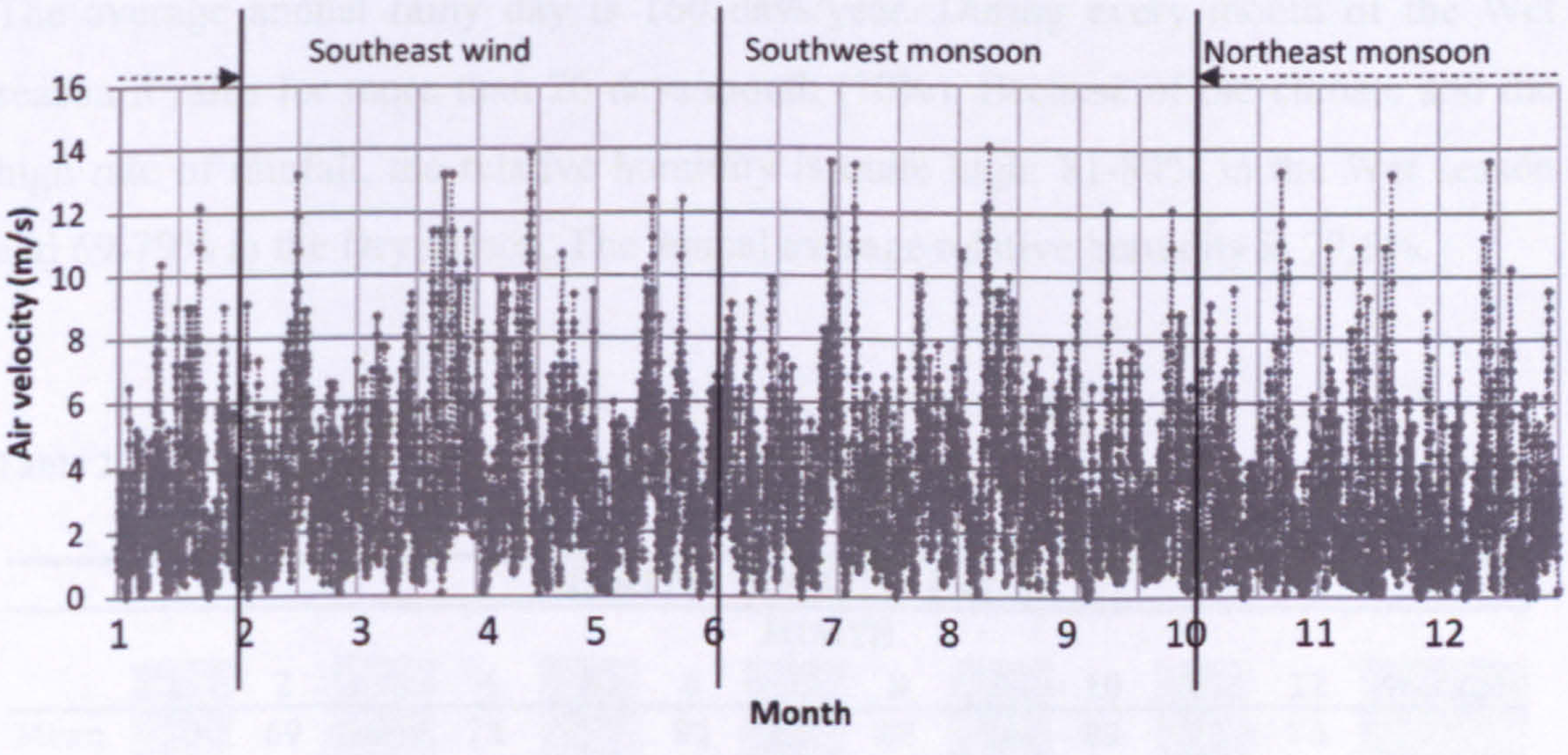


Figure 2.17 Wind speed and wind direction of HCMC (Le, 2010)

The HCMC wind conditions are a part of the Southern climate wind conditions which are influenced by the monsoon wind. In the Wet season, the North-North East breeze comes from the South China Sea. In the Dry season, the West-South West breeze comes from the Indian Ocean. In addition during the months of March to May a minor breeze comes in from the East-South East direction. The annual average wind speed is 2m/s to 4m/s. During the Wet season, it can be between3.1m/s to 4.6m/s.

2.3.7 Humidity and Rainfall

The distribution of rainfall varies across the city. Rainfall is higher in the South East (1800mm to 2000mm) and lower in the North-West (1200 mm to1500 mm). As mentioned above the climate of the country is divided into two seasons and 90% of the rainfall happens during the seven months of the Wet season (May to November). Furthermore, during these seven months, the rainfall distribution also varies being highest in June and September (330 mm) and lowest in August. During the Dry season, November-December has lowest rainfall (56 mm).

The average annual rainy day is 160 days/year. During every month of the Wet season it rains for more than 20 days/month (70%). Because of the climate and the high rate of rainfall, the relative humidity is quite high: 81-84% in the Wet season and 69-79% in the Dry season. The annual average relative humidity is 79.5%.

Table 2.7 Monthly Relative Humidity *RH* [%] of HCMC

RELATIVE HUMIDITY [%]													
	MONTH												
	1	2	3	4	5	6	7	8	9	10	11	12	*Average*
Mean	70	69	69	71	77	81	82	83	84	83	79	75	*77*
Max	99	99	98	99	99	100	100	100	100	100	100	100	*100*
Min	23	22	20	21	33	30	40	44	43	40	33	29	*20*

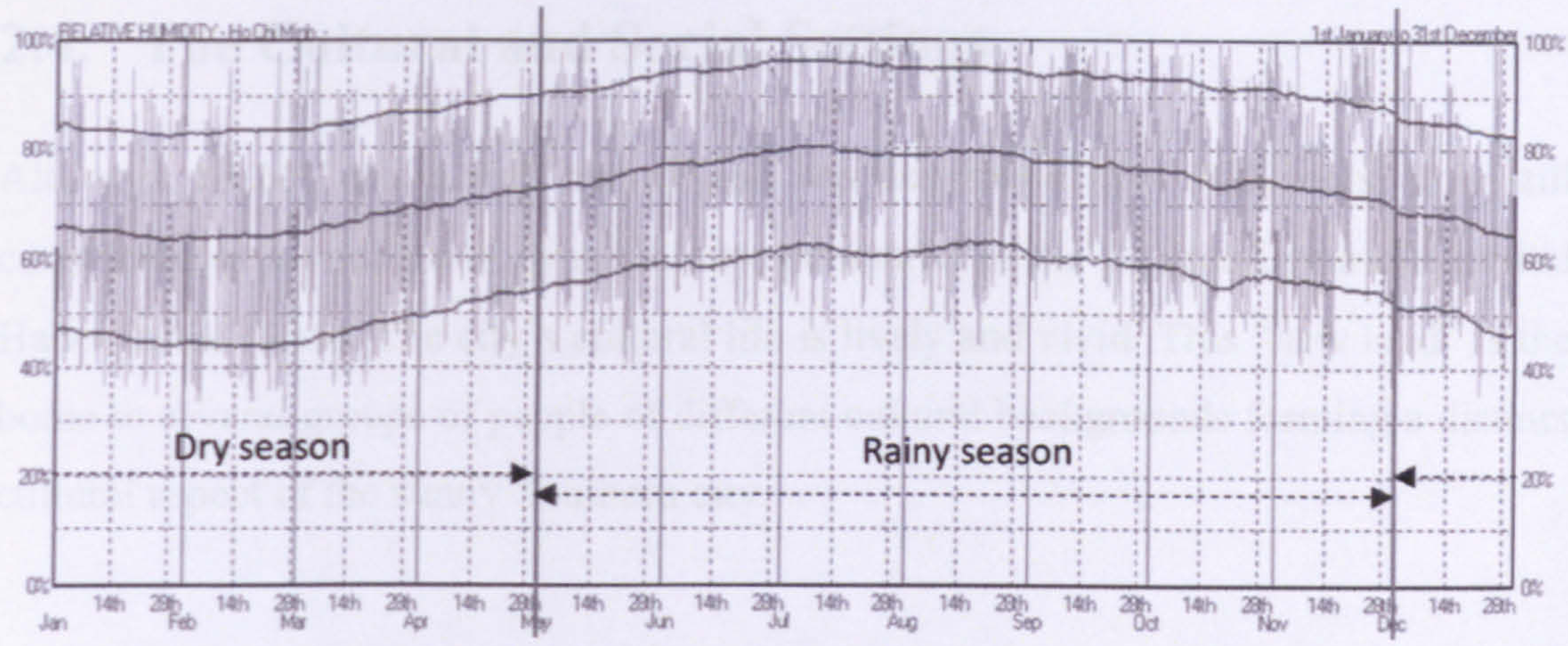
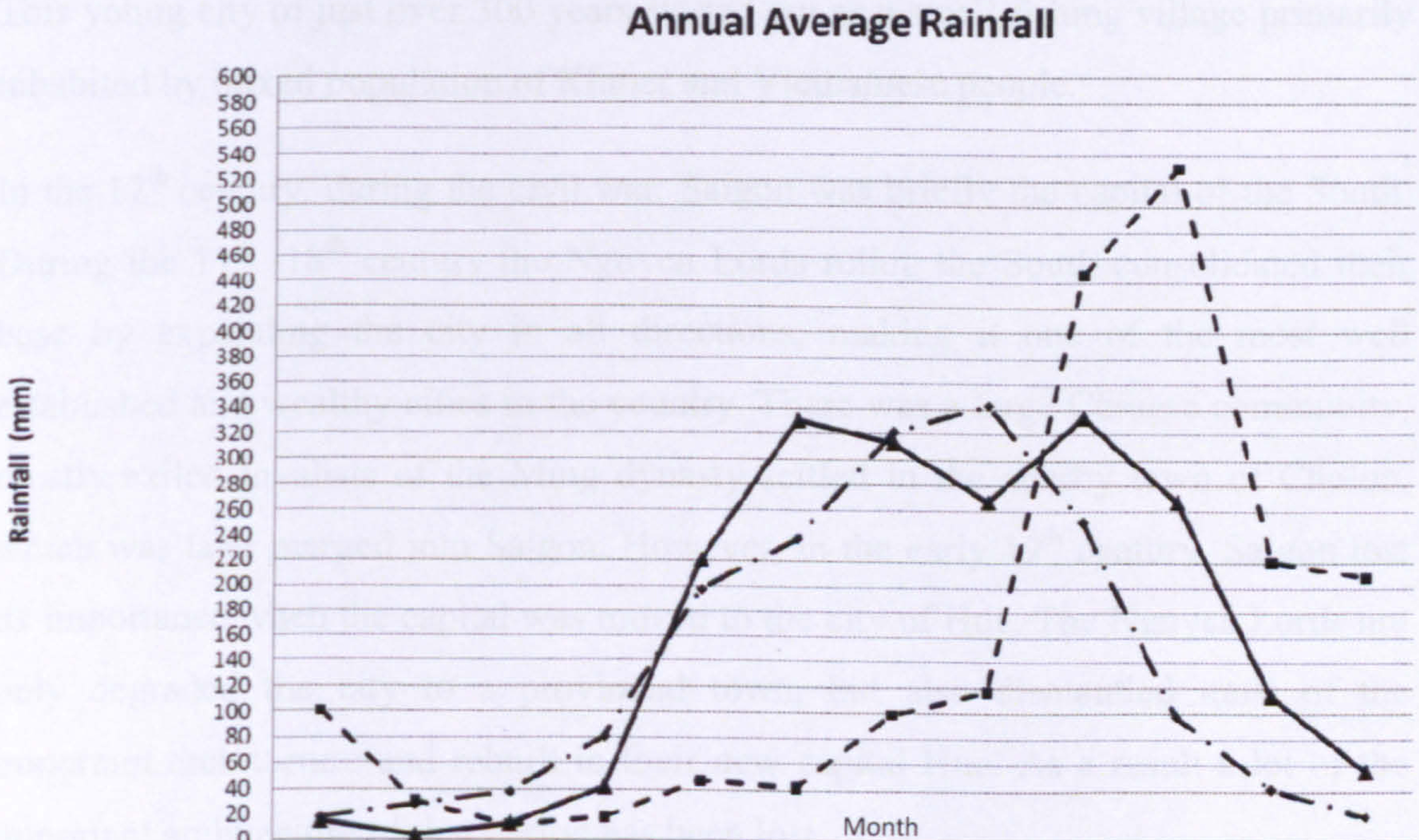


Figure 2.18 Monthly data of mean Relative Humidity *RH* [%] of Ho Chi Minh City (Le, 2010)



	1	2	3	4	5	6	7	8	9	10	11	12
HANOI	18	28	38	81	197	238	322	343	252	98	42	21
DA NANG	101	31	12	18	47	42	99	117	447	530	221	208
HO CHI MINH CITY	15	4	13	42	221	331	314	268	334	268	114	56

Figure 2.19 Average Rainfall [mm] of Ho Chi Minh City, Da Nang, and Ha Noi.

2.4. The Cultural and Social Settings

Although HCMC has a rich history and has developed over 300 years, it is still considered as a young and dynamic city, compared to the thousand year old capital Hanoi in the North. The city's cultural life is lively and vivid. This "new land" is the home to several groups of people of different cultural backgrounds forming a distinct cultural aspect of the sunny Southern city.

2.4.1. Brief history of Ho Chi Minh City

The first form of city establishment that has been acknowledged in the historical documents of Vietnam dates back to 1698. Its strategic location allowed the city to grow into a regional trading post which later developed into an important seaport. This young city of just over 300 years started out as a small fishing village primarily inhabited by mixed population of Khmer and Vietnamese people.

In the 17^{th} century, during the civil war, Saigon was briefly the capital of the South. During the 17^{th} -18^{th} century the Nguyen Lords ruling the South consolidated their base by expanding the city in all directions, making it one of the most well established and wealthy cities in the country. There was a large Chinese community, mostly exiled loyalists of the Ming dynasty settled in the nearby town of Cholon, which was later merged into Saigon. However, in the early 19^{th} century, Saigon lost its importance when the capital was moved to the city of Hue. The Nguyen Lords not only degraded the city to a provincial town, but also dismantled most of the important architecture and rebuilt in their new capital Hue. As a result a lot of the important architecture of that period has been lost.

In the early 19^{th} century, Saigon was one of the first Vietnamese cities to be colonized by the French (i.e. the siege of Saigon in 1859). They demolished most of the ancient citadel along with many traditional Vietnamese buildings to eliminate anti-colonial resistance and to make way for a new colonial architecture. The new city plans implemented by the French were very European in nature and the architecture was heavily influenced by Western architecture. Several buildings constructed during this period exist till today. The city grew into an important political, commercial and cultural centre of the colonial French Indochina; it was once called "Paris in the Orient".

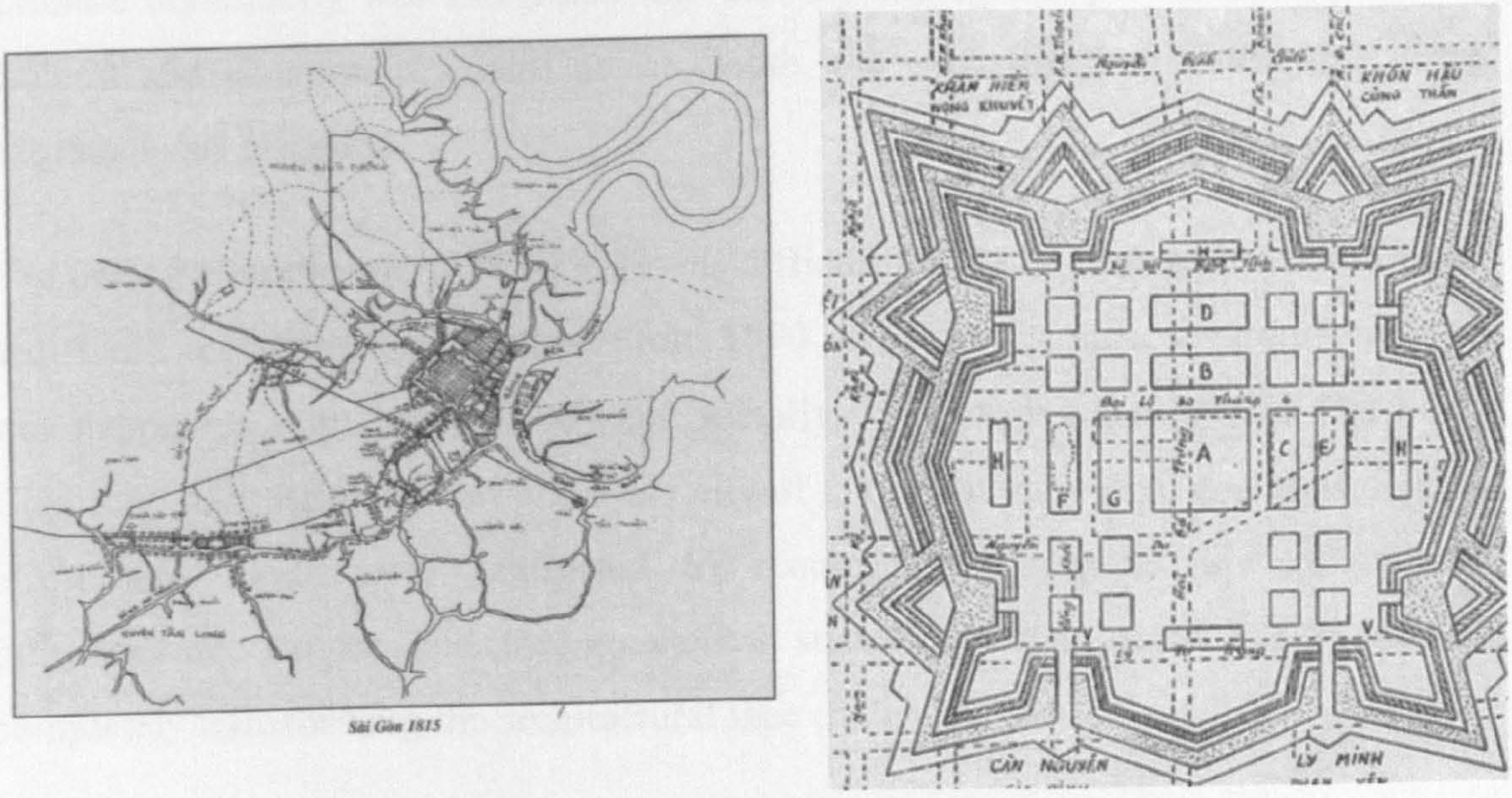


Figure 2.20 Early map of the citadel and Saigon and Cholon area in 1815. (Truong, 1997)

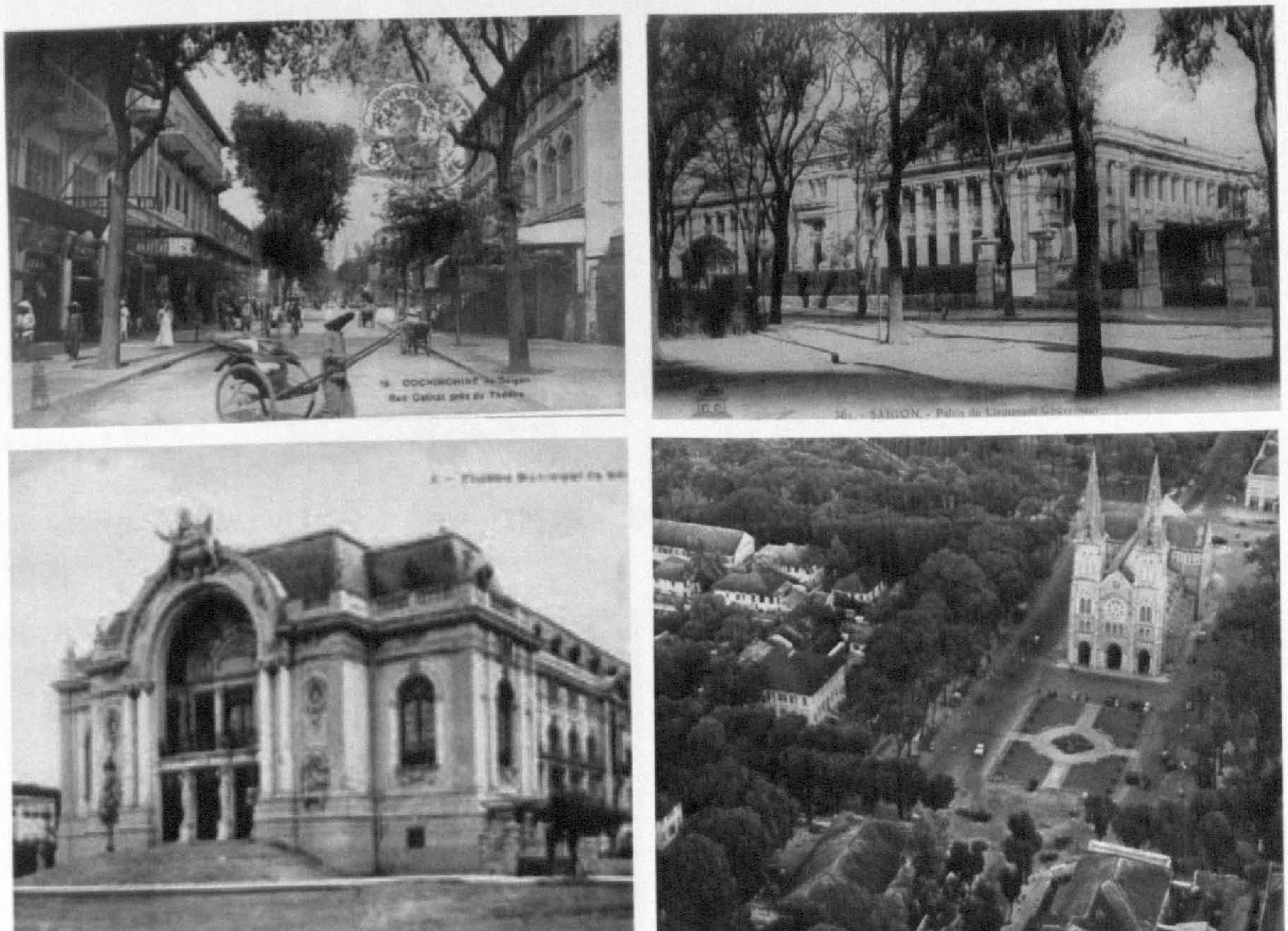


Figure 2.21 Saigon in the 19th century under the French colonial occupation. (Nguyen, 2009)

In the early 20th century, Saigon was once again made the capital of the South Vietnam during the Vietnam War (1945-1975). Cholon town along with its large Chinese community was integrated into the city during this period. As a political, cultural and economical centre of the South, the educational infrastructures were upgraded and extended.

The period after the war (1975-1990) was difficult for the country as it went through a difficult reconstruction process. From 1990 onwards a significant transformation was happening both economically and socially. Saigon, renamed as Ho Chi Minh City, took back its role as an important city of the Southern region, and considerable effort and funds were redirected to renovate and expand the educational infrastructure. Private and foreign capital started pouring into the city thereby completely transforming the architectural face of the city.

Figure 2.22

Downtown Saigon in 1966. (Briggs, 2009)

Figure 2.23

Aerial view of Saigon in 1960s. (Briggs, 2009)

Figure 2.24 Downtown Saigon in 2010. (Panoramio, 2010)

2.4.2. The cultural and social influences

HCMC is a young city and its development was influenced culturally and socially by immigrants from different backgrounds. The main influences are the Vietnamese Chinese, Western, Khmer and Indians.

2.4.2.1. The Vietnamese influence

Vietnamese, mainly of Kinh ethics, form the main population of the city. They bring with them their unique culture originally developed a thousand years ago in the Red river and the central coast. The Vietnamese Nguyen Lords arrived in Saigon in the 17th century and expanded it to a populous and wealthy trading port. New houses, villages and temples were built in the Vietnamese traditional styles. Buddhism became the main Vietnamese religion. Civil life in the 17th-19th century was still dominated by Confucianism.

Figure 2.25 Examples of 17th-18th century traditional Vietnamese architecture in HCMC. (Truong, 1997)

Vietnamese culture is among the oldest Asia Pacific cultures and is based on the agricultural civilization of wet rice cultivation. The origin of its culture can be traced back to before the Dong Son period which has defined the aspects of early Vietnamese civilization. There is very little known about education from this early period. Between 111 BC and 938 AD the country witnessed long periods of domination and relations with its powerful northern neighbour, China. The latter resulted in Vietnam being historically included into the East Asian Cultural Sphere that included a profound turn to Confucianism. Although the Vietnamese education system was established very early (since 11th century), Confucianism has had a dominant influence on the thousand years of the country's development. This Confucian ideology still has a large influence on modern civil life (Tran, 2001).

2.4.2.2. The Chinese influence

Chinese are among the most important minorities in HCMC. They emigrated to HCMC in the 17th century mostly due to the political change in China when the Manchurian Qing dynasty dethroned the Han Ming dynasty. The Chinese brought with them a rich Chinese, predominantly Cantonese, culture. However, they concentrated in the Cholon town area, and their influences can be seen more in cuisine, religion and music rather than on architecture. As mentioned above HCMC lost its importance during the early 19th century when the Nguyen Lords won the war and moved their capital to Hue. Many of the important buildings built in traditional styles were dismantled and rebuilt in Hue. What was left of the traditional buildings was destroyed by the colonial French and by the wars.

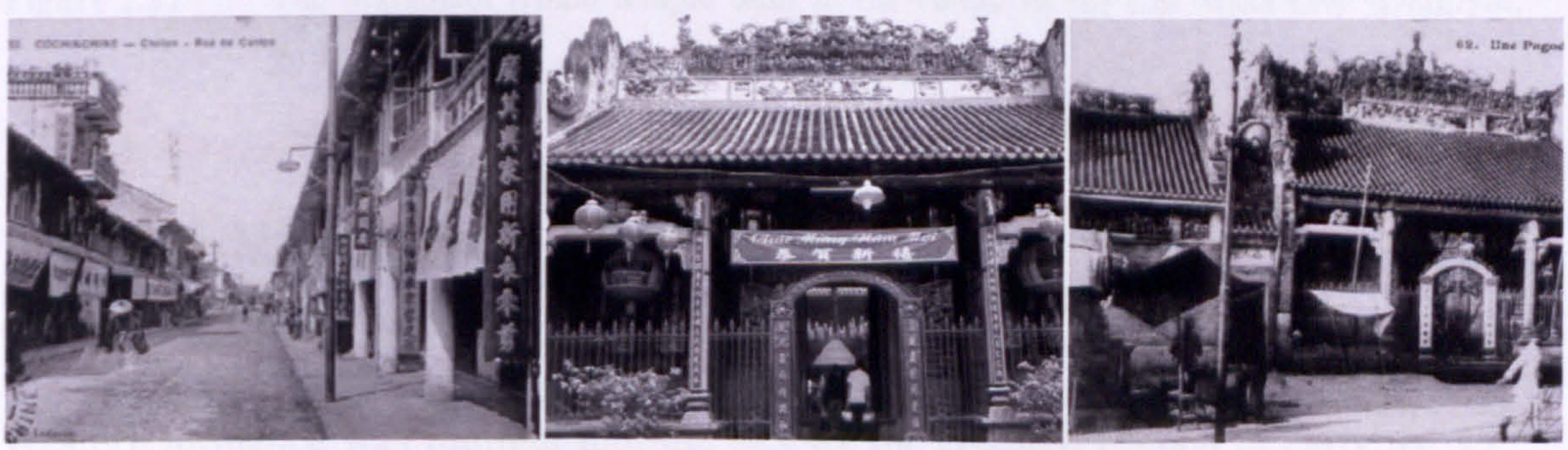


Figure 2.26 Chinese town built in Cho Lon area (Thanh Nien News, 2009)

2.4.2.3 The Indian – Khmer Influence

Before the official establishment of the city in the 17th century, Saigon was a fishing village built on swamp land. Early history shows that the Southern territory was comprised of several ancient pre- Angkor Indianized kingdoms, the most notable being the Funanese kingdom. The remains of their culture can be found at the archaeological excavations at the ancient port of Oc Eo. Hinduism and Buddhism were the main religions of the Funanese. Historic documents report the Funanese as *"people who lived on stilt houses, cultivated rice and sent tributes of gold, silver, ivory and exotic animals"* (Pelliot, 1903).

After the decline of Funam Kingdom in the 7^{th} century, this vast southern land was inhibited by the Khmer people. Saigon at that time was known as Prey Nokor. The influences of Indian and Khmer culture are more dominant in the Mekong Delta which is home to the larger Khmer population rather than in HCMC. In the city several Hindu temples still stand, and Indian-Khmer food is quite popular and makes up part of the Vietnamese Southern cuisines.

Figure 2.27 The Mariaman Hindu temple built in the centre of Ho Chi Minh City (Dragfyre, 2010).

2.4.2.4 The Western influence

Western influence was brought into the city by the colonial French in early the 19^{th} century. Current lifestyle shows that the Vietnamese and French influences are most dominant. Saigon was briefly the capital of the French Indochina Colony. The westernization process was furthered in the 20^{th} century through the American involvement in Vietnam. Christianity was introduced to Vietnam in the early 19^{th} century and it grew rapidly into one of most the important religions. Westernized palaces, theatres and cathedrals were built alongside French styled boulevards. However, the French influence was mixed with local cultures forming a new variation, often referred to as Indochina.

Figure 2.28

Saigon city centre in the late19th century, featuring colonial French buildings. (Nguyen, 2009)

Figure 2.29

Downtown Saigon in 1969. (Briggs, 2009)

Figure 2.30. Modern downtown HCMC featuring architectures built in different periods. (Do, 2009)

2.4.3. The development of education systems in HCMC

Education plays a very important role in Vietnamese civil life. Traditionally, scholars and education have always been regarded as the most valuable assets of the country. In 2007, an estimated 18-20 % of the national budget was allocated to education and training (EduNet, 2007). Although Saigon was officially established in the 17th century, its educational foundation has inherited the rich history of Vietnam's educational development. This was established in the North dating back to the 11th century when the first university was built in 1070 (Vietnam Institue of History, 2007).

2.4.3.1. Brief review of the History of Vietnam's educational development

2.4.3.1.1. The early establishment of education in Vietnam

The first foundation of education was established during the reign of the Ly dynasty (1010 - 1225 AD). After gaining independence from the Chinese, the cultural and social development of the country started flourishing.

The first Vietnamese University, Quốc Tử Giám (meaning Imperial Academy), was founded in 1070. Regular examinations were held every three years to select capable commoners for government positions. However, access to education was limited to nobles, royalty and other members of the elite and this was mostly under private tutors rather than at an established public system (Vietnam Institue of History, 2007). The cultural and civil life of Vietnam during the Ly Dynasty (1010-1225 AD) and Tran Dynasty (1225-1400 AD) was heavily influenced first by Buddhism and then by Confucianism and Taoism. Buddhist temples were extensively built across the country.

In the 15th century, the Chinese influence was considerably reduced. However, the ruling Le dynasty strictly applied Confucianism to civil life in order to stabilise the country. Buddhism and Taoism were at this stage, out of favour. The education system was greatly extended to the commoners and they were allowed to attend public education. Provincial schools were built and the national University *Quốc Tử*

Giám was extended. The National Library *Bí Thư Khố* was established (Vietnam Institue of History, 2007). Every three years, the Le emperors organized state examinations (thi Hương, thi Đình, thi Hội) to recruit talents for the court.

In the 18th century, the ruling Nguyen emperors re-established the state education system. A new imperial university was opened in 1803 in the new capital of Hue. The education system was expanded to the local districts. The court also assigned officers who looked after educational development at several levels. Private schools were very popular in local villages. Famous private schools may have had a few thousand students. The state also reorganized the examinations to recruit talents for the administration system, but used earlier procedures.

Although education was established very early in Vietnam, access was limited only to nobles and wealthy people. The teaching methods were only standardized in the few state schools for the royals. Private schools although popular in the 16th century were self established and operated privately. Groups of students were organized in classes and guided by a local tutor. There was no formal classroom and students often sat on the floor of the tutor's village home (as illustrated in figure 2.32). The method of teaching was purely learning by rote. As the influence of Confucianism heavily dominated the country's civil life, the curriculum was limited to literature, history and Confucian philosophy. Studies of science, technology and commerce were not much appreciated.

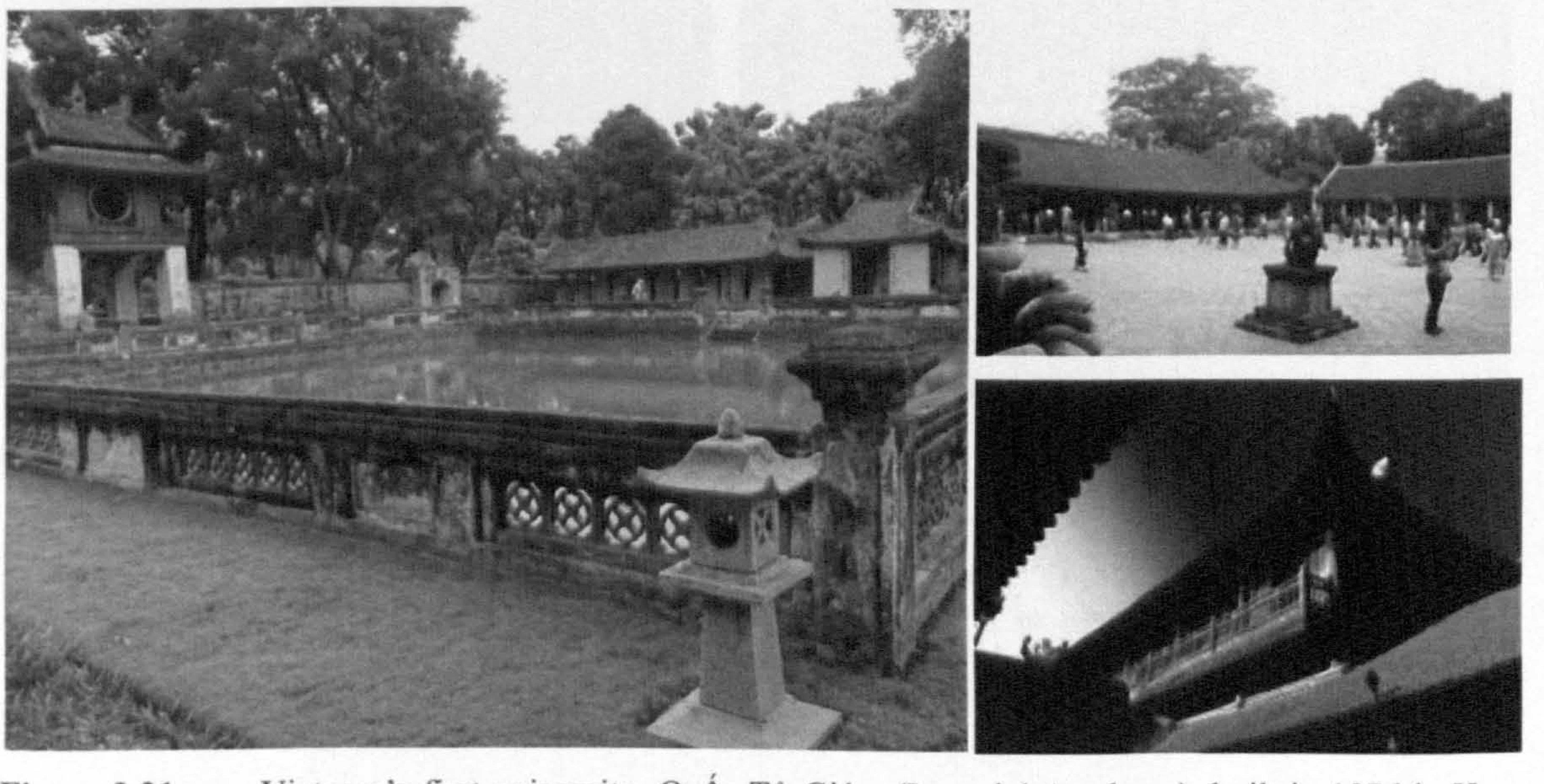


Figure 2.31 Vietnam's first university, Quốc Tử Giám (Imperial Academy), built in 1076 in Ha Noi and extended during different periods, is the finest example of Vietnamese architecture, and is also the origin of Vietnamese education. (Vaulot, 2006)

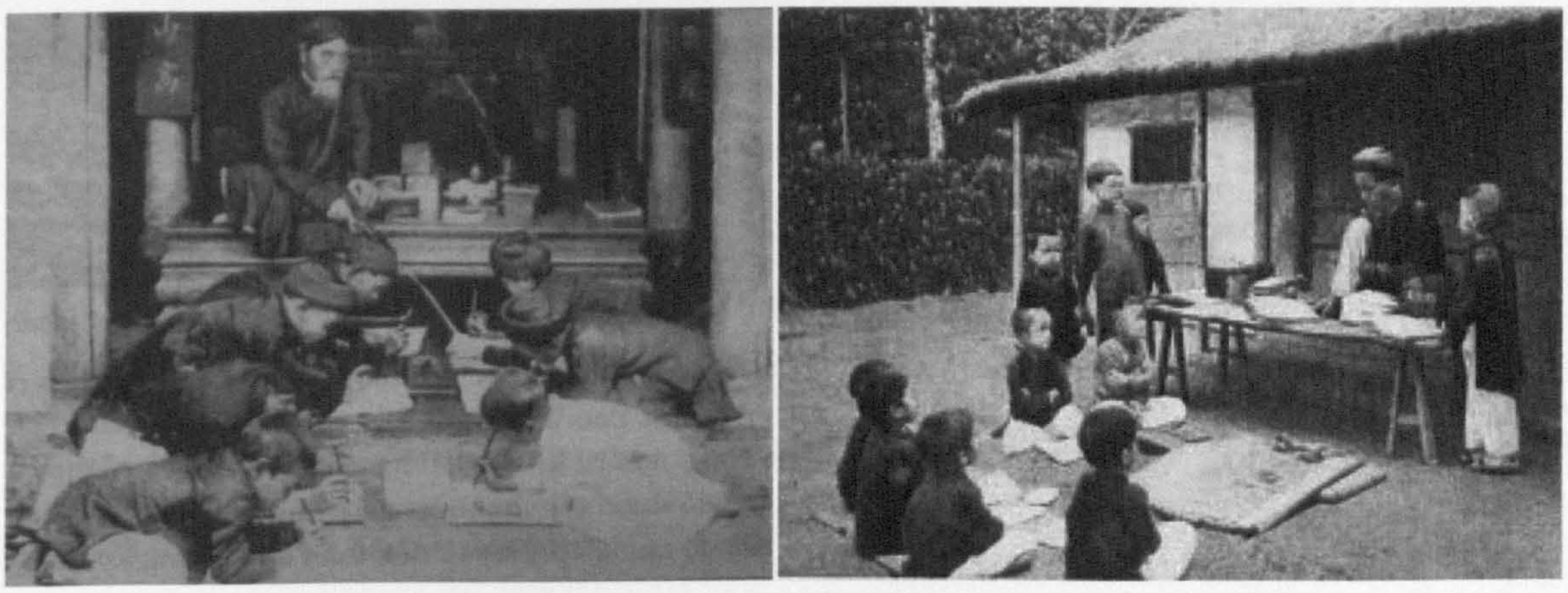


Figure 2.32 Students study with the local teacher in Vietnam around the late 19^{th} Century, Nguyen Dynasty. (Le, 2009)

Figure 2.33 A State exam organized by the Royal court to recruit talents during Nguyen Dynasty (early 19^{th} century)

Left: The Examination venue. Top right: Successful candidates pay their respect in front of Temple of Literature where Confucius is worshipped. Bottom right: New successful candidates in awarded cloak and gowns. (Le, 2009)

2.4.3.1.2. Education in French Colonial period (1887-1945)

As part of its colonization process, the French closed down the imperial education system along with Confucianism studies and introduced its own westernized system. An extensive westernized schooling system was built across the country, replacing the old village schools. The new education system introduced by the French was divided into three levels: Primary, Secondary (College) and Higher education (University).

Primary education was divided into three sub levels: pre-primary, primary and higher primary. Each level was taught in terms of three years. The study curriculum included both social science and natural science. Teaching languages were French (majority) and Vietnamese (minority) depending on the subjects. Primary schools were built in some important provincial cities although secondary education was only available in big cities such as Ha Noi and Saigon. Teaching was standardized as per the Westernized system and students studied in formal classrooms with desks and a blackboard.

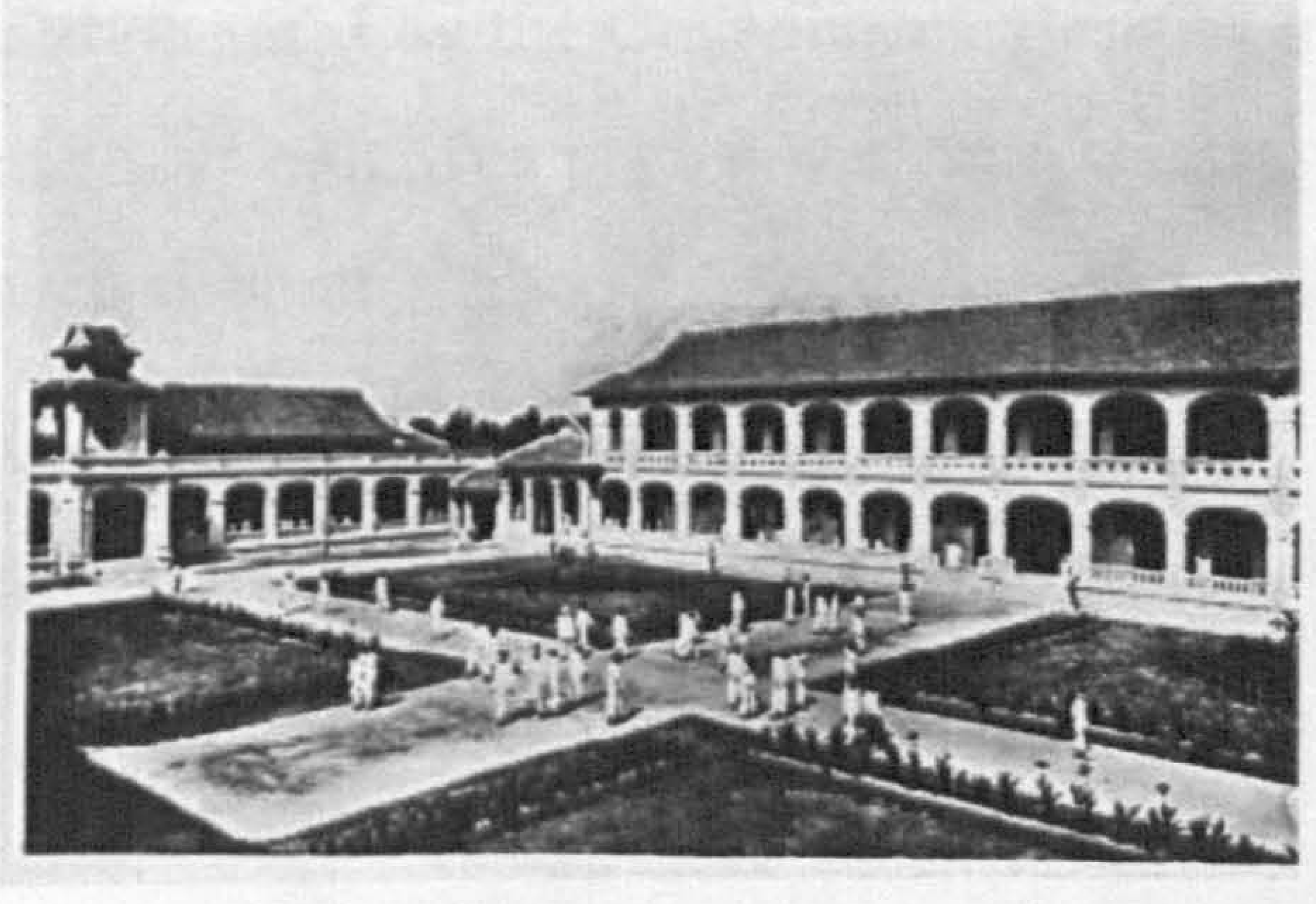



Figure 2.34 Westernized colonial schools and classrooms were formally established in the 19th century. (Petrus-Ky, 2002)

2.4.3.1.3. Education during the Vietnam War (1954-1975)

Immediately after regaining independence in 1945, the Vietnamese government started rebuilding the national education system based on the *Hoang Xuan Han* programme. Vietnamese as the teaching language replaced the dual French-Vietnamese programme. During the Indochina war (1945-1954), teaching continued to be conducted. After 1954, the country was divided and the North and the South developed their own education systems. Although the country was politically united in 1975, the education system was merged only after 1985.

The North Vietnam Education system

In the North, the government used the *Hoang Xuan Han* programme which had been established in 1946. In 1950 a new education system was introduced. Students had to complete eleven years of education before entering university. The initial eleven year education was divided into three levels: primary (four years), secondary (three years) and high school (four years). At the higher education level (university), French was still the main language of teaching until 1950, partly because of the lack of staff and the teaching material. The main task of the government in the 1945-1950 periods was to increase the literacy rate. In 1956, both the schooling systems and the study curriculum were reformed again. It was modelled after the Soviet Union system. The initial education was shortened to 10 years: primary (three years), secondary (three years) and high school (three years). All of the schools were owned and operated by the Government. Because of the war, teaching facilities were basic and low cost. Temporary war time classes were conducted in all kinds of spaces, such as bomb shelters.

Figure 2.35
The Map of Vietnam in 1954-1975. (The Historic Place, 1999)

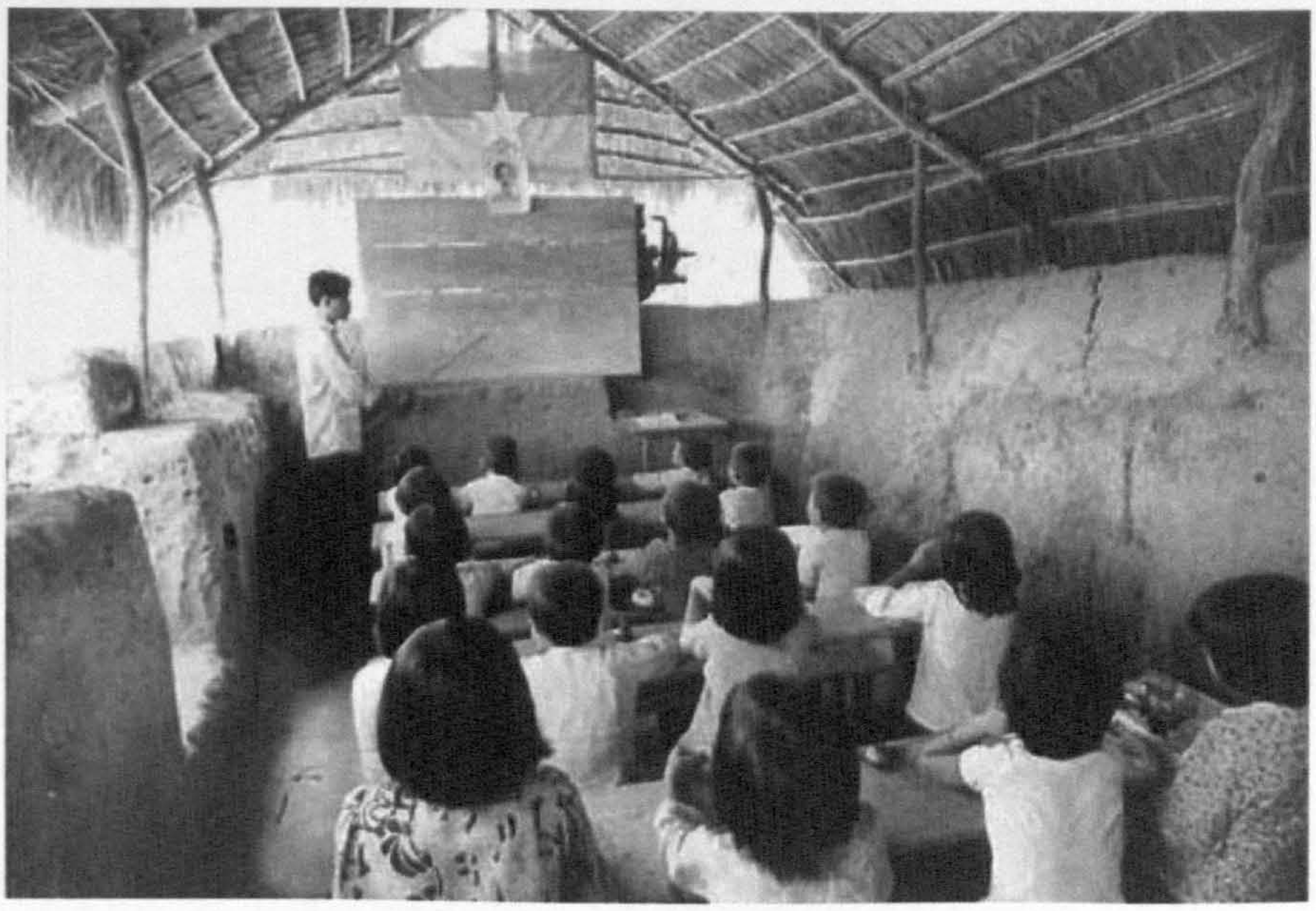


Figure 2.36
A temporary war time class set up in the local village. (Duong, 2009)

The South Vietnam Education system

In the South, the colonial French schooling system was still used until 1950. After 1950, this system was replaced by the new Vietnamese system. Schools were built and operated both by the government as well as privately.

The new education system was divided into three levels: Primary, Secondary level 1 and Secondary level 2. Students completed Primary level in five years. The academic year lasted for 9 months and students studied 25 hour a week. Secondary level 1 and Secondary level 2 each could be completed in 3 years each. Students completed these three levels in twelve years before they could enter the university. However, the impact of war was severe and education was not considered a top priority for investment. During the war time both the North and the South were able to gather resources to develop their own education system. However, each system was developed along different lines for decades.

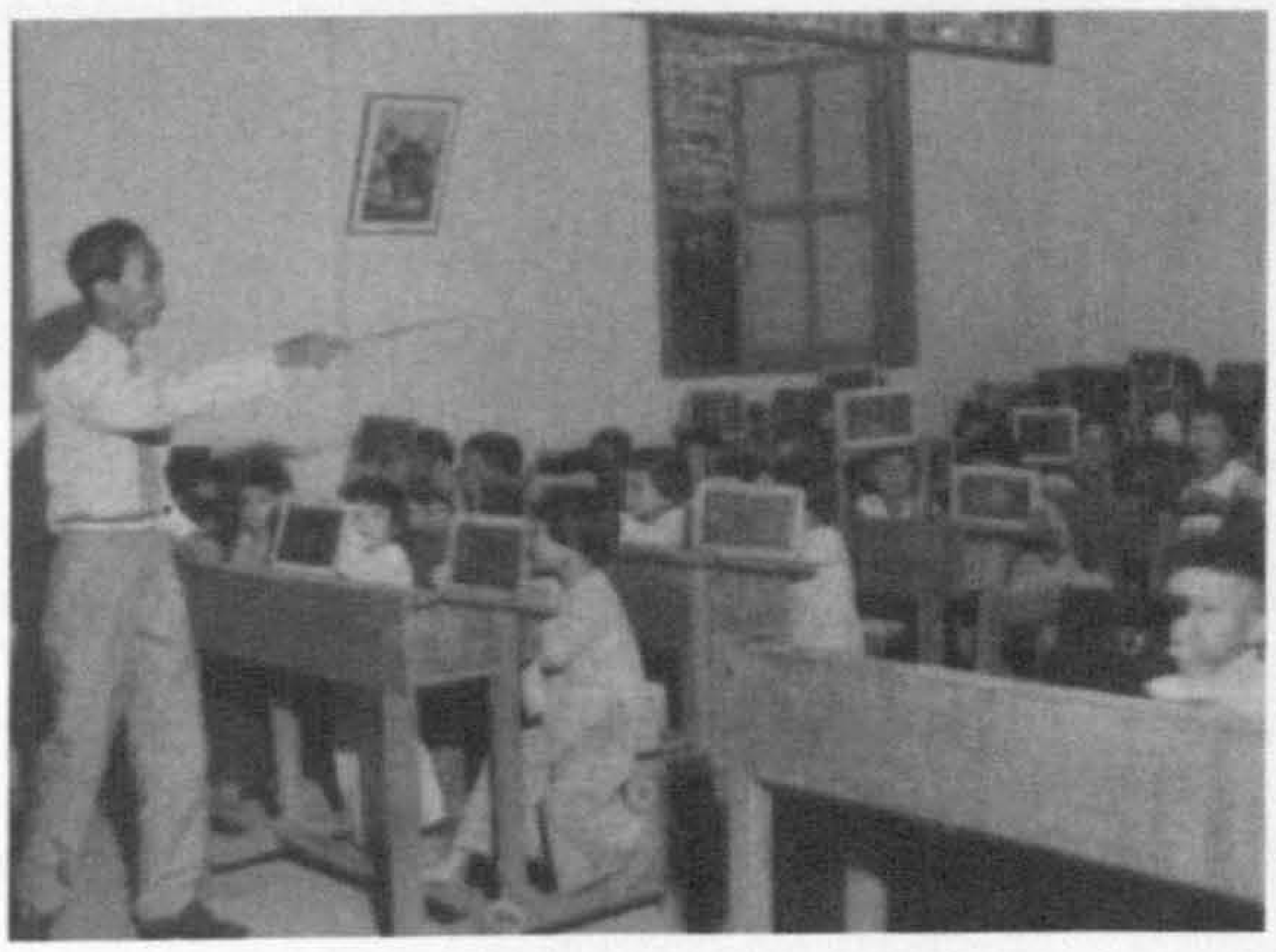


Figure 2.37

A primary classroom in 1960-1970, South Vietnam . (USIA, 2010)

Figure 2.38

Contemporary view of Gia Dinh High School in Saigon, South Vietnam. The school was originally built in 1956. The school architecture is a fine example of a typical school built in South Vietnam during 1954-1975. (THPT-GiaDinh, 2010).

2.4.3.1.4. Education in post-war Vietnam (1975- 1990)

Although the country was politically unified in 1975, the post war education system was very patchy because of the differences between the North and the South systems (Shapley, 1975).

From 1976 to 1986, the North and the South continued to run their separate systems: ten years in the North, and twelve years in the South for initial education. And all private-run schools in the South were nationalized. Although Saigon was mostly intact after the war, most of the country's industry and economy were heavily damaged. Lack of funds, facilities and availability of staff left the city's infrastructure in poor condition. Not too many new schools were built after the war and the existing schools were over crowded. There were often 50 to 60 students in one standard classroom originally designed for a maximum of 40 students. Due to the limited number of classrooms, students had to study in three shifts (morning, afternoon and evening). Study materials (text books and teaching equipment) were in short supply. In some schools electricity was not always available and oil lamps were the main light sources. Providing basic education for a large population was the main priority.

In 1986 a significant reform was carried out in the country in different sectors including education. A new twelve year national system was introduced for the whole country. In Vietnam, the basic education lasted for twelve years and was divided into compulsory elementary school from grades one to five, basic secondary school from grade six to nine and general secondary school from grade ten to twelve (see figure 2.39). After completing each level, students had to pass the national examinations before entering the next level. There was also pre-primary school for children aged from 18 months to five years to study alphabet and basic math. At six years of age, children began grade one. The sixth form student had to be eleven years of age and have primary education diploma. The high school student had to be fifteen years old and have basic secondary education diploma. Apart from this there were also special education schools, dormitory schools for minority pupils, as well as community colleges, art and technology institutes, professional secondary schools and vocational schools.

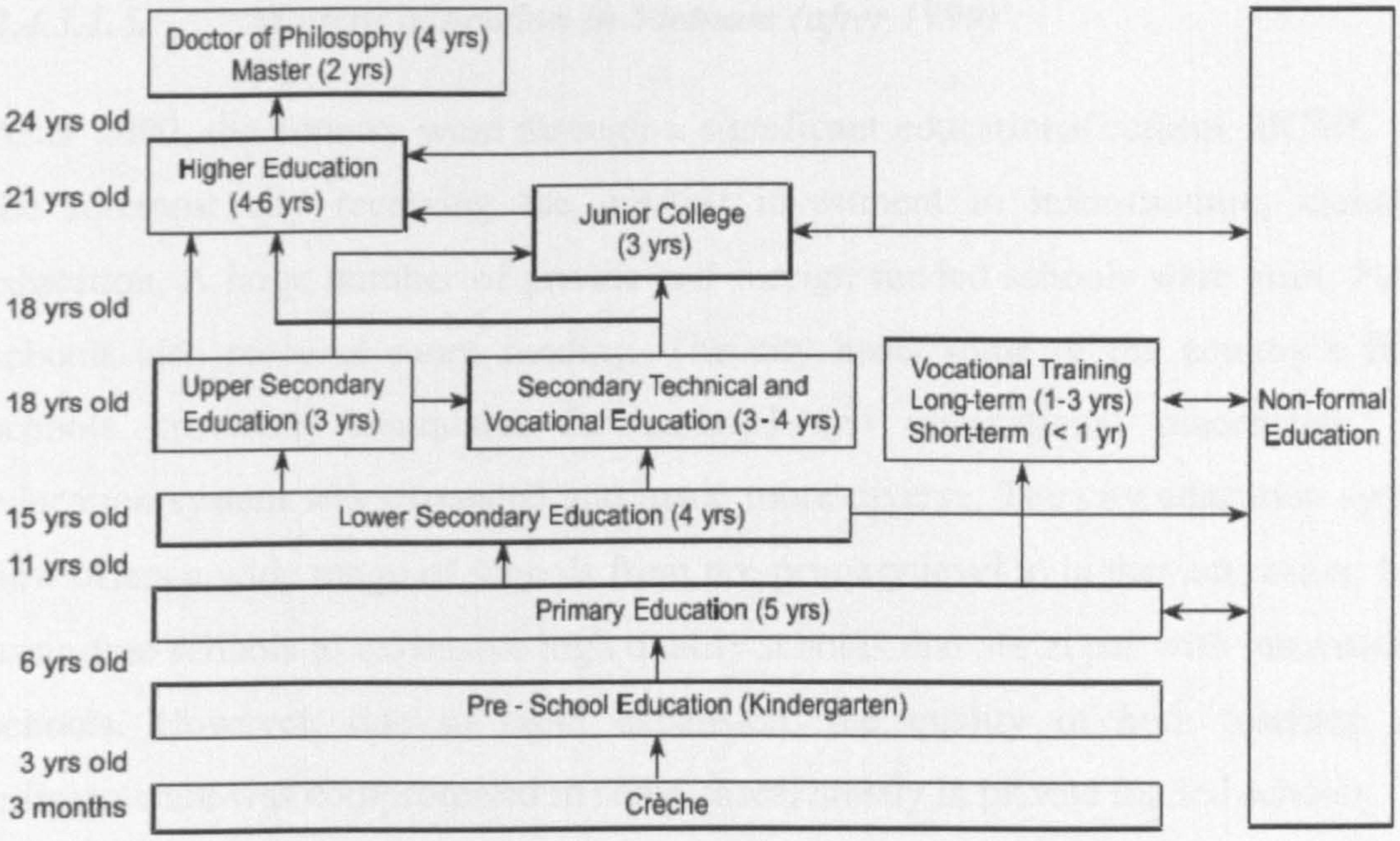


Figure 2.39 Vietnam's Education systems. (Ministry of Education and Training, 2006)

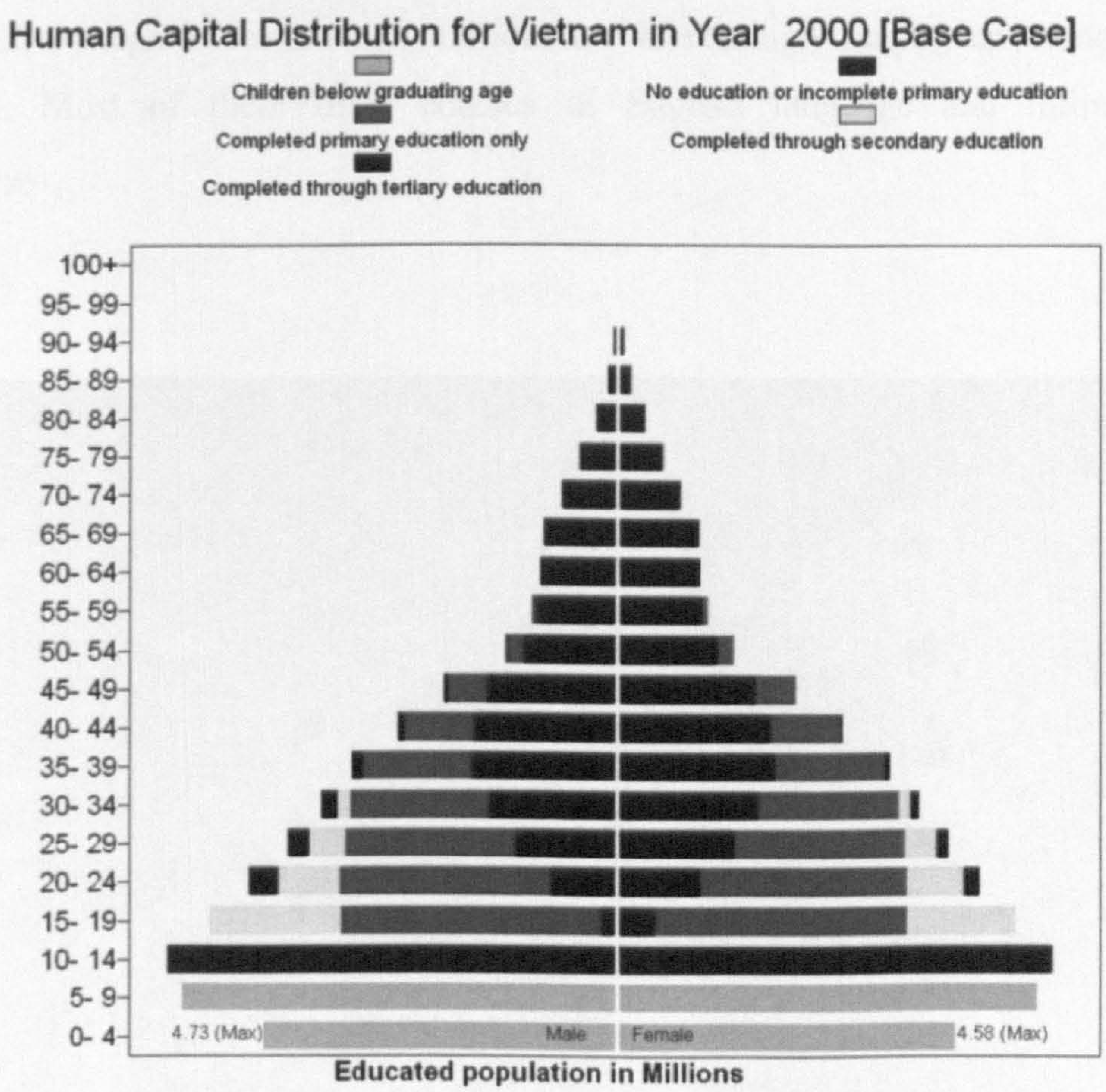


Figure 2.40 Educated population distribution of Vietnam in 2000. (World Bank, 2005)

2.4.3.1.5. Modern education in Vietnam (after 1990)

After 2000, the country went through a significant educational reform. HCMC was the foremost city receiving the greatest investment in infrastructure, including education. A large number of private and foreign funded schools were built. Public schools also received more funding. The city hosts some of the country's finest schools providing candidates for national and international placements. The education system was expanded and made more diverse. The city education system now offers a wide range of schools from pre-primary level to higher education; from basic-free schools to expensive high quality schools that are at par with international schools. However, due to rapid expansion, the quality of both teaching and infrastructure was compromised in some cases, mostly in private funded schools.

Before 2000, all schools were public schools but after that Vietnam opened its doors to private and foreign investment in education. Nowadays, private funded institutions play an important part in providing education to the public, especially in big cities. Foreign educational institutions are increasingly setting up branches in Vietnam. Most of them offer courses in English language and information technology.

Figure 2.41 The Vietnam campus of the Australian Royal Melbourne Institute of Technology in HCMC. This foreign invested educational institution was among the first to be established in the city's new urban area of South Saigon. (RMIT, 2006)

The World Bank in its 2008 report on Vietnam's education system stated that *"during the past decade, Vietnam has accomplished great progress in the field of education. The primary net enrollment rate has increased from 86 percent in 1990 to 91 percent in 2003 and the dropout rate has declined from 12 percent to about 3 percent". Nevertheless, the country still faces a huge educational crisis and respected scholars are calling for overall systematic changes"* (Youth News, 2007). Since 2000 the government has been reforming elementary, intermediate and high schools to ensure a suitably skilled workforce to drive a globalized economy. Currently, the Ministry of Education and Training is planning to continue reforming educational management methodology, teaching and exam methodology; socializing (or privatizing) education, training teachers, restructuring schools systems and upgrading school facilities.

Table 2.8 Statistic figures of Vietnam Primary school systems in 2001-2003.(Ministry of Education and Training, 2006)

School year	Number of primary schools	Number of students	Number of primary education teachers
1989 -1990	12,296	8,583,025	251,052
....	......	....	....
1994 - 1995	13,540	10,047,564	288,173
1995 - 1996	13,778	10,218,169	298,407
1996 - 1997	13,888	10,377,830	310,264
1997 - 1998	14,240	10,431,337	324,431
1998 - 1999	14,507	10,250,214	336,294
1999 - 2000	14,815	10,063,025	340,871
2000 - 2001	14,968	9,748,164	347,833
2001 – 2002	15,090	9,400,000	353,804

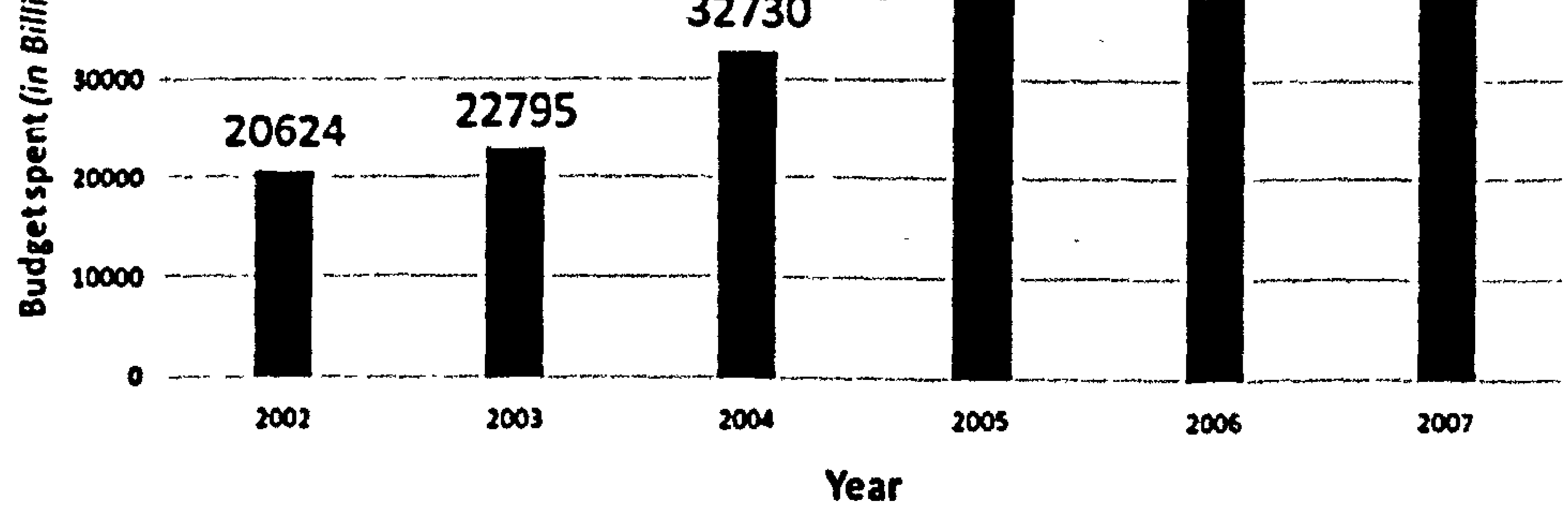
Table 2.9 Statistic figures of Vietnam Secondary school systems in 2001-2003. (Ministry of Education and Training, 2006)

	2001 - 2002		2002 - 2003		Notes
	Basic Secondary Education	General Secondary Education	Basic Secondary Education	General Secondary Education	
School quantity	8,092	1,393	8,396	1,532	•
Class quantity	153,700	48,684	161,329	52,131	
Student quantity	6,253,525	2,333,069	6,497,548	2,458,446	
Averaged Student per class	40.69	47.92	40.28	47.16	
Classroom quantity	102,166	33,626	108,898	36,976	
3 shift per day classroom	103	18	113	12	
Class per classroom	1.51	1.49	1.64	1.42	
Teacher quantity	243,208	81,684	262,543	89,357	

2.4.3.2. Relevant Government Plans and Policies

Education has an important role in the country politically, economically and socially. Vietnam's Education Law was established on December 11th, 1998. The Vietnamese government has been spending a large part of its budget for education to achieve the goals set by the Education Law. In 2007, an estimated 18-20% of the national budget was allocated to education and training, which was about VND 66,770 billion (US$3.9 million), compared to VND 15,609 billion in 2001 (EduNet, 2007). There are plans to increase the budget for education to 21% of the whole national budget by 2020 (Labour News, 2008).

Despite all the reform efforts since Vietnam launched its open door policy in 1986, there are many challenges ahead. It is reported that the current education system does not meet the demand and there is an urgent need for further reforms in education. The country's most popular mainstream newspaper is running a campaign calling for a movement to make educational reform a priority (Youth News, 2007).



VIETNAM'S BUDGET FOR EDUCATION & TRAINING (Billion VND)

Figure 2.42 Vietnam has allocated an increased budget for education in recent years. 2007's budget is almost double that of 2004's. (Ministry of Education and Training, 2006)

Firstly, the study curriculum was criticized for being out of date and for there being little or no balance between academic theory and practical information. The methodology limits students' independent thinking and creativity. Teaching methods in the public school system have been criticized for being teacher-oriented, although it is slowly changing to becoming more learner-oriented. Vietnamese students are considered among the most studious and disciplined in the classroom but they are shy and hesitant to communicate while in a group. As a matter of fact, pupils' parents still complain about over-loaded school programs (VN Express, 2008) .

Secondly, the evaluation system, or state examination, is outdated and inefficient. It focuses too much on theory rather than on practical skills. Preparing for the state examination is stressful, time consuming and expensive not only for the students, but also for their parents. The criticism also points out that the examination system does not properly evaluate students' knowledge and ability (Vietnam Review, 2007).

Thirdly, some challenges that have been identified are poor planning, shortages and ineffective utilization and management of resources for education and training, misuse of human resources and lack of funds. The ratio of teachers per class is 1.54 teachers/ class in basic secondary education level and 1.64 teachers/ class in general secondary education level. It is estimated that the system still lacks about 18,700 teachers (Ministry of Education and Training, 2006). This had lead to compromises in teaching quality (Vietnam Review, 2007).

The fourth problem is the degraded school infrastructure and the shortage of training facilities. The school infrastructure has been poorly equipped and maintained. It is reported that the classrooms are insufficient, meeting only 50% of the demand. The number of three-shift classrooms were reported to be as high as 2,026 (Ministry of Education and Training, 2006). It should be pointed out that limited budget is not the main issue in some cases. In big cities, large investment, both private and foreign funded, has been spent on building new schools. The lack of either updated architectural standard guidance or a strong local law enforcement of school design regulations has resulted in inappropriately designed schools. Recent reports on newly built classrooms highlight the inappropriate lighting systems (Vula, 2009).

The government has started reviewing the current situation and much effort is being made to investigate the problems. The focus of the government investigation will be on improving the study curriculum, teaching methodologies and reforming the state examination systems. Second priority would be improving management and restructuring the operating systems. It focuses on defining responsibilities and roles of each government agency, at all levels in the administration of education and training to ensure that the government has an active role in education. Improving human resources, e.g. teaching and management staff is also a priority.

More budgets will be allocated from various sources like the state budget, private and foreign investment. The objective of the investment will be to eliminate the three shift classes, build new schools and classes, with the aim of entitling students to whole-day classes, instead of the current three shift classes (or half day classes in big cities).

2.4.3.3. The existing conditions and future development

2.4.3.3.1. The current conditions: system, management, and operation

HCMC is the most important centre for education in South Vietnam. The city's education system offers all levels of training, from pre-schooling, nursery, to higher education and research. There are also many types of schools existing in the city: public, part-public, private and international schools. All of these schools offer a very wide range of training from basic to professional international degrees. The education system has been standardized along the lines of the national structure. The initial education comprises of three levels: primary (five years), general secondary (four years) and upper secondary (three years, also called high school). The city has its own *Department of Education and Training* (DET) which is directly responsible for all education related issues. Each of the city's 24 districts organizes its own *District Office for Education and Training* (DOET). In general, all the schools are under direct administration of the *DET*. However, *DET* has direct responsibility for daily issues of upper secondary level, while *DOET* takes care of general secondary and lower levels.

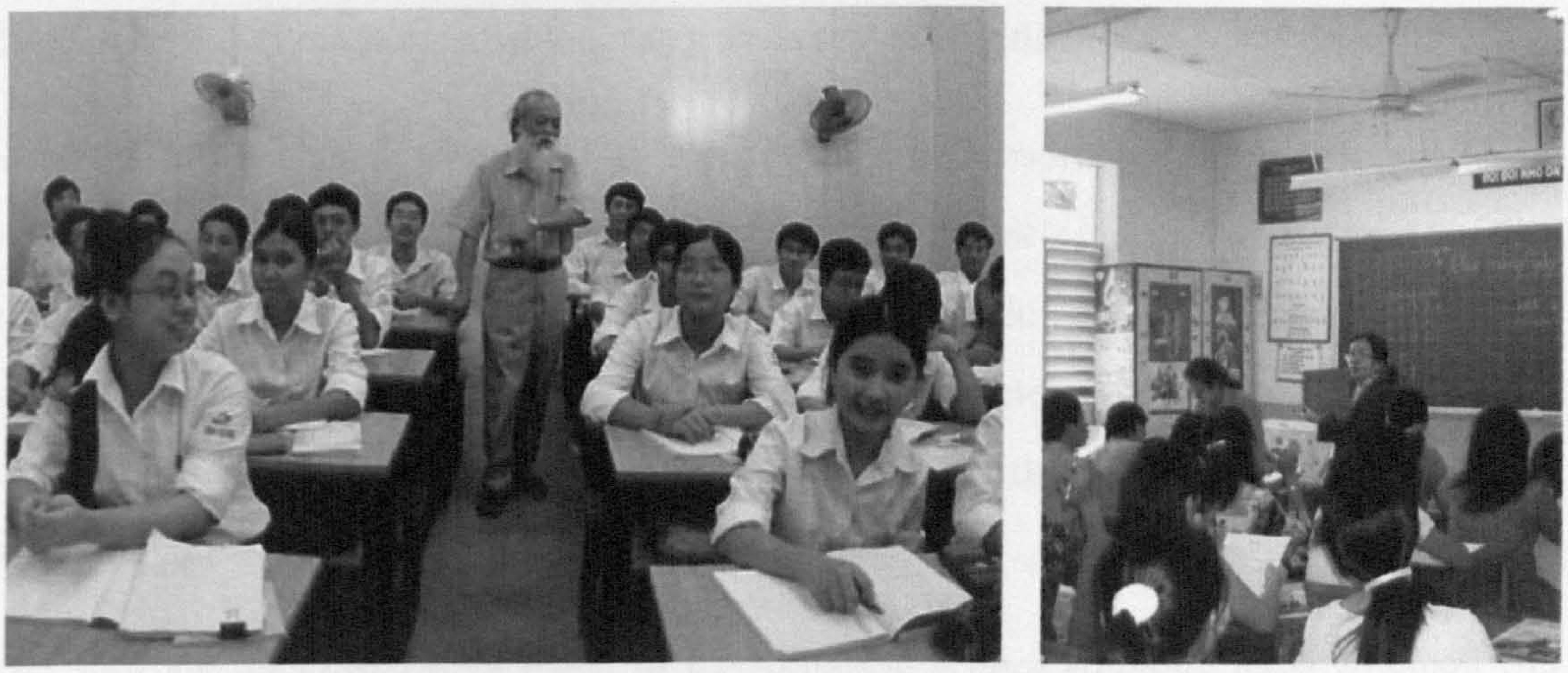


Figure 2.43 A typical class in a city school. (Vietnam Weekly, 2009)

Table 2.10 Primary and Secondary school systems in HCMC as of 2009-2010.

	Public	Part-public	Socializing funded	Private funded	Financial Independence – Public school	*Total*
Primary	435	4	29	3	2	*473*
General Secondary	215	17	5	2	4	*243*
Upper Secondary	68	6	3	8	4	*89*

(source: Department of Education and Training of HCMC)

Table 2.11 Statistical data of students, teacher, and classroom in the academic year of 2009-2010.

	Students	Teachers	Classroom	Students per Teacher	Students per Classroom	Shift (as per standard 40 students/classroom)
Primary	474919	15379	11036	31	43	1.075
General Secondary	316416	14979	6262	21	51	1.26
Upper Secondary	186464	9861	4080	19	19	<1

(source: Department of Education and Training of HCMC)

2.4.3.3.2. Teaching and learning delivery methods

Students are assigned to a class as well as to a classroom for the whole academic year. Students study in that classroom for all the subjects, except those that require extra teaching equipment. Although the national code allows a maximum of 40 students per standard classroom, classroom shortages means there are often 50 to 55 students studying in one classroom. Table 2.11 shows that general secondary school has the highest students per class ratio.

The shortage of classrooms leads to the situation where students have to share the same classroom in shifts for studying. Two-shift classes are still popular in HCMC. This means the same classroom will be used by two groups of students: one in the morning (7h00 to 11h30) and one in afternoon (13h00 to 17h30). Such a schedule maximizes the use of the facilities but also compromises the users' comfort.

In general, all of the schools have to follow the state curriculum prepared for each level. As of 2010, a general secondary students have to study Mathematics, Physics, Chemistry, Biology, Technology, Literature, History, Geography, Citizen Study, Foreign Language, Gymnastics, Music, Art and Computer Science. Each subject is structured and taught in credit systems and each credit is equal to 45 minutes of teaching. In a shift, either in the morning or afternoon, students usually have to finish five credits of 45 minute class each. There are often one or two long breaks of 15 to 30 minutes, and a short break of five minutes between classes to allow teachers to move from class to class. In this system, the students stay in the same classroom most of the time. Each teacher of a certain subject moves from class to class to deliver their lectures on that subject. Therefore, classrooms often have fixed layouts with study benches and writing desks.

The teaching method is quite outdated, and mostly one way studying. Learning activities are often simple as the teacher writes something on the board, explains it, and students have to write it into their note books. Though there are more interactive activities but they are limited. Most of the classrooms are poorly equipped. Only a few schools can afford projectors and other modern teaching equipments. In some cases, if there is a need for projector and screen, portable devices have to be used; they are set up before the class begins and then removed after use. Therefore, a "standard classroom" will be equipped with long study benches and writing desks (usually two or more students share the same bench and desk), a teaching board (mostly chalk boards), a document cabinet and a teacher's desk. Some schools can afford to have a single chair and desk for each student and white teaching board instead of chalk board.

Often one or two computer pools are shared for the whole school. There are also some laboratories used for teaching biology or technology. When these subjects require experiments, students are asked to move to these shared facilities. As far as physical training is concerned, most of the city's secondary schools do not have their own gymnasium hall. Students often practice in the school's concrete paved ground or go to external sport halls hired by the schools. This is due to the lack of funds and limited availability of land in the city.

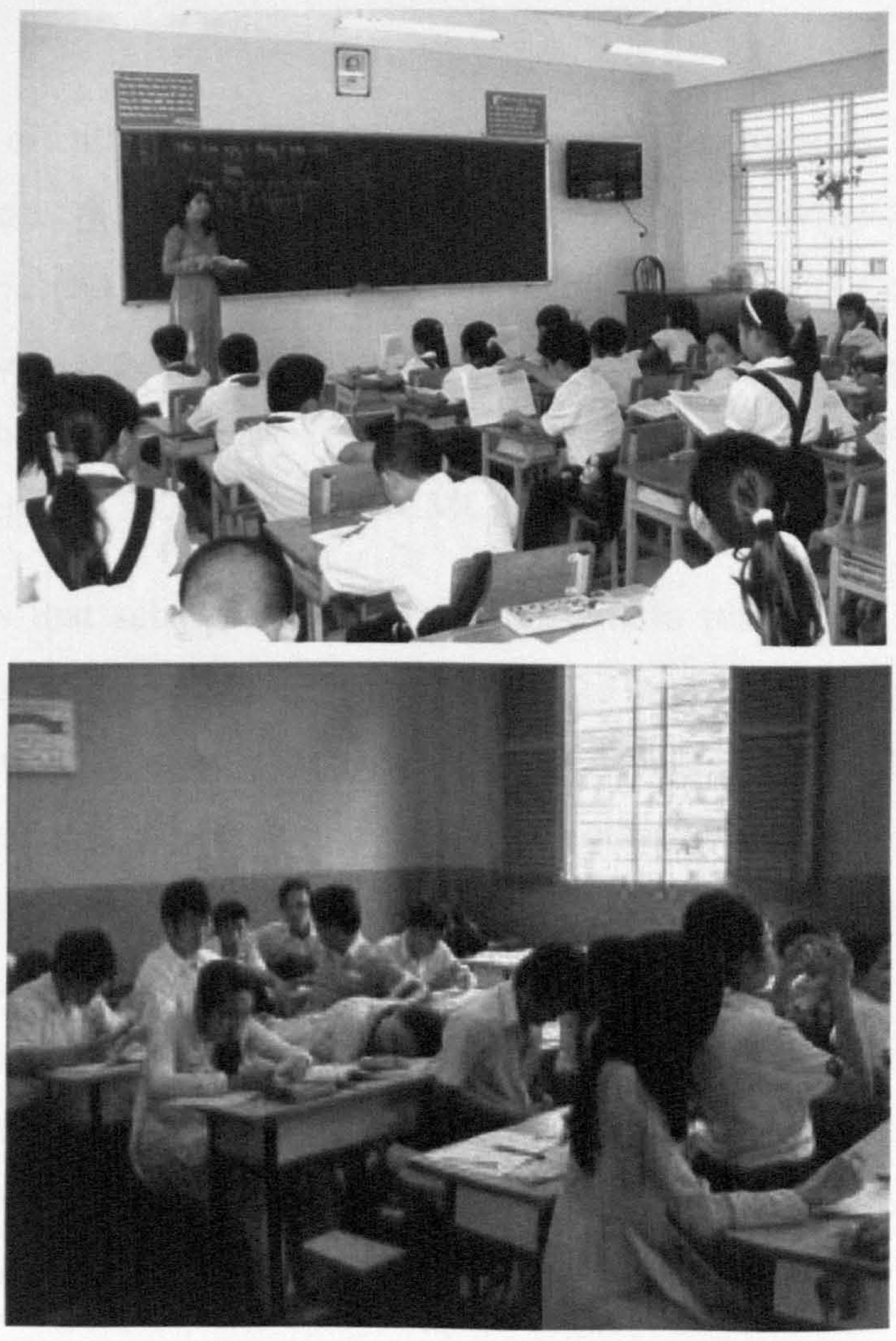


Figure 2.44 Typical classrooms in HCMC during the teaching hour. Forty to fifty students are assigned to a standard classroom with fixed furniture (often simply chair and writing desk). The teaching station is simply a teacher's desk and a teaching board (usually chalk board). Note that the class in the top picture has a LCD screen, which is not so common. (Viet-Bao, 2001)

2.4.3.3.3. Difficulties and Challenges

Many reports have shown that the HCMC school classrooms do not perform well. Poor lighting is considered as one of the problems contributing to the high number of short-sighted students. Investigation has found that limited budget, in some cases, is not the main reason (Youthnews, 2008). As the most populous metropolitan area, classrooms in HCMC are often overcrowded.

Another issue is that some schools are not properly built. They are converted from other buildings to teaching spaces to tackle the classroom shortage. Thus they do not meet the required standards. In some cases, the classrooms were originally designed as per the codes. However due to the rapid growth in the city the site contexts have also changed and the classroom indoor environment is no longer as good as when initially built.

The other issue often with big cities is the limited land allowance. Most of the city schools do not meet the national requirement on *Building Coverage Ratio* (BCR) and *Floor Area Ratio* (FAR). Very little green space is seen in the city schools. All available space is saved for teaching and training facilities. School grounds are often concreted to provide flexibility. The code allows maximum four storey levels for schools but exceptions are not rare in HCMC.

Another issue is that schools are often located within residential and commercial areas. Thus, noise and pollution are major threats to teaching quality. It is often seen that students have to compromise between ventilation and daylight over noise and pollution. Furthermore, neighbouring buildings sometimes block access to daylight or cast shadows on the main windows. Other problems, as discussed in the code review, are the lack of appropriate codes developed specifically for HCMC. National codes in some cases are not applicable since they have been developed from studies and research of the Northern climate and are not suitable for the city. There is a need to develop design guidance for classrooms in HCMC which takes into account the local characteristics.

Figure 2.45 Lack of land is among the main difficulties that HCMC's schools are facing. There are very little green spaces for playing or training grounds in the city schools.

Figure 2.46 Although the codes do not allow more than four storeys, there are many exceptions of "high rise" school buildings in the city.

Figure 2.47 Classroom windows open directly to the noisy and polluted streets. This leads to compromises over the access to daylight and natural ventilation.

2.4.3.3.4. Education in the future

The top priority, for the short term, is providing sufficient classrooms for all students, thus reducing the students per class ratio and allowing whole day classes. Since students will stay longer in their classrooms, providing an enjoyable studying space is also in the top priority list. Students will have opportunities to attend various types of classes and teaching activities, and more flexible classroom layouts will soon be introduced. Hence, architecture should be able to provide a multi function classroom space.

The government is planning to revise the current study curriculum and teaching methods to a friendlier, interactive and independent thought encouraging approach. There will be greater flexibility in the curriculum. Thus learning should cease to be a one way process and would become an interactive process. Perhaps learning activities will not be limited to reading, writing and listening. In the UK, the new revised code for lighting has already suggested that facial recognition also plays an important part in the teaching and learning process. Thus, architectural and lighting design should be able to create a more enjoyable and interactive studying space with good contact between students, and between students and staff.

The development of technology also affects the process of teaching and learning. Traditional chalk boards have gradually been replaced by white boards and video screens. In the next few years, we will see increased use of *Information and Communication Technology* (ICT). All classrooms hence must be designed to accommodate multimedia teaching equipments. The lighting systems should have multi-scenes settings to switch between different activities.

It can be seen that in the near future, students will have their own hardware (e.g. laptop), so the role of textbooks and papers will be not as important as present. Therefore, classrooms of the future should be interactive and flexible spaces integrating many types of multimedia equipment and accommodating different types of teaching and learning activities.

This suggests that the promotion of good design will receive more attention. Study spaces should be more interesting, inspiring and enjoyable. The school classroom design should reflect the city's richness of history and culture, reflecting the local characteristics while meeting international standards. Environmental issues are also becoming an important priority. Greener designs are those that will have minimum impact on the environmental. This can be achieved through various means such as low energy use, reduced wastage, and better planning and design.

Classroom designs will become more sustainable, integrating the cultural and practical aspects of the city. The aim is to make studying more inspiring, interesting and enjoyable.

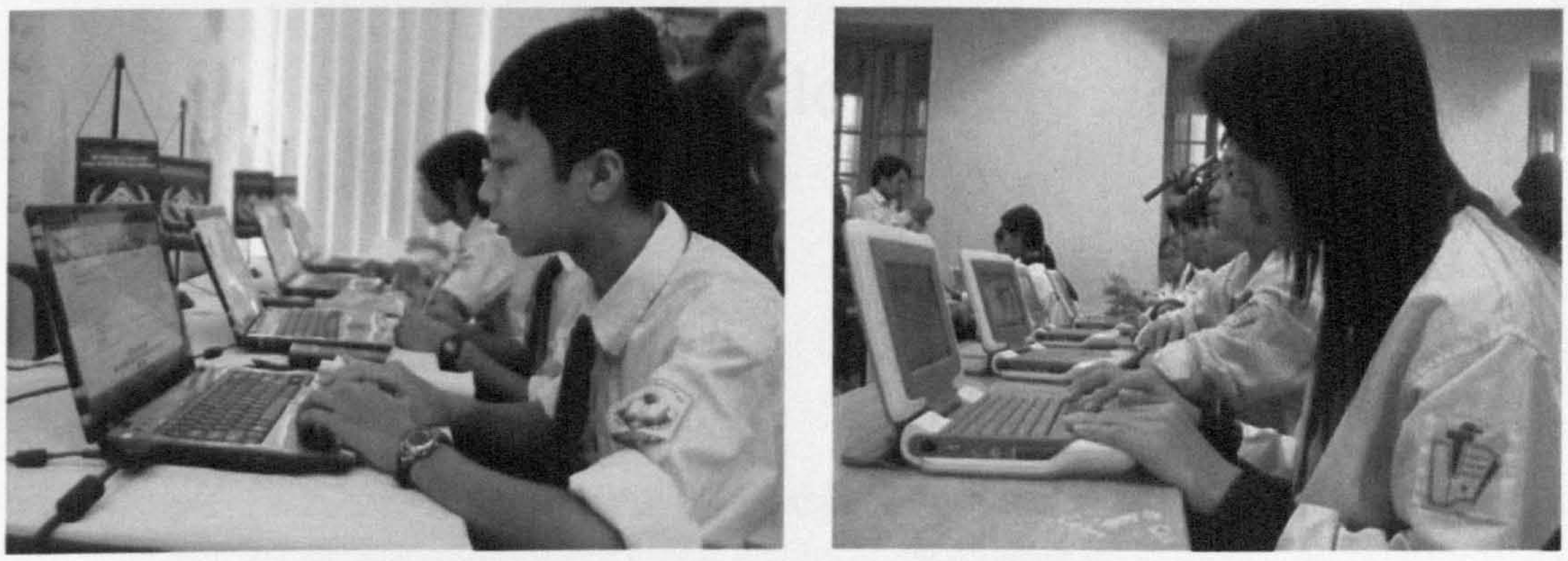


Figure 2.48 New ways of learning and the impact of ICT can be expected in near future. (Vietnam IT, 2008)

2.5 Conclusions

The review of the natural settings of HCMC indicates that there is a lot of potential to use daylight in school classrooms in the city. The first advantage of this is that similar terrains are found in a large part of the city. Secondly, it is also found that the climatic conditions are quite stable with two distinct seasons: the Dry and the Wet season. The daylight availability is high throughout the year.

The review of the social settings also indicates that there may be some difficulties. Firstly the development of school design in the city has been held back for many years, due to wars, budget constraints and low public awareness. Furthermore, the recent rapid economic development has compromised the quality of the classroom environment for commercial benefit. Current school classrooms are found to be in poor condition and are often overcrowded.

Finally, the review of teaching and learning methods used currently and what may be used in future suggests that there are going to be major changes in the classroom lighting design.

Chapter 3

Best practices for classroom lighting, with particular relevance to Ho Chi Minh City

3.1. Introduction

This chapter provides an overview of established theories behind classroom lighting and its thermal consequences, and of how these theories were derived in the light of established studies and codes in the Vietnam and other countries.

This chapter is divided into three parts:

- The first part provides a brief description of the key factors for best practice classroom lighting.
- The second part looks more specifically at the theories and recommendations focusing on visual comfort criteria.
- The last part reviews the literature on classroom thermal comfort.

3.2. Key factors for best practice classroom lighting

Providing good visual comfort in a classroom is regarded as the most important criteria in all the classroom design guidance. Best practice guidance for classroom lighting often prioritises the requirements for visual comfort (i.e. task illuminance, glare, and light distribution); followed by recommendations for light fixtures and energy efficiency.

The design of a building is regulated by many requirements established from various sources such as results from field studies, best practice guidance and national and international codes. Thus specific recommendations and their applicable criteria may be different, are subjected to local environment, which are different from place to place and are constantly changing. As a result it is difficult to make recommendations that can be applied worldwide, or even on a nationwide scale.

3.2.1. Overview

Lighting is an important component in classroom architectural design. Lighting design provides the framework for appropriately lit environment for teaching and learning activities but also creates an interesting, inspiring, and stimulating space that encourages the learning process. Designing good lighting scheme does not only involve complying with numeric requirements but also means taking into account a wide range of other considerations and determining features (as summarized in figure 3.1).

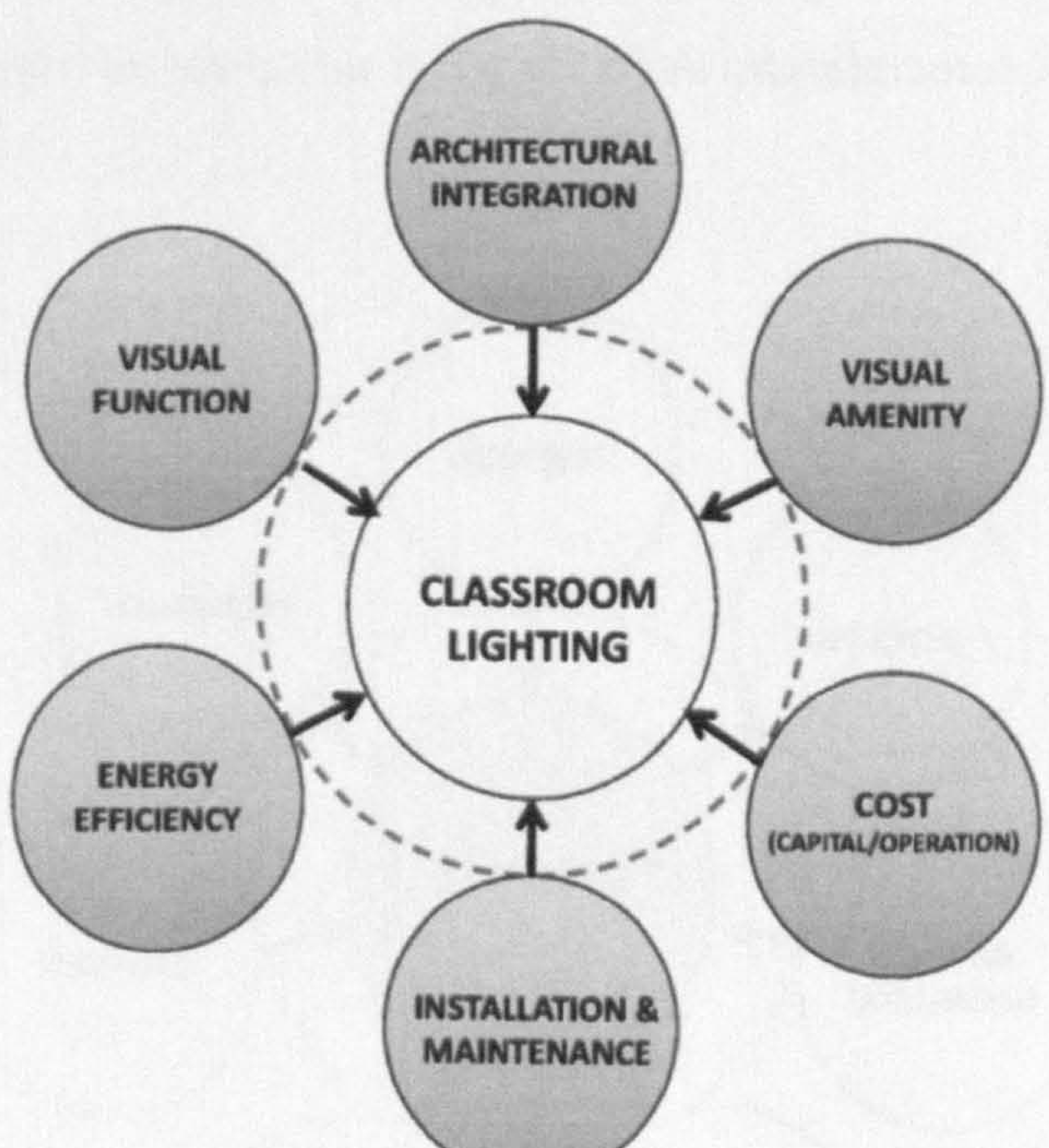


Figure 3.1 Framework showing main components of lighting design & determining factors.

Visual function is the most important consideration for classroom lighting. To ensure good visual function, it is usually recommended that specific requirements of the following be included: task illuminance, uniformity, colour rendering, flickering, discomfort glare and disability glare.

Visual amenity is another important factor. Interesting lighting schemes can significantly improve the students' academic performance and encourage creativity. This issue is often related to the light pattern, overall lighting, colour perception, glare, and view.

Architectural integration must be considered in the early stage of design. Lighting is an integral part of the whole architecture and cannot be separated from other issues.

Energy efficiency is an issue that has become an important concern recently. Efficient lighting schemes minimize the energy used both for artificial lighting as well as for heating-cooling due to solar gain.

Cost is another factor that needs to be considered, especially for school buildings where budget is low. School buildings are usually a 15 to 20 year investment, thus both the capital cost and operating costs should be considered.

It is also important that *Installation and maintenance* should be kept simple. The lighting scheme should be such that it requires low maintenance, is easy to clean and is easily replaced.

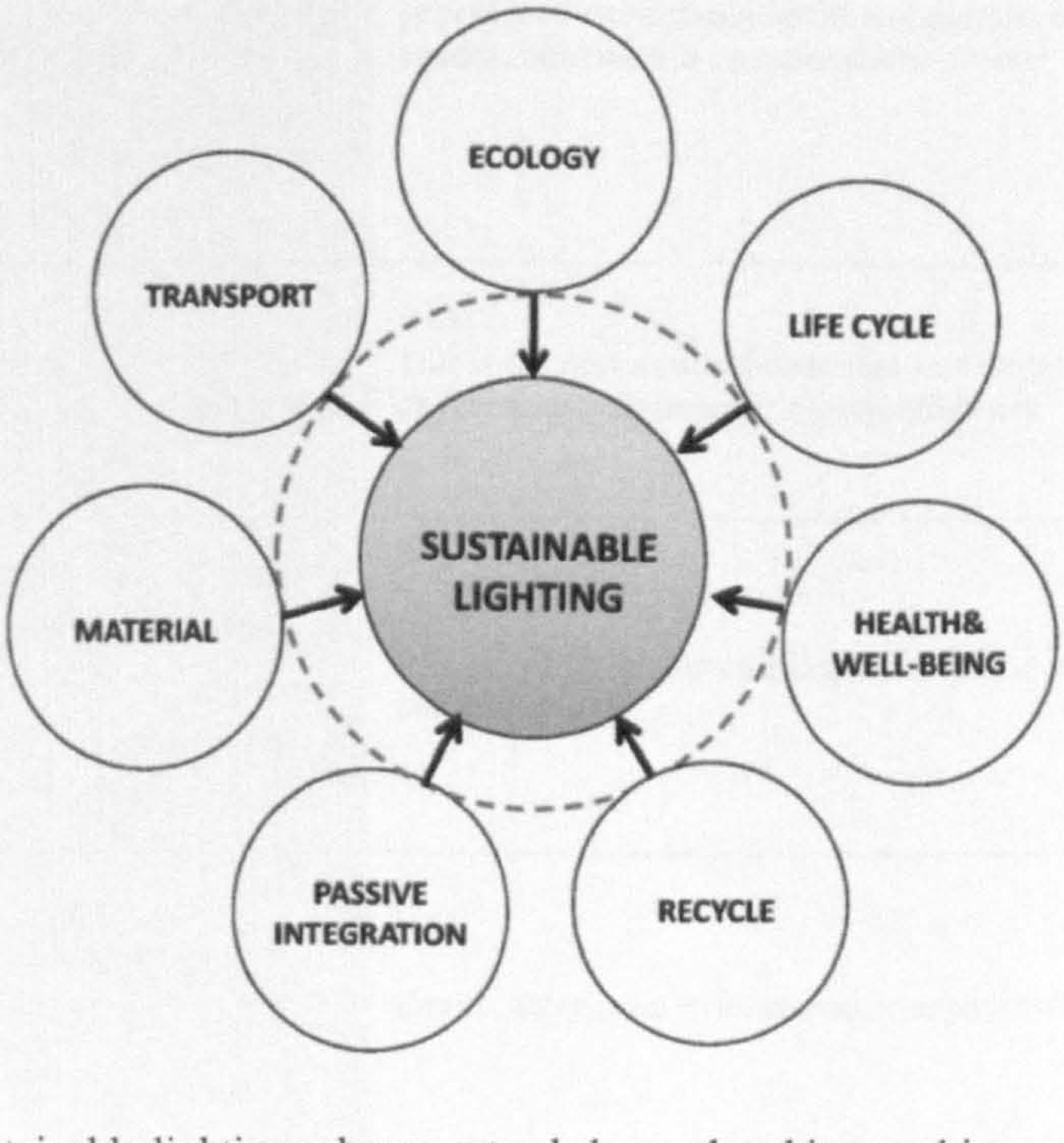


Figure 3.2 Sustainable lighting scheme extends beyond architectural issues.

3.2.2 Overview of the Vietnamese environmental design codes for classroom lighting

Table 3.1 Relevant Vietnamese codes covering school design requirements

Type	Code	Descriptions
Design codes	**TCVN: 3978 (1984)** *General school design standard*	This code covers all school types. It provides general requirements e.g. site and planning, layout and standard classroom design. Section IV provides specific information on classroom architectural design requirement. Recommendations for day lighting are addressed in section V and artificial light is addressed in section IX.
Lighting codes	**TCVN: 4400 (1987)** *Lighting Technique – Terminology and Definitions*	Part of the set of lighting codes for buildings TCVN: Lighting design techniques for buildings issued by Ministry of Construction. This code explains generally all the lighting glossary and definitions.
	TCXD: 16 (1986) *Artificial lighting in Civic works*	This code covers the artificial lighting requirement for non-domestic buildings. Secondary school classrooms are classified in CAT I-b of this code.
	TCVN: 5176 (1990) *Artificial lighting-Method of measuring the illuminance*	This code explains the methods to measure, calculate, and define values relating to artificial illumination.
	TCVN: 29 (1991) *Natural light in Civic work*	This code covers all requirements for daylighting in non-domestic buildings including school buildings.
Thermal comfort performance	**TCVN: 4605 (1988)** *Heating techniques - Insulating components - Design standard*	These codes provide specific requirements for designing building thermal performance, e.g. ventilation, comfort temperature. TCVN: 4605:1988 provides constructional recommendations, while the latter provides specific information on room micro-climate.
	TCXDVN:306 (2004) *Dwelling and public buildings-Parameters for micro- climates in the room*	
Energy Efficiency	**QCXDVN:09 (2005)** *Energy Efficiency Building Code (EEBC)*	This is the new national code that sets target energy use andrecommendations for energy efficiency
Ergonomics	**TCVN:7114 (2008)** *Ergonomics-Lighting of Work places*	Sets out requirements for Ergonomics at work place, including schools and classrooms.
	505/1992/QD-BYT (1992) *Microclimate at workplace*	
Hygiene	**1221/2000/QĐ-BYT (2000)** *Requirement for school hygiene*	Health, Safety and Hygiene requirements by Ministry of Health
	TCVN: 5713 (1993) *Requirements of school classroom hygiene*	

In Vietnam, school design must comply with relevant national codes. Local governments may establish further specific requirements, but these are based on the same principles as provided by the national codes. In general, the relevant codes that directly address environmental classroom design are summarized in table 3.1.

There are sub-standards (codes) for specific areas; these codes are prepared by the relevant Government Agencies, for instance, the construction codes TCXDVN by Ministry of Construction (MoC), School Hygiene by Ministry of Health, codes for building energy efficiency by Ministry of Science and Technology (MoST). There are also several design guidelines with lower legal standing, published by national research institutions.

Historically, codes issued before 1990 are often modelled after Soviet Union codes while the codes instituted after 1990 comply with International Standards (i.e. ISO). These codes sometime overlap each other, or even provide conflicting requirements. There are several public concerns over these problems, but it seems that no review is going to be made yet (SGTT, 2009).

3.3. Recommendations for lighting

There are two options of classroom light sources: natural light and artificial light (or electric light). Most of the classroom lighting codes recommend that classrooms must be day lit. Even after the advent of electric light, natural light has always been regarded as the priority source for classroom illumination. Because natural light is variable electric light has been brought in as a supplementary source. Researchers have proven that day lit classroom not only helps to improve the students' academic performance but also is beneficial to health (Heschong, 1999).

Daylight is a free and clean energy source; it is often addressed as a key factor for designing energy efficient buildings. Furthermore, there is strong relationship between daylight, which is generated from solar energy, and the other environment factors such as heat gain and natural ventilation (relating to the size and position of the windows). Specifically, in a hot and humid climate, optimizing daylight access and indoor thermal comfort are among the most concerned issues. Therefore, the first part of this discussion on lighting focuses on daylighting.

3.3.1. Recommendations for daylight

Natural light, in the broad sense, is the electromagnetic radiation given off by the Sun. Solar geometry is often defined by the latitude of a location and the orientation of the buildings. It is well known that the Earth both rotates along its tilt axis and orbits around the sun, and the availability of solar radiation on Earth changes from place to place, and from time to time. The relative position of a place on Earth to the sun influences how much solar radiations it receives as well as the position of the sun on the sky.

3.3.1.1. Daylight and site planning

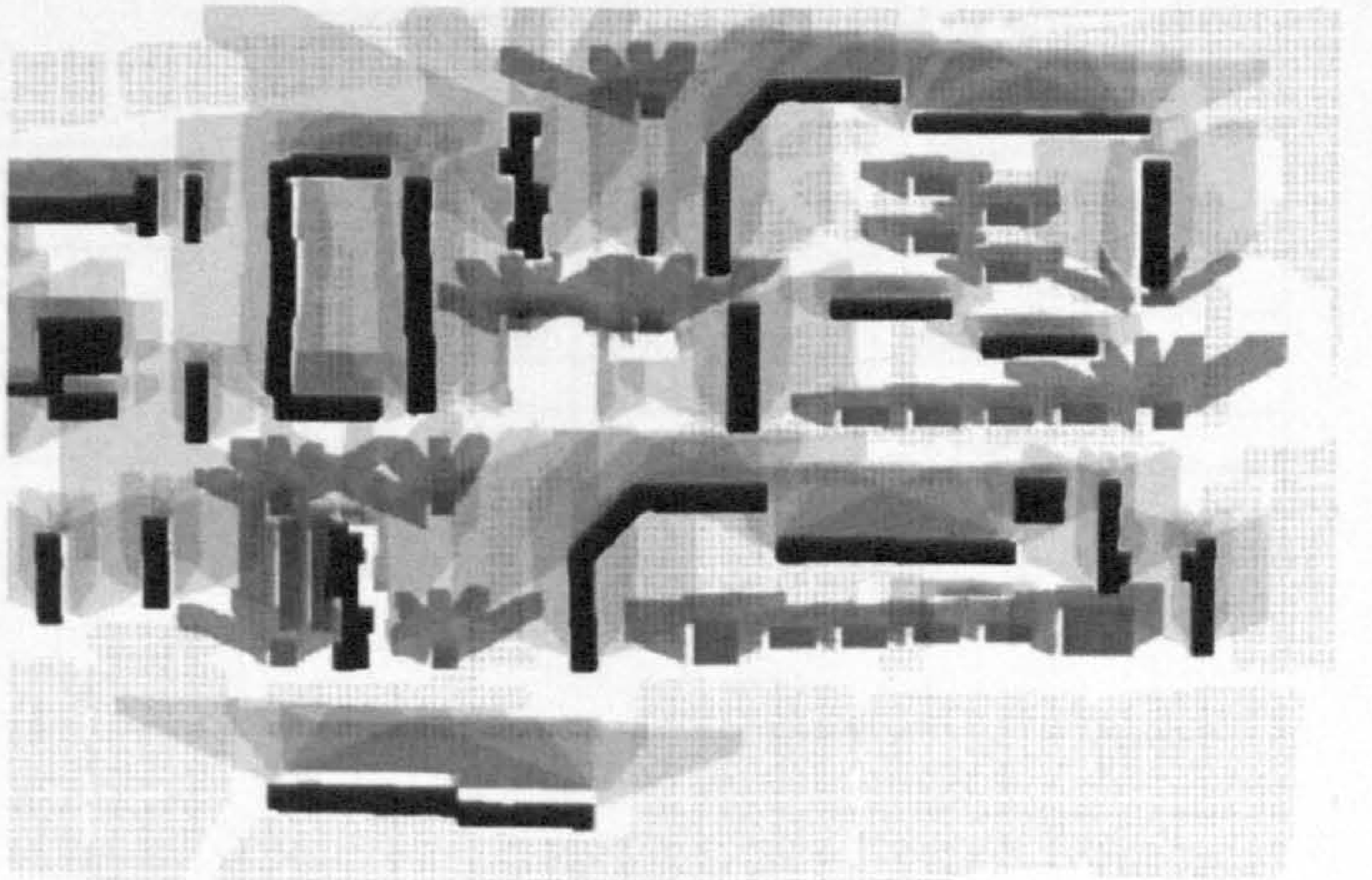
3.3.1.1.1. Overview

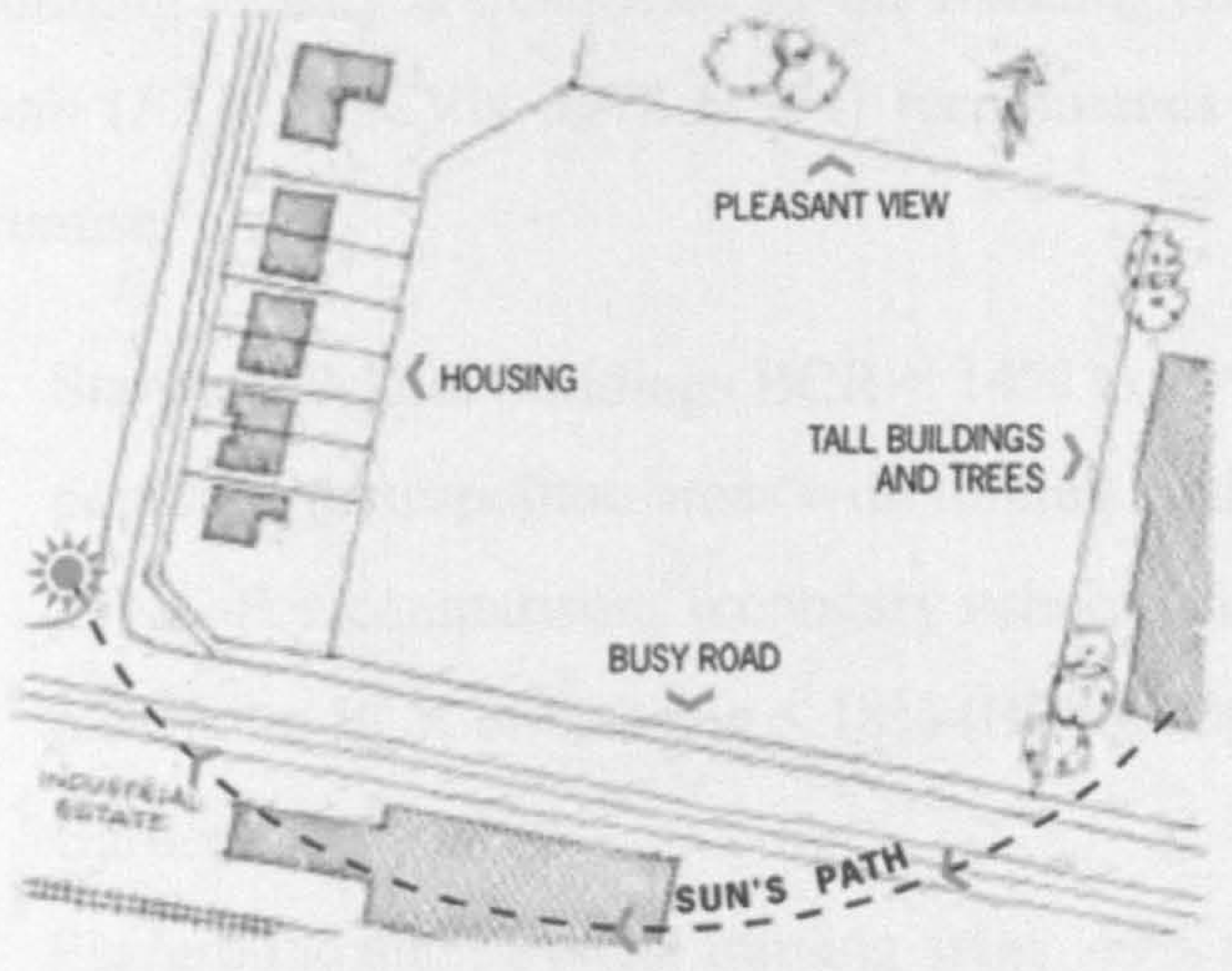
Because positioning of the buildings has a major impact on defining the quantity and quality of natural light entering the classroom, site planning plays an important role in the design process. Specifically, in HCMC, majority of the city's secondary schools are located within densely built areas with buildings competing with each other for land, daylight access and natural ventilation.

Good site planning can be achieved by manipulating the layout (both site and classroom arrangement layout), building density, orientation and the wise use of terrain and environment features. For example, traditional Vietnamese architecture often have main facades facing South or South-East and the landscape often has large water surfaces and green spaces. The water surfaces help to soften, reflect and diffuse daylight. Trees provide shading and interesting views.

Figure 3.3

Shading study in a large-scale urban area in Berlin. Existing building blocks are shown in black, proposed new buildings in grey. It is important to carry out such study for developing a school master plan that stimulates the impact of surrounding urban space on its access to daylight (SHC, 2000).





This figure represents a notional site with commonly occurring features:
neighbouring tall building and trees;
pleasant view;
busy road and view to industrial estate;
neighbouring housing.

For the purpose of the example, the north point has been placed to the top of the site.

The plan is not to scale.

The following diagrams indicate some advantages and disadvantages of placing a school in various positions on the site: for clarity the plan is over-simplified.

It will be seen that the best result must be a compromise after the various components have been considered.

DIAGRAM 'A' BUILDING ON NORTH OF SITE

	NORTH FACING CLASSROOMS	SOUTH FACING CLASSROOMS
ORIENTATION	low sky luminance	high sky luminance
SOLAR GAIN	none	risk of gain in summer
OVERSHADOWING	none	none
VIEW	very pleasant	less pleasant
LIGHT TRESPASS	a possibility	a possibility

DIAGRAM 'B' BUILDING ON EAST OF SITE

	EAST FACING CLASSROOMS	WEST FACING CLASSROOMS
ORIENTATION	medium sky luminance	medium sky luminance
SOLAR GAIN	little risk	little risk
OVERSHADOWING	In early morning from tall buildings	none
VIEW	less pleasant	pleasant
LIGHT TRESPASS	a probability	a probability

DIAGRAM 'C' BUILDING ON WEST OF SITE

	EAST FACING CLASSROOMS	WEST FACING CLASSROOMS
ORIENTATION	medium sky luminance	medium sky luminance
SOLAR GAIN	little risk	little risk
OVERSHADOWING	none	none
VIEW	pleasant	less pleasant
LIGHT TRESPASS	low possibility due to screening by school	low possibility due to screening by school

DIAGRAM 'D' BUILDING ON SOUTH OF SITE

	NORTH FACING CLASSROOMS	SOUTH FACING CLASSROOMS
ORIENTATION	low sky luminance	high sky luminance
SOLAR GAIN	none	risk of gain in summer
OVERSHADOWING	none	none
VIEW	very pleasant	least pleasant
LIGHT TRESPASS	a possibility	a possibility

Figure 3.4 Daylight and Site layout analyses in British classroom lighting code. (BB:90, 2010).

3.3.1.1.2. *Building density*

Building density is quantified by the *Building coverage ratio* (*BCR*) and *Floor area ratio* (*FAR*). TCVN 3978 (1984) recommends the following BCR for the school premise:

- Standard School buildings BCR = 14% to 20%. For schools located in dense and populous metropolitan areas with limited land allowance, it is allowed for BCR = 25%. For comparison, secondary schools in the UK are recommended to have maximum BCR of building ≤ 18% (BB98, 2004).
- Gardens: 16% to 20%
- Playground and physical training areas: 40% to 45%.
- Pathways and access road 15%.
- Trees and green vegetation should cover 40% to50% of the site.

In terms of Floor Area Ratio (FAR), TCVN: 3978 (1984) requires that school buildings must not be built higher than four levels. In contrast US guideline for high performance schools in a hot-humid climate recommends single-story school design. (NREL, 2002).

3.3.1.1.3. *Orientation*

Good site orientation is among the key design elements of tropical architecture. It helps in integrating passive and active solar strategies, maximizing daylight use, taking advantage of natural ventilation and prevailing wind patterns. In a tropical climate, most of the guidelines often recommend that the long axis of the building is orientated along the East-West axis with minimum windows on the East and West walls (NREL, 2002; McGee, et al., 2008).

Since classrooms in Vietnam are often designed in a fixed layout; classrooms can be arranged in a linear layout along the West-East axis; main windows are orientated to North, South or South East to optimize the daylight contribution and to catch cool breeze for ventilation.

The Vietnamese classroom design codes, TCVN: 3978 (1984) and TCVN: 5713 (1993), require that all classrooms must be day lit mainly from North and North East windows. Daylight should come from the student's left hand side (since majority of the students are right-handed). For the HCMC climate, Prof. Pham (2006) suggests that South or South East elevation usually enjoys the best natural ventilation (see figure 3.6). Therefore, it is often seen that schools classrooms have windows located on both side walls (North and South).

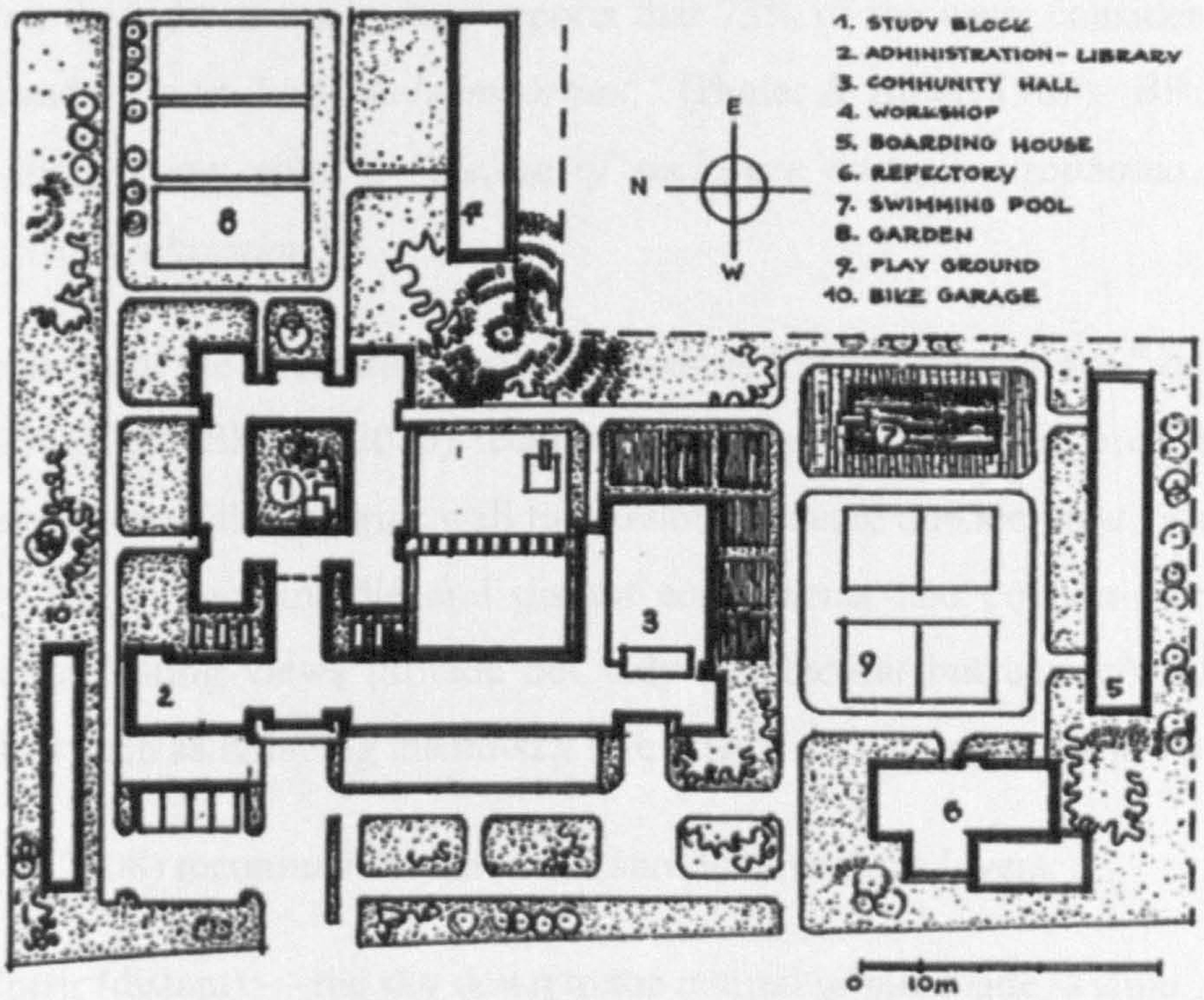


Figure 3.5 Typical standard school site layout in Vietnam. (UNICEF, 1982)

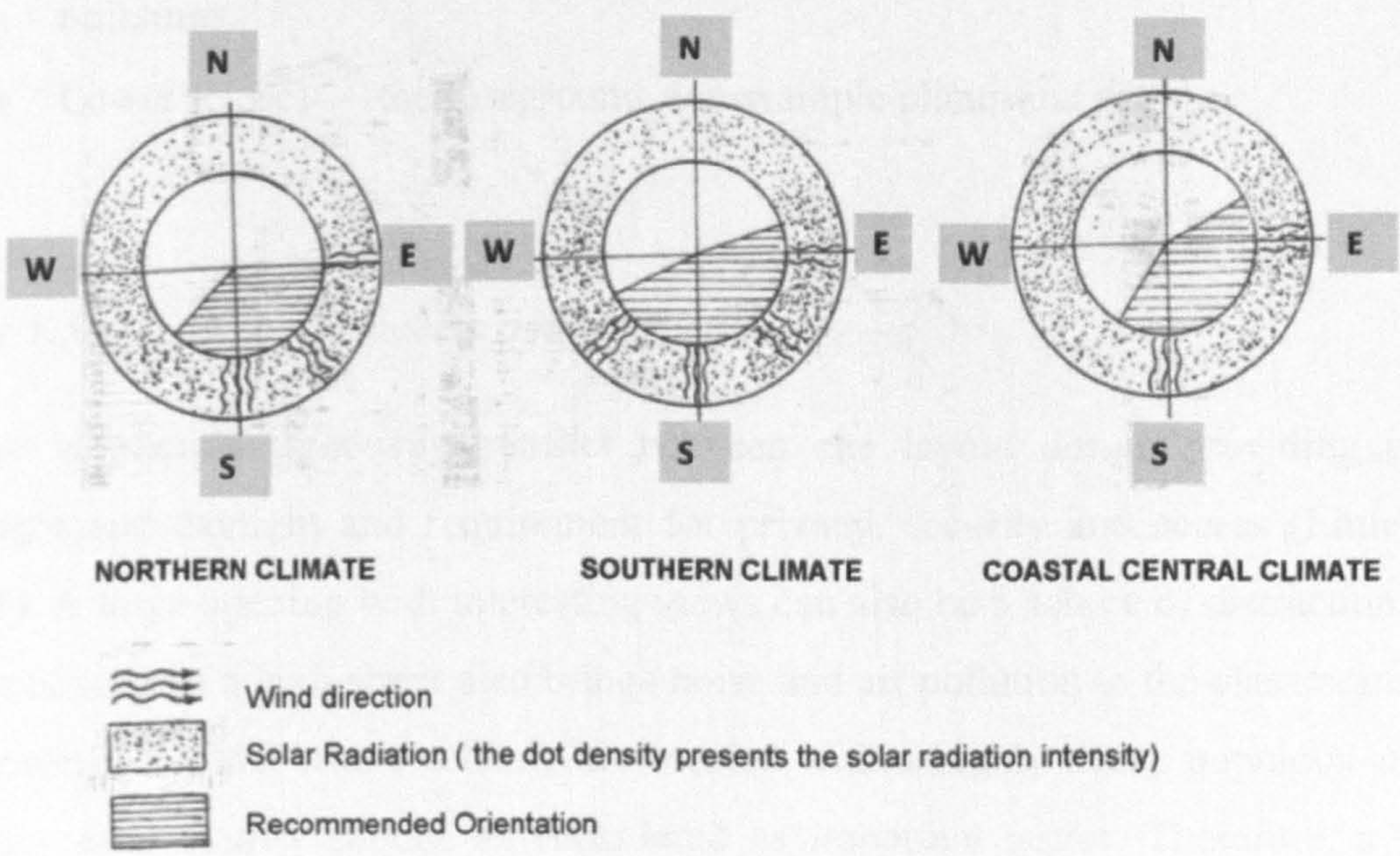


Figure 3.6 Good orientation, solar radiation and wind direction for Vietnam's climate. HCMC is located within the Southern Climate zone. (Pham, et al., 2006)

3.3.1.1.4. View

Interesting views provide the connection to the outdoors. Windows not only provide daylight but also a sense of time, weather and distant focal points – all of which prevent fatigue and contribute to greater alertness in class (Designlights, 2009).

A study on daylight at work place reports that 73% of the users considered having windows and view as *"extremely important."* (Butler & Biner, 1989). BB:90 (2010) suggests that a view gives a *"feeling of enclosure and claustrophobia, and also provides visual relaxation".*

However, none of the Vietnamese codes addresses the requirement for "view". Both BB:87 (2003) and BB:90 (2010) recommends a minimum glazed area of 20% of internal elevation of the exterior wall to provide adequate outside view. View should preferably have close, middle and distant components and contain some natural elements. Interesting views provide not only satisfaction but also contribution on other factors such as reducing the no-sky line effect, i.e. where no sky is visible.

BS 8206-2 (2008) recommends that views should have three layers:

- Upper (distant) — the sky down to the natural or manmade skyline.
- Middle — natural or man-made objects such as fields, trees, hills and buildings.
- Lower (close) — the foreground, for example plants and paving.

3.3.1.1.5. Privacy, access and distraction

There is often a three-way conflict between site layout design providing good sunlight and daylight and requirement for privacy, security and access (Littlefair, 1991). A large opening with interesting views can also be a source of distraction and a direct view to a high street also brings noise and air pollution to the classrooms. In the case of HCMC where schools are located within highly dense populous areas, privacy and security should be considered as important issues. Therefore, a well designed layout should take into account all of these factors to balance the benefit of enjoying natural light and also its negative impacts.

3.3.1.1.6. Site planning and daylight access

The external environment has a major role in interior illumination. To safeguard adequate access to daylight, several local planning authorities need to assess the impact of new buildings on existing neighbourhood's daylight access prior to granting building permission. Apart from the regulations on Building coverage ratio (BCR) and Floor area ratio (FAR), the Vietnamese codes do not provide any further specific requirements or methods to evaluate the daylight access of the site.

In the UK, the right of individuals to have access to daylight is well respected; it is legally protected under the "*Rights of Light*", which is a form of easement in English law against threats from new constructions or extensions to existing buildings. The assessment is often based on the fact that minimum 0.2% sky factor is required for reading and other work involving visual discrimination (Anstey & Harris, 2006). Another method which is also often used in planning applications is the method developed by P.J. Littlefair (Littlefair, 1991). A summary of P.J. Littlefair method is given in appendix M.

In high density urban space, assessing daylight is not an easy job. In Hong Kong, one of the densest cities in the world, some efforts have been made to develop an easy and effective method of using *Vertical Daylight Factor* (VDF) to evaluate the daylight site context.

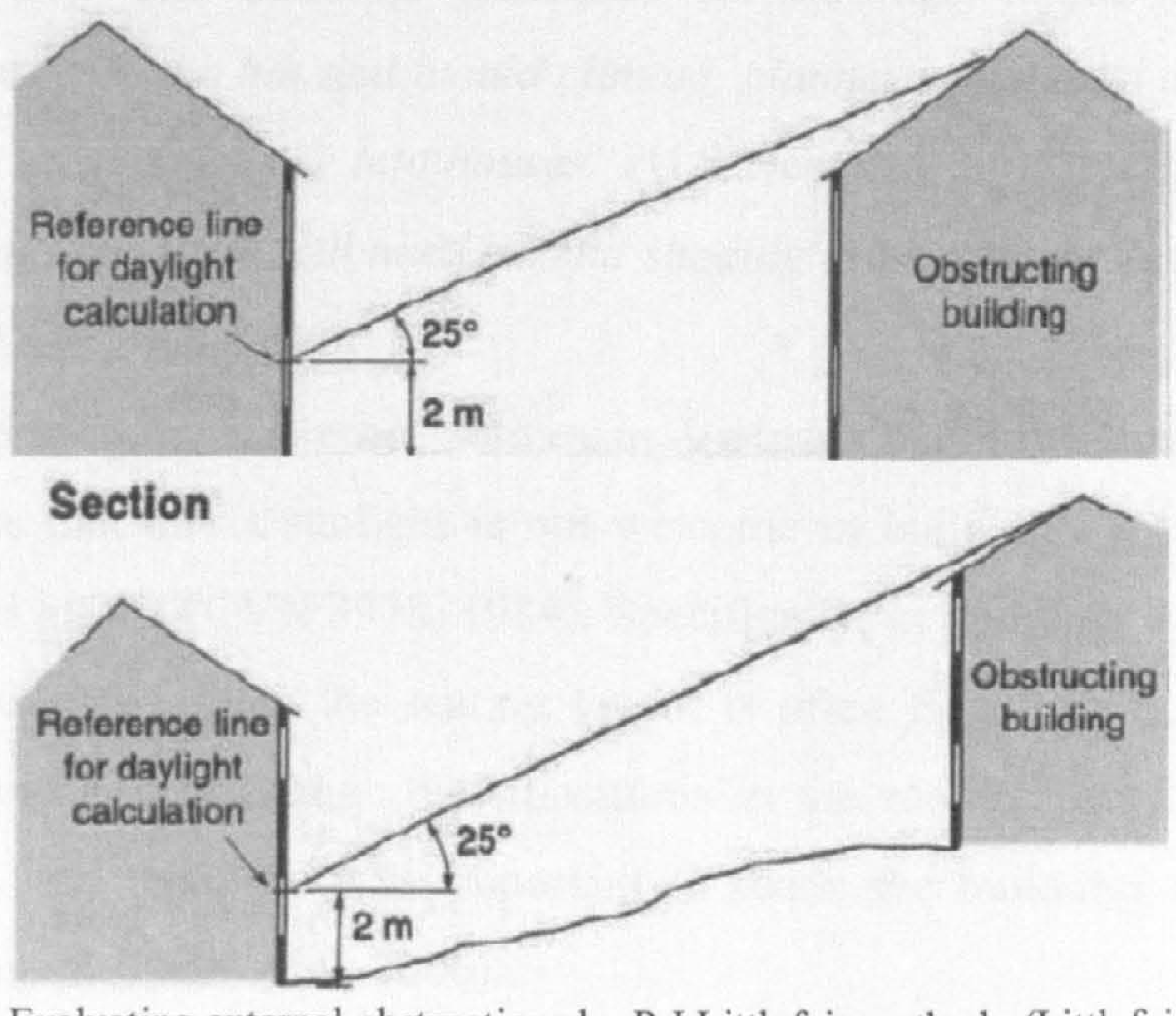


Figure 3.7 Evaluating external obstructions by P J Littlefair method. (Littlefair, 1991)

3.3.1.1.7. Access to sunlight

European codes, such as BS 8206-2 (2008), often require buildings to have adequate access to sunlight. Littlefair (1991) suggests that people prefer having sun lighting in the interior. BS 8206-2 (2008) suggests that " *Interiors in which the occupants have a reasonable expectation of direct sunlight should receive at least 25% of probable sunlight hours , at least 5% of probable sunlight hours should be received during the winter months, between 21 September and 21 March*". In the UK, the popular method to estimate access to sunlight is using the sunlight indicator developed by P.J Littlefair (1991).

However, it is the fact that sunlight availability greatly varies to the latitude. These above recommendations are based on the fact that there is very little sunlight available during European winter time. For instance, in midwinter in Britain, daily sunshine hours are only one to two hours (BBC, 2010). This is among the main reasons that cause *Seasonal Affective Disorder* (aka SAD). Long winter with little sunlight is proven to link to the increases in the production of melatonin, which is an important chemical for the human brain (NYTimes, 2002).

However, in tropical climate, due to prolonged excessive solar radiation, direct sunlight should be kept out of the interior (McGee et al, 2008). For comparison, in HCMC, the average number of hours of sunshine during the period of September to March is 7 hours, and the solar radiation is approximately 700 W/m^2 (see section 2.3.4.3, page 25). The building guidelines for hot and humid climate often recommend that: " *In the hot and humid climate, planners should do all they can to avoid the entry of solar energy into houses*" (U.S Department of Energy, 2004), and "*In tropical buildings these will need careful shading to prevent the ingress of direct sunlight*" (CLEAR, 2004).

Both Vietnamese codes and other studies in Vietnam building climate, including HCMC, address that direct sunlight is not welcome in building's interior to avoid overheating and glare (TCVN:3978, 1984). Specifically, in buildings such as offices or school classrooms, where the seating layout is often fixed, the occupants have very little opportunity to change their positions in the room to avoid exposure to direct sunlight, and therefore it is important to shade the buildings against direct sunlight penetration (Pham et al, 2006).

3.3.1.2. Sky models

Sun is the main source of daylight. However, as a result of atmospheric scattering and reflection off clouds, the entire sky dome also emits light. As all of these conditions change every day it is difficult to define the specific brightness of the sky. The *Commission International de l'Eclairage* (CIE) has tried to standardize some theoretical sky models to use in calculations, the three most common are uniform, overcast and clear sky.

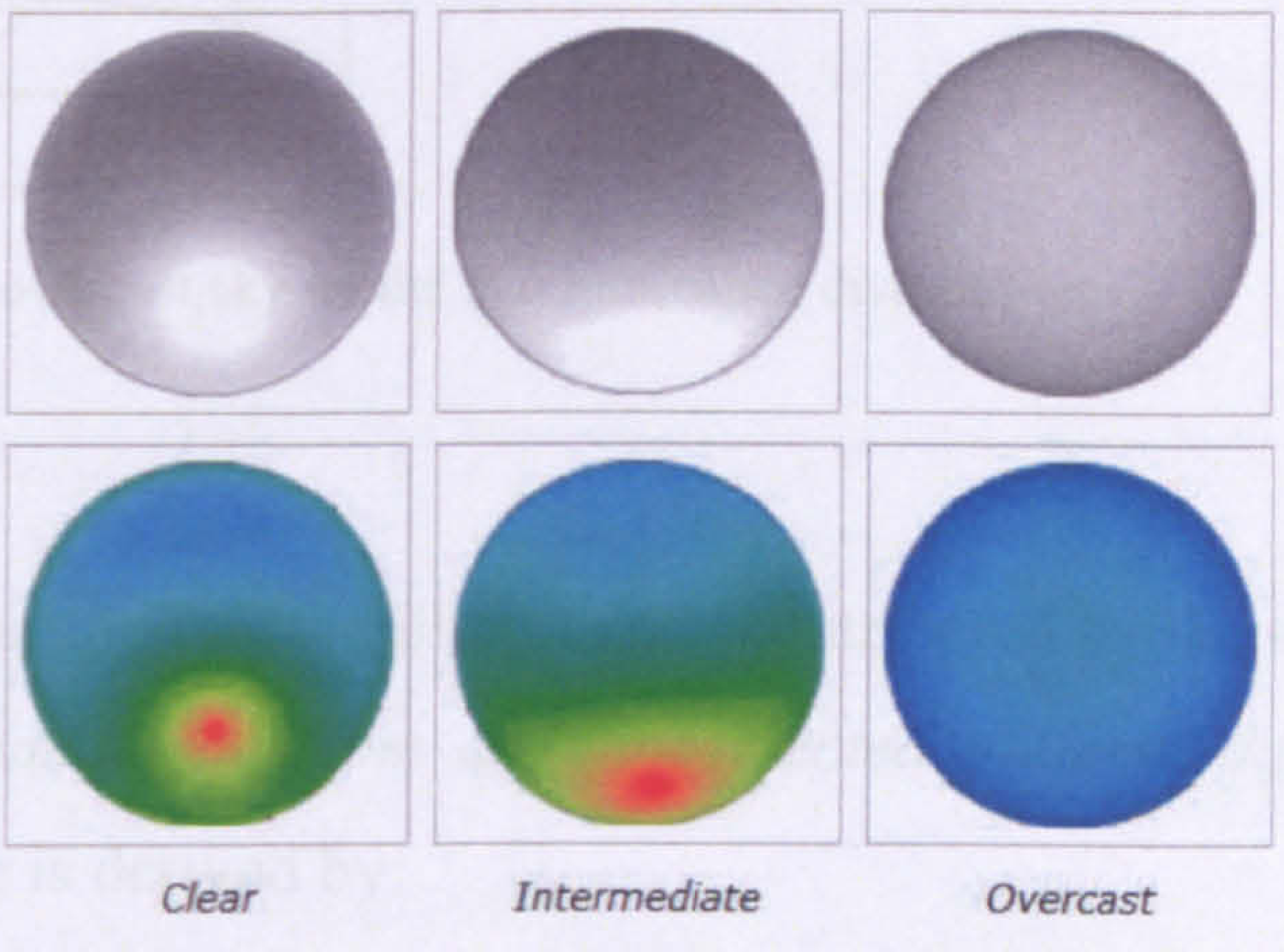


Figure 3.8 A comparison of the three main CIE sky models (Natural Frequency, 2010).

The simplest sky model is uniform sky characterised by a sky with a constant value of luminance in all directions. Overcast sky represents the worst case, when the sky is mostly clouded. The clear sky model considers the presence of the sun; it is a more complex sky model with non-uniform luminance distribution where the area around the sun is much brighter than in other place (see figure 3.8).

Uniform sky is often used in simple calculations and some researchers suggest that the uniform sky is quite appropriate for tropical regions as it simplifies the calculation process a lot (Natural Frequency, 2010). Overcast sky is the standard sky model often used in European daylight code. As Vietnamese daylight code is derived from Russian codes it is also based on the CIE overcast sky model.

Uniform sky model represents a sky with a constant value of luminance in all directions. Overcast sky model is characterized by the fact that the zenith is three times brighter than the horizon. In this model, the relative luminance of the sky at angle of elevation θ_{sky} , L_θ [cd/m^2], measured with respect to the horizon and is derived as:

$$L\theta = \frac{L_z(1+2\sin\theta)}{3} \quad (3.1)$$

Where L_z: Luminance of the sky at the zenith [cd/m²]

θ_{sky} and L_θ are defined in figure 3.9

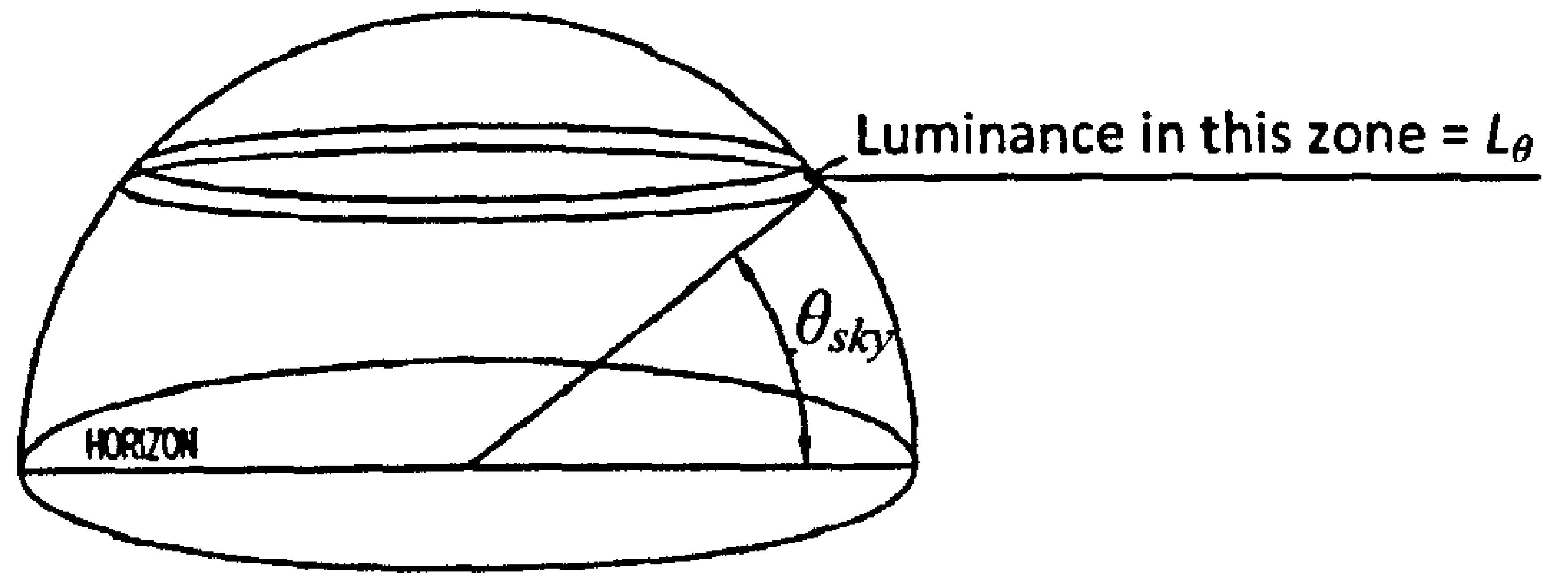


Figure 3.9 CIE overcast sky model and luminance distribution.

Based on these assumptions, the illuminance contributed by the sky can be estimated. The *horizontal illuminance from an unobstructed uniform diffused sky* (E_{Hu}) of constant luminance is derived by:

$$E_{Hu} = \pi .\ L_z \quad [lx] \quad (3.2)$$

The *horizontal illuminance from an unobstructed CIE overcast sky* (E_{Ho}) is derived by:

$$E_{Ho} = \frac{7}{9}\pi .\ L_z \quad [lx] \quad (3.3)$$

Therefore, for a given sky model, the *sky index* C_{SKY} defined as the ratio between *the illuminance at the outer face of the window (Eev*, in lux) and the *illuminance on a horizontal plane received from an unobstructed sky* (*Eeh*, in lux) is fixed; C_{SKY} is described as:

$$C_{SKY} = \frac{Eev}{Eeh} \quad (3.4)$$

Where *Eev* and *Eeh* are expressed in lux and C_{SKY} is expressed as a decimal.

Values of C_{SKY}	
Uniform Sky	CIE Overcast Sky
$\frac{E_{V_U}}{E_{H_U}} = \frac{0.5\pi L_z}{\pi L_z} = 0.5$	$\frac{E_{V_O}}{E_{H_O}} = \frac{0.97 L_z}{\frac{7}{9}\pi L_z} = 0.396$

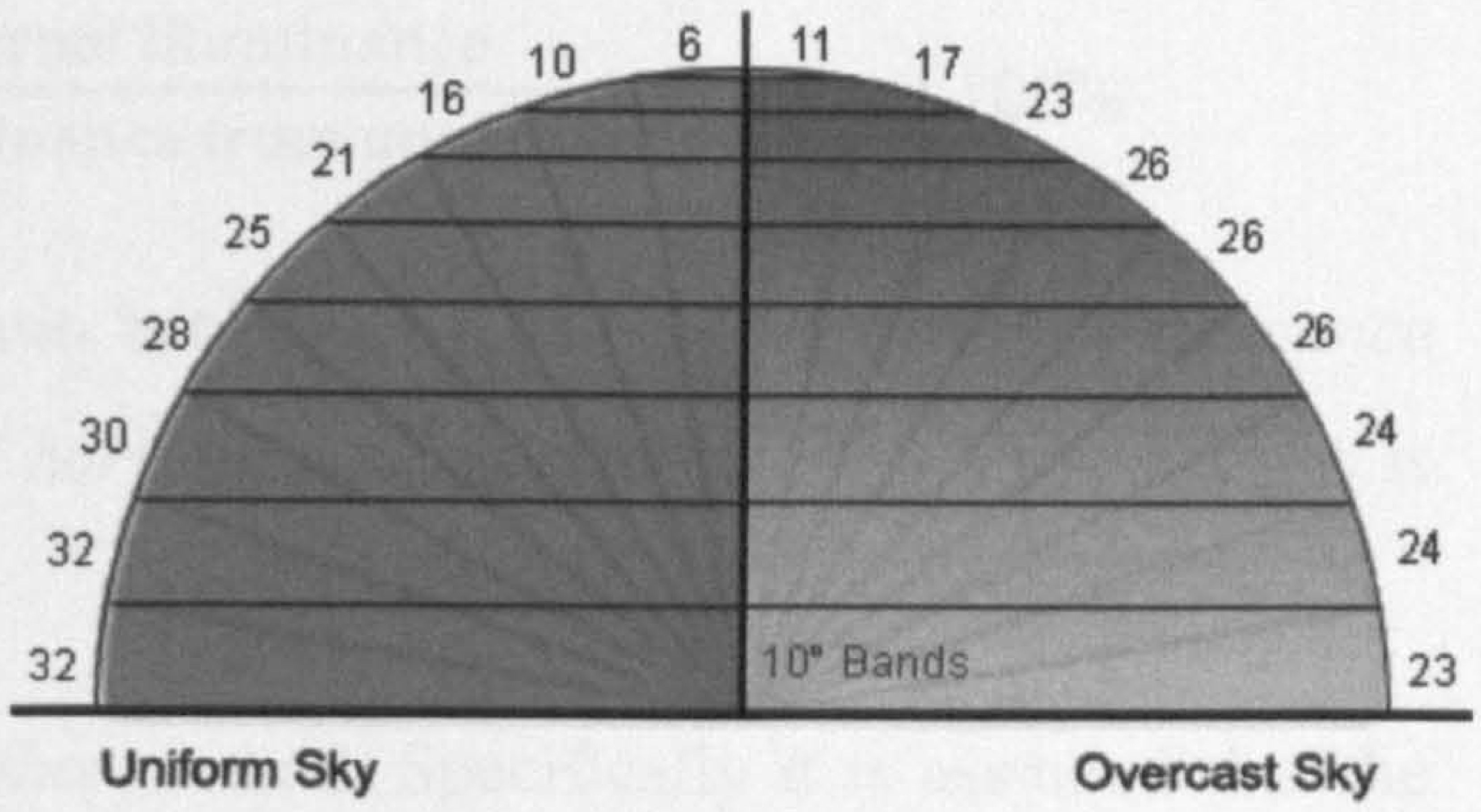


Figure 3.10 C_{SKY} values of unobstructed sky in Uniform sky and CIE overcast sky model. (Wilkinson, 2008;Natural Frequency, 2010)

According to CIE standards a clear sky produces an illuminance in the ground between 50 000 to 100 000 lux, the cloudy sky generates between 20 000 to 100 000 lux and overcast sky has the illuminance in the range between 5 000 and 20 000 lux. In practice, designers often use the *design sky value,* which is the horizontal illuminance value that exceeds 85% of the time between the hours of 9h00 and 17h00 throughout the working year, to estimate the daylight contribution in interior from *Average Daylight Factor* ($\overline{D}$). Vietnamese daylight codes suggest a design sky value of 4000 lux; while other studies suggest that design sky value for HCMC should be 10 000 to 15 000 lux (see chapter 2, section 2.2.3.2, page 16-19).

3.3.1.3. Daylight and room brightness

There are several methods for estimating daylight contribution on room brightness particularly on working plane (i.e. task illuminance). They vary from graphical methods, mathematical calculations to using physical models. Each method has advantages and disadvantages regarding its accuracy and the time and effort involved. This section describes some popular daylight calculation methods: the *Daylight Factor (DF)* method which has been adopted in many international codes, the *Waldram diagram,* and the *ĐRASTN* method introduced in the Vietnamese daylight code TCXD:29 (1991).

3.3.1.3.1. Daylight factor

The Daylight Factor (DF) method is the most commonly used calculation procedure for predicting level of daylight in buildings (Robbins, 1986; Brotas, 2004). The basic concept of the Daylight Factor is based on the following principle:

$$DF = \frac{\text{Internal Illuminance}}{\text{Horizontal illuminance from unobstructed sky}} \times 100\%$$

This means *DF* is defined as the ratio between the *indoor horizontal illuminance (Eih)* and the *outdoor unobstructed horizontal illuminance* (*Eeh*). The sunlight is excluded.

The *DF* was derived from the *split-flux* method. Specifically it is assumed that the horizontal illuminance of a given point in the interior is the sum of three components: *the sky component* (SC) - due to daylight received directly at the point from the sky, the *externally reflected component* (ERC) - due to daylight received directly at the point from external reflecting surfaces, and the *internally reflected component* (IRC) - due to daylight reaching the point after one or more inter-reflections from interior surfaces (IESNA, 2000). This principle is illustrated in figure 3.11.

To estimate the daylight contribution in interior space, *Average Daylight Factor* ($\bar{D}$) is introduced. It is expressed as the ratio between the mean illuminance in a space and that from an unobstructed external sky; it is derived as (J. Lynes 1979, as cited in Brotas 2004):

$$\bar{D} = \frac{\tau A_w \theta}{2A_r\,(1-\rho)} \qquad (3.5)$$

Where A_w Window's net glazed area [m^2].

A_r Total area of the interior surface [m^2].

θ Angle of visible sky measured in sections through the window, in degree, as in figure 3.12.

τ Diffuse transmittance of the glazing, including the effects of dirt, expressed as a decimal.

ρ Area-weighted average reflectance of the interior surface, expressed as a decimal.

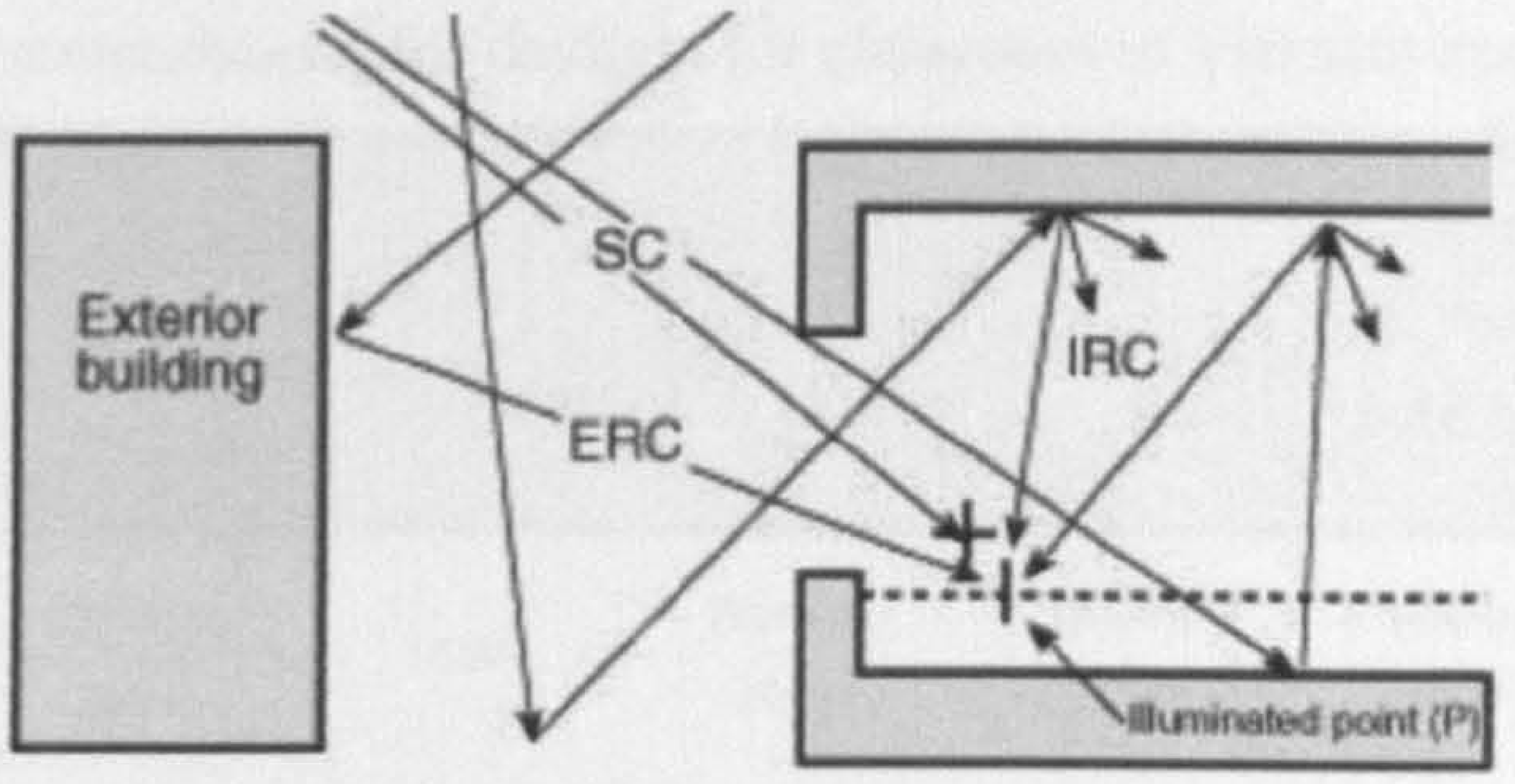


Figure 3.11 Daylight components and room brightness (IESNA, 2000)

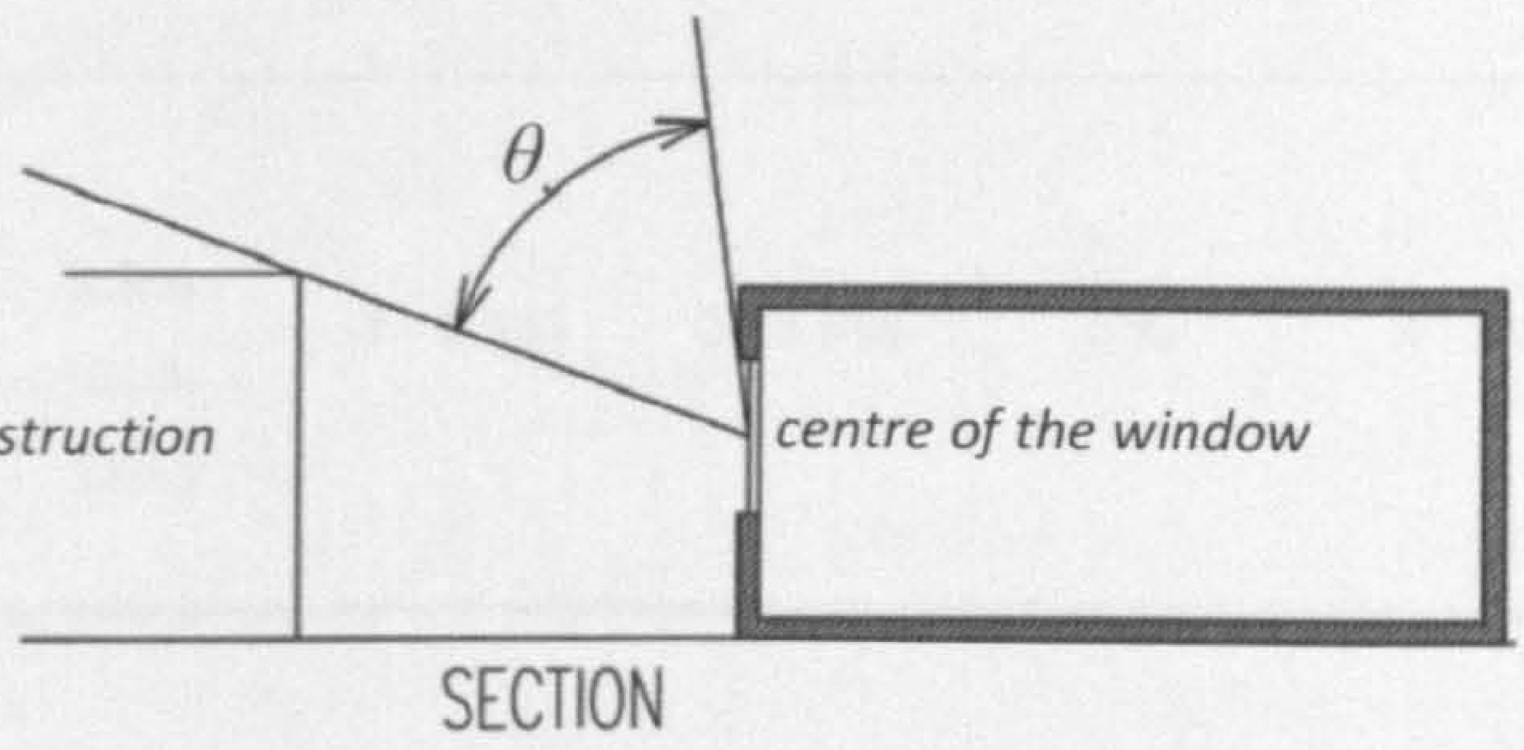


Figure 3.12 Defining angle of visible sky θ [°]

Originally, J.A. Lynes (1979) estimated that the *average daylight factor on the vertical outside window surface (D_w)* is (Brotas, 2004; Tregenza & Wilson, 2011):

$$D_W \approx \frac{\theta}{2} \tag{3.6}$$

Daylight factor method is widely used in Northern Europe, Australia, New Zealand and Northern America. It has also been adopted in the building codes of Hong Kong, Malaysia and Indonesia. In the European codes, $\overline{D}$ is calculated as per the CIE overcast sky model.

Following from this theory the *Average Daylight Factor on the working plane*, $\overline{D}_{BRE}$, can be calculated by using the formula developed by the UK *Building Research Establishment (BRE)* and adopted in the daylight code BS: 8206-2 (2008) :

$$\overline{D}_{BRE} = \frac{\tau A_W \theta}{A_r(1-\rho^2)} \tag{3.7}$$

All the definitions of (3.5) are applied for equation (3.6) and (3.7). See appendix K for further details of how these formulae are derived.

Table 3.2 Recommendations for daylight for classroom in Vietnam and others countries.

Country	Vietnam	Hong Kong	Malaysia	Indonesia	UK	Australian & New Zealand		The U.S
Source	TCXD: 29 (1991)	(Burnett, 2004)	GBI	(Binarti, 2009)	(BB:90, 2010)	(Branz, 2007)	(Millet & Bedrick, 1980)	(Heschong, 1999)
Criteria	*ĐRASTN* *i.e. minimum daylight factor at given point*	$\overline{D}$	$\overline{D}$	$\overline{D}$	$\overline{D}_{BRE}$	$\overline{D}$	$\overline{D}$	Interior illuminance
Requirements	**2 - 4%**	**2.5%** (D_w 8-12%)	**1 - 3.5%**	**2 - 3.5%**	**5%**	**4 - 5%**	**2.5 - 4%**	**15 - 50** foot-candles

Table 3.3 Recommendations for $\overline{D}$ in U.S codes . (Millet, Bedrick, 1980)

Task	Ample winter daylight (nearer equator)	Scarce winter daylight (nearer pole)
Ordinary seeing tasks, such as reading, filing, and easy office work	1.5%	2.5%
Moderately difficult tasks, such as prolonged reading, stenographic work, normal machine tool work	2.5%	4.0%
Difficult, prolonged task, such as drafting, proofreading poor copy, fine machine work, and fine inspection	4.0%	8.0%

Table 3.4 Daylight code for the U.S classrooms. (Heschong, 1999)

Daylight Code 5	Classroom is adequately and uniformly lit with daylight, such that teacher could successfully instruct with electric lights off, for most of the school year. 50± footcandles on most desks.
Daylight Code 4	Classroom has major daylight component, and could occasionally be operated without any electric lights. Daylight may have strong gradient. 30± footcandles on many desks.
Daylight Code 3	Classroom has adequate levels in limited areas, such as near windows. Some, but not all, electric lights could occasionally be turned off. 15± footcandles at some desks.
Daylight Code 2	Classroom has poor and/or very uneven daylight. Not likely to ever operate without electric lights fully on. 10± footcandles in limited areas.
Daylight Code 1	Classroom has minimal daylight. Very small and/or darkly tinted windows or inadequate toplighting. Not possible to operate without electric lights. 5± footcandles in limited areas.
Daylight Code 0	Classroom has no daylight.

In British codes, BS:8206-2 (2008) recommends that when $\bar{D}_{BRE}$ is 5% or more, the interior is considered as a good day-lit room and will not required additional electric lighting. If $\bar{D}_{BRE}$ falls below 2% then full use of electric lighting will be required (BB:90, 2010). Furthermore, $\bar{D}_{BRE}$ is also used to assess the interior daylight uniformity ratio. For side lit room, the ratio of minimum daylight factor to average daylight factor should be 0.3 - 0.4 whereas in top-lit room it can be expected to be as high as 0.7. However, there is a limitation for using this method: It should not be used where the windows face complex external obstructions.

In Australian and New Zealand codes, classroom should have $\bar{D}$ of 4% to 5%. The Australian energy efficiency rating system, *Green Star* (GS), recommends 2% $\bar{D}$ for learning spaces. It awards one *GS* point for 30%, two *GS* points for 60% and three *GS* points for 90% of the nominated space for achieving 2% $\bar{D}$. An extra point is awarded if it is demonstrated that 50% of learning spaces achieve 4% $\bar{D}$ for 95% of the area of the learning space at desk height level (USG, 2009). All of these recommendations are summarised in table 3.2

3.3.1.3.2. Waldram diagram

Another popular and simple graphical method often employed in site planning is using the *Waldram diagram*. The Waldram diagram is a rectangular representation of half of the sky vault. Figure 3.13 shows a schematic of this representation, where the vertical axis corresponds to the *altitude angle* γ_0, and the horizontal axis represents the *sky-wall azimuth* z. A particular feature of the Waldram diagram is that the vertical scale of altitude γ_0 and *horizontal scale* of z are so contrived, as to make equal areas on the diagram represent equal contributions of illuminance from the sky (Wilkinson, 2008).

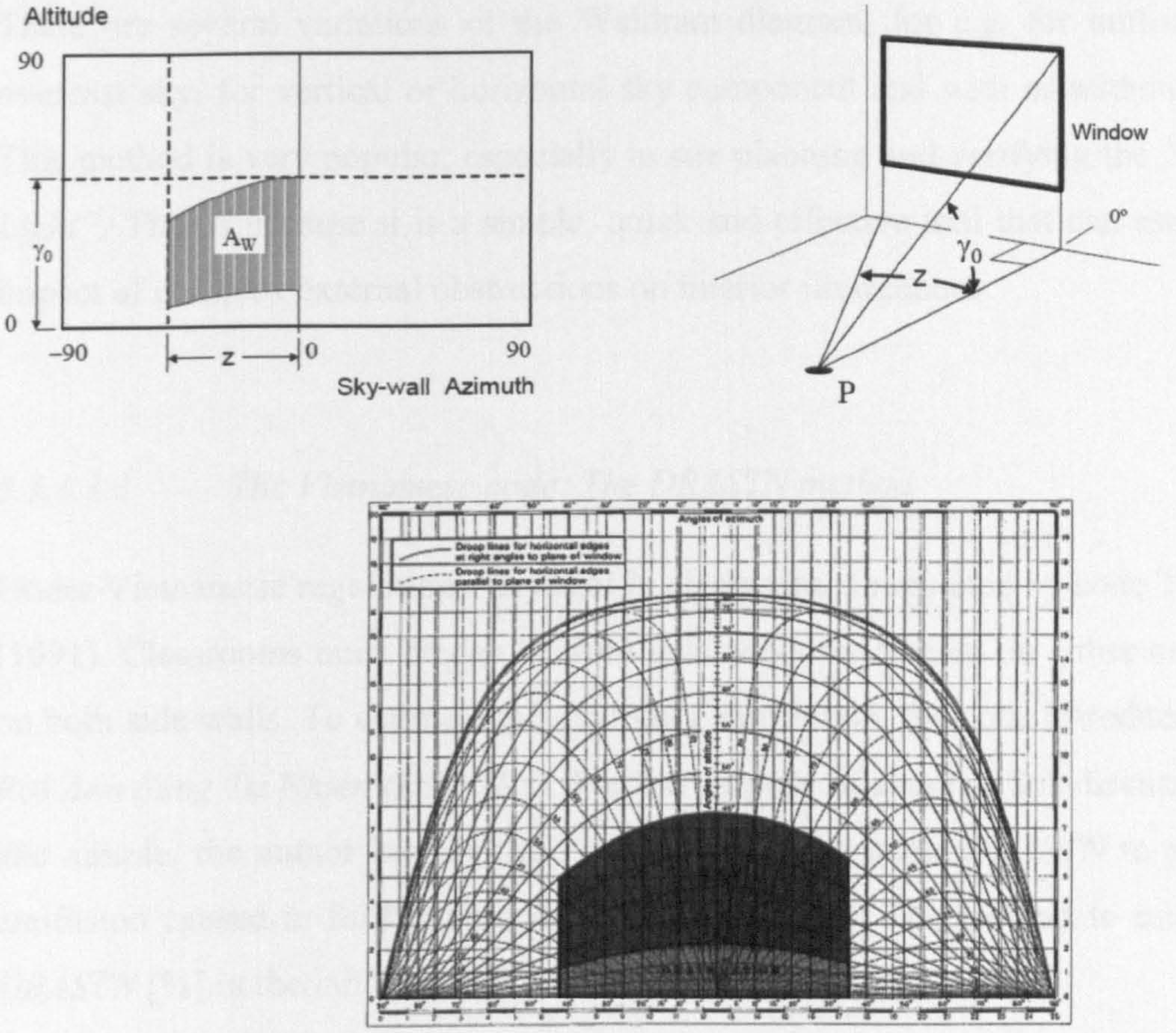


Figure 3.13 Schematic of *Waldram Diagram* and an example of a building being plotted in Waldram diagram. (Wilkinson, 2008)

External obstructions can also be plotted in the same way as the window is plotted. The *Sky Factor* SF (in uniform sky, or *sky component* SC in CIE overcast sky) at the given interior point is proportional to the unobstructed window area $Aw_{unobstructed}$ on the Waldram diagram, derived by:

$$SF = \frac{Eih}{Esky}100\% = \frac{Aw_{unobstructed}}{2AD}100\% \tag{3.8}$$

Where: *SF:* Sky Factor, [%]

Eih: Interior horizontal illuminance, [lux]

Esky: Illuminance of the whole sky, [lux]

$Aw_{unobstructed}$: Window area or unobstructed area plotted in Waldram diagram, [cm^2]

AD: Area of the Waldram diagram, [cm^2]

There are several variations of the Waldram diagram, for e.g. for uniform or for overcast sky, for vertical or horizontal sky component and with or without glazing. This method is very popular, especially in site planning and verifying the *"Rights of Light"*. This is because it is a simple, quick and effective tool that can estimate the impact of complex external obstructions on interior illuminance.

3.3.1.3.3. The Vietnamese code: The ĐRASTN method

Under Vietnamese regulations, daylight in classroom is regulated by code TCVN: 29 (1991). Classrooms must be day lit from side windows located on either one side or on both side walls. To estimate the daylight contribution, the code introduces the *Độ Rọi Ánh Sáng Tự Nhiên (ĐRASTN)*. For the purpose of keeping this discussion clear and simple, the author has kept the original Vietnam name *ĐRASTN* to avoid any confusion caused in further comparison in later parts. The method to estimate the *ĐRASTN* [%] in the initial design process requires two steps:

- STEP 1: Defining the window area to comply minimum *ĐRASTN*, by using the equations provided by the code.
- STEP 2: Verifying the *ĐRASTN* by using *Danhiluc diagram.*

Pham (2006) suggests that the *ĐRASTN* equation, that used in step 1, was originally derived from the theory developed by the Soviet illuminance engineer N. M. Gusev (Gusev & Makarevich, 1973) and an empirical formula to calculate Daylight Factor using lumen method developed by H.G.Fruhling in 1928 (Kota & Haberl, 2009).

The TCVN: 440 (1987) defines *ĐRASTN* as the ratio between the interior illuminance at a given point on the working plan and the exterior horizontal illuminance given by the unobstructed sky. This means the principle of *ĐRASTN* is quite similar to the Daylight Factor (i.e. $\overline{D}$) approach discussed in earlier sections. However, it should be noted that *ĐRASTN* is a minimum value calculated at given point on the reference plane (i.e. minimum daylight factor) where $\overline{D}$ is calculated from the average illuminance of all interior surfaces and $\overline{D}_{BRE}$ is calculated from the average illuminance of the whole reference plane.

The second step adopts the sky diagrams developed by another Soviet Union engineer A.M. Danhiluc. This diagram was widely used in the Soviet Union before 1990 and it was adopted in the Vietnamese code in 1975. It is noted that all of these concepts (i.e. N. M. Gusev, A.M. Danhiluc, and H.G.Fruhling) are based on a simple uniform sky model. However, the Vietnamese code introduces the *luminance coefficient* (*q*) to convert the results for use under standard *CIE* overcast sky model. Sun light is excluded in all these calculations. Details of each step of the *ĐRASTN* method are described below:

STEP 1: ***Defining the window area to comply minimum ĐRASTN*** [%]

The main purpose of this step is to give a quick estimation of *Window area* (S_{cs}) providing adequate daylight at work place. The S_{cs} is calculated by the equation developed by N. M. Gusev:

$$\frac{S_{cs}}{S_s} = \frac{Eih.K.\eta_{cs}}{Eeh.\tau_{cs}.r_1} \tag{3.9}$$

By the definition of *ĐRASTN*, the above formula can be rearranged as:

$$100.\frac{S_{cs}}{S_s} = \frac{ĐRASTN.K.\eta_{cs}}{\tau_{cs}.r_1} \tag{3.10}$$

Where:	S_{cs}:	Total window area [m^2]
	S_s:	Total floor area [m^2]
	K:	Maintenance factor (by dirt, cleaning frequency), expressed as a decimal, often taking K=1.2
	η_{cs}:	Window-Room index, expressed as a decimal, obtained from table J.1 of appendix J
	τ_{cs}:	Window transmittance index: $\tau_{cs} = \tau_1.\tau_2.\tau_3.\tau_4.\tau_5$
	τ_1:	Glazing transmittance index, expressed as a decimal, obtained from table J.2 of appendix J

τ_2: Window frame index, expressed as a decimal, obtained from table J.3 of appendix J

τ_3: Roof structural index for roof windows; for side windows the value is given as $\tau_3 = 1$

τ_4: Shading device index, expressed as a decimal, from table J.5 of appendix J

τ_5: Protection screen index for roof windows, expressed as a decimal, for side window $\tau_5 = 0.9$

r_1: Reflectance correction factor by internal reflected light and external reflected light from ground, expressed as a decimal, obtained from table J.6 of appendix J.

Table 3.5 Requirement of minimum *ĐRASTN* [%] for school; excerpt from TCVN:29(1991)

BUILDING TYPE	Calculating plan height [m]	ĐRASTN [%]	
		Top lighting and combined lighting	Side lighting
2.1.Classroom and lecture hall		4	2
2.2. School laboratory		-	2
2.3. Drawing and designing workshop		4	2
2.3. Drawing and designing workshop		3	1.5
2.4. Metalwork workshop	0.8	3	1.5
2.5. Woodwork workshop		3	1.5
2.6. Tailoring, sewing /Cooking classroom		3	1.5
2.7. Sports hall		-	1
2.8. Administration office		2.5	1
3.1. Library reading room		4	2

The code TCXD: 29 (1991) defines that if the room is lit through one side window, the reference point is defined by the intersection of the room section and the working plan, offset 1m from the wall opposite the window. If the room is lit from both sides, the reference point is defined at the middle of the room, at the height of the working plan. In a classroom it is often set at desk height (0.8m). Minimum *ĐRASTN* for a classroom, as shown in table 3.5, is required to be 2%. The ratio of the minimum to the average *ĐRASTN* values in the room should not excess 3:1.

The code does not describe how the equation (3.10) is derived. The original work by N. M. Gusev is in Russian, and it is not easy to obtain a copy nowadays. However, it is said that his work is influenced by an earlier theory developed in the late 1920s by the German scientist H.G.Fruhling (Pham, Nguyen, & Tran, 2006). Based on lab experiments, H.G.Fruhling assumes that under a sky dome with constant luminance distribution, the external vertical illuminance *Eev* received from the direct sky component, measured at the outside of the window surface is calculated by:

$$Eev = C_e.Eeh \qquad (3.11)$$

Where:	*Eeh:*	External horizontal illuminance at open ground, received from unobstructed uniform sky [lx]
	C_e:	Coefficient of Utilization, expressed as a decimal

The *Coefficient of Utilization* (C_e) represents the light reduction by external obstructions and it is dependent on the obstructing angle γ_c (similar to θ in *BRE ADF* method) and the relative position of the window to the opposite buildings. It remains unclear as to how this C_e is calculated, as it can be obtained from a series of utilization factor tables developed by H.G.Fruhling. Furthermore, with the following equation, H.G. Fruhling estimates that the light reaching the task plane *(Eih)* is a fraction of the total light entering the windows *(Eev),* scaled by *interior daylight distribution coefficient* (Π) and the ratio of the total net window area (S_{cs}) to total floor area (S_s):

$$Eih = Eev.\eta.\frac{S_{cs}}{S_s} = Eeh.C_e.\eta.\frac{S_{cs}}{S_s} \rightarrow \frac{S_{cs}}{S_s} = \frac{Eih}{Eeh.C_e.\eta}$$

Where S_{cs}: Total window area [m^2]

S_s: Total floor area [m^2]

η: Interior daylight distribution coefficient for light reaching the task plane, dependent on the room shape, position of the window and surface reflectance, expressed as a decimal.

However, it has been noted that Frulling's formula does not take into account the light coming from the ground and the external reflected component or inter-reflection of light in the room (Kota & Haberl, 2009). In the 1970s, N. M. Gusev then furthered this concept by adding some correction factors such as *window transmittance index*(τ_{cs}), *Window-room index* (η_{cs}) and *Reflectance correction factor* (r_1). In the code, there is no further description or equation to show how these correction factors are calculated. They can be obtained from series of tables provided in the code (see appendix J).

Based on the tables of values presented in appendix J, it seems that the *window-room index* (η_{cs}) represents the impact of room and window geometry on light distribution in the interior of a room. It is dependent on the $\frac{L}{B}$ ratio of room length (L) to room depth (B), and the $\frac{h1}{B}$ ratio of the height of the window head to working plan (h_1) to room depth (B).

The *reflectance correction factor* (r_1) is characterized by the room geometry and area-weighted average reflectance of all interior surfaces (ρ_{tb}). It is in some ways, similar to the *BRE ADF* method.

The *window transmittance index* (τ_{cs}) is calculated from several sub correction indices (τ_1. τ_2. τ_3. τ_4. τ_5), which are mostly related to window properties. The *glazing transmittance index* (τ_1) is defined by the type of glazing used. The *window frame index* (τ_2) is defined by the construction of the window (e.g. window frame or window bar). It seems that τ_2 is the correction factor for the light lost by the window's construction. Special attention should be given to the *shading device index*

(τ_4) which includes consideration of different types of external shading devices (e.g. overhangs, vertical fins, window louvers). This shading device index (τ_4) estimates the light reduction by shading devices; if there is overhang then the index τ_4 is dependent on the *vertical shading angle VSA* (as shown in figure 3.14) .Therefore, the *ĐRASTN* equation described in step 1 is independent of external obstructions, it should be emphasized that it considers window shadings, including overhead overhangs, as part of the window properties reducing the window transmittance index (τ_{cs}).

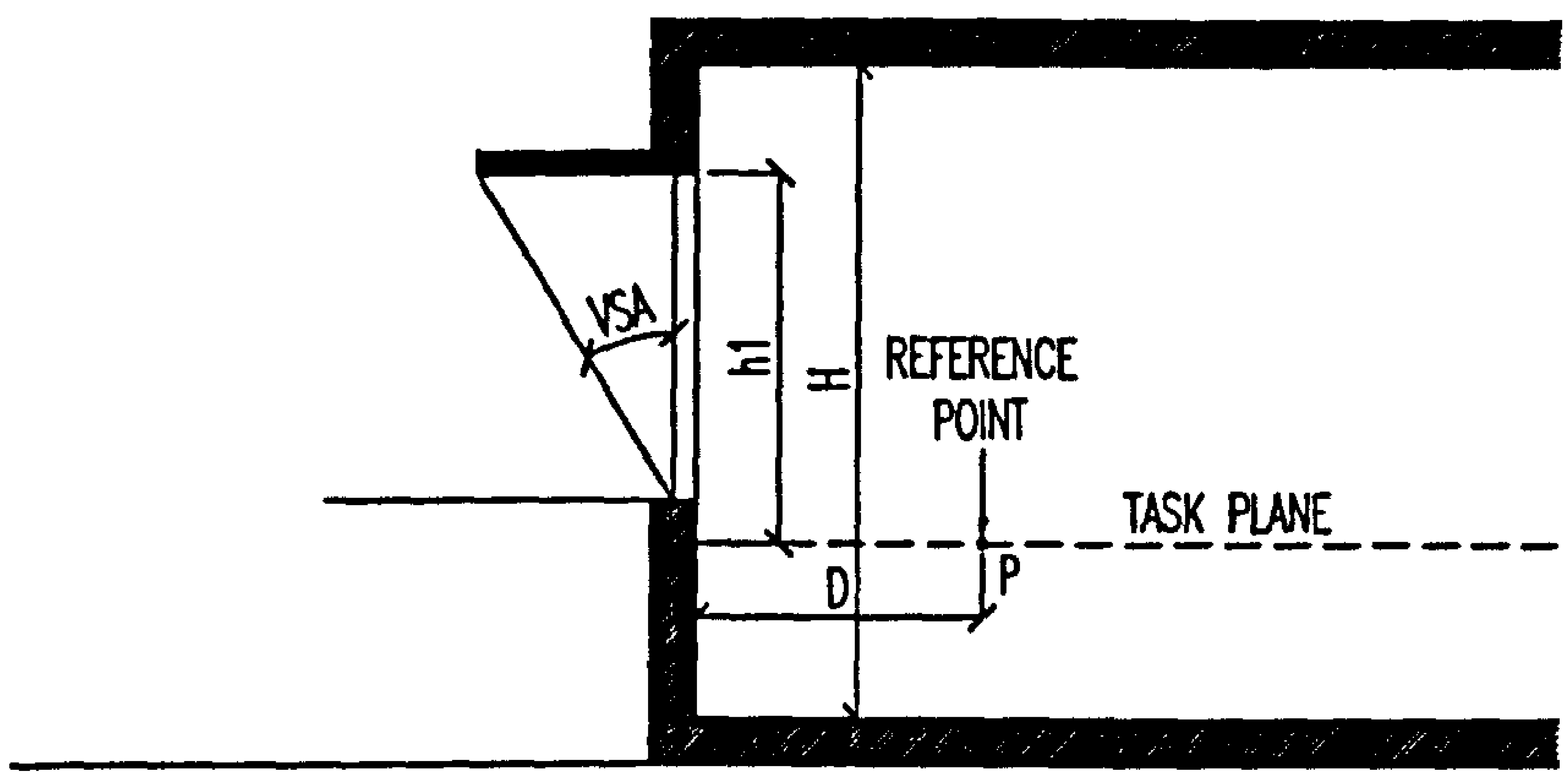


Figure 3.14 Vertical shading angle, *VSA* [°]

Generally, if R_O is the ratio between the window net area to the total floor area (i.e. window-to-floor ratio), expressed in percentage, R_O is calculated as:

$$R_o = \frac{S_{cs}}{S_s}.100 \qquad (3.12)$$

And W_{index} is the factor that characterizes all the window properties, including shadings and maintenance factor, it is calculated as:

$$W_{index} = \frac{\tau_{cs}}{K} \qquad (3.13)$$

The room index *I* defined by the room geometry and reflectance, given by:

$$I = \frac{\eta_{cs}}{r_1} \qquad (3.14)$$

The principle of the *ĐRASTN* equation is then simply described by:

$$\rightarrow ĐRASTN = \frac{S_{cs}.\tau_{cs}.r_1}{S_s.K.\eta_{cs}}.100 = R_o.W_{index}.I \qquad (3.15)$$

to be simplified as:

ĐRASTN = Window-to-floor ratio x Window index x Room index

This means that, generally speaking, *ĐRASTN* is described as a function of window properties and room geometry. This means that *ĐRASTN* is independent of external obstructions and it does not take into account the external reflected light component.

The principle of the *ĐRASTN* method seems to be similar to the *BRE ADF* approach in many ways. Both equations take into account the maintenance factor and area-weighted average reflectance of the interior surfaces. There is a minor difference: *ĐRASTN* is the function of the floor area S_s and several room geometry indices (i.e. η_{cs}, r_1), while *BRE ADF* calculation is just a function of the total area of all internal surfaces. However, *BRE ADF* includes the external obstructions defined by the angle subtended by the visible sky θ. The *ĐRASTN* integrates external shading devices, including overhangs, as properties of window transmittance, while the *BRE ADF* method considers them as external obstructions defined by the angle θ. Perhaps it is the main reason for the Vietnamese code to introduce the second step employing the Danhiluc chart to verify the results (i.e. window area) found in step 1.

STEP 2: Verifying the ĐRASTN by using Danhiluc chart

The code describes that the results found by the equation (3.10) introduced in step 1 should be verified by using the Danhiluc chart.

The Danhiluc chart method was developed by A.M. Danhiluc and was adopted in the former Soviet Union codes before 1990. The principle of the Danhiluc chart method is very similar to the Waldram diagram. A Danhiluc chart comprises of two parts, D_I and D_{II}, representing the sky dome plotted in plan and section. These two parts are constructed from the plotting of the uniform sky vault which divides equally into 10 000 components, defined by the grid of 100 latitudes n_1 and 100 altitudes n_2 (figure 3.15). Sunlight is excluded.

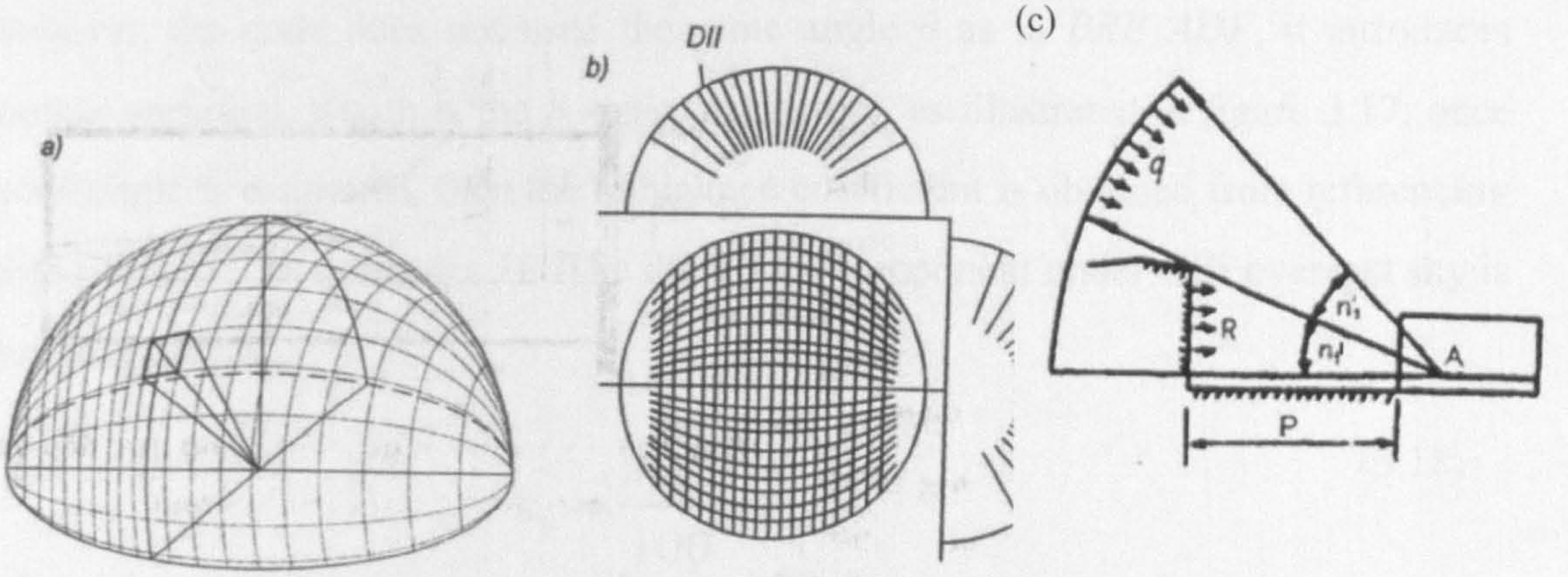


Figure 3.15 (a) The principle of the Danhiluc charts, its two diagrams (b) used for section and plan to calculate the number of the direct beam n_1 and reflected beam n_1' described in (c)

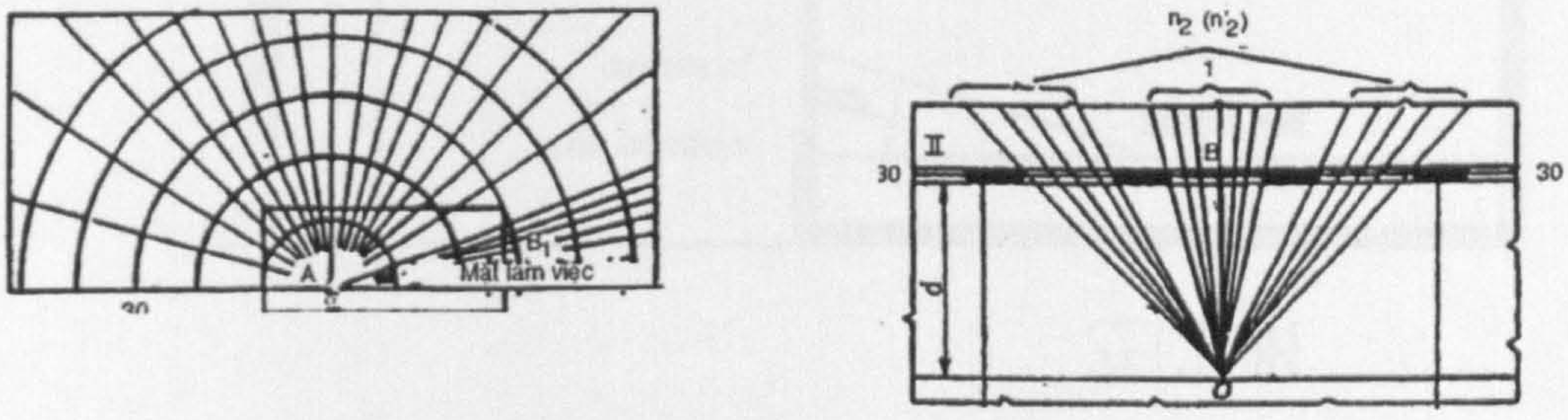


Figure 3.16 Quantifying daylight components, by overlaying the appropriate chart over the section or the plan of the room, and counting the number of beams projected through the window opening.

The daylight components entering the room are quantified by the area of visible sky seen from windows, and defined by overlaying the appropriate chart over the section or the plan of the room and counting the number of beam n_1 and n_2 projected through the window openings, as in figure 3.16. The *direct sky component* $\varepsilon_{b\_uniform}$ [%] received from the unobstructed uniform sky is proportional to the area defined by the number of direct beams n_1 and n_2, and thus calculated as:

$$\varepsilon_{b\_uniform} = \frac{n_1 . n_2}{100} \tag{3.16}$$

Because the Danhiluc sky vault represents the uniform sky dome, to convert it into CIE overcast sky the code introduces the *luminance coefficient* *(q)* which is expressed as a decimal. The luminance coefficient *(q)* is derived from the definition of luminance distribution of CIE overcast sky:

$$L_\theta = \frac{L_z(1+2\sin\theta)}{3} \rightarrow q \approx \frac{1+2\sin\theta}{3} \tag{3.17}$$

All the definitions of equation (3.1) are applied.

However, the code does not used the same angle θ as in *BRE ADF*, it introduces another variation, which is the β angle, in degree, as illustrated in figure 3.17; once this β angle is estimated, then the luminance coefficient is obtained from referencing table (table J.7 of appendix J) . The direct sky component under CIE overcast sky is then derived by:

$$\varepsilon_b = \frac{n_1.n_2}{100}.q \tag{3.18}$$

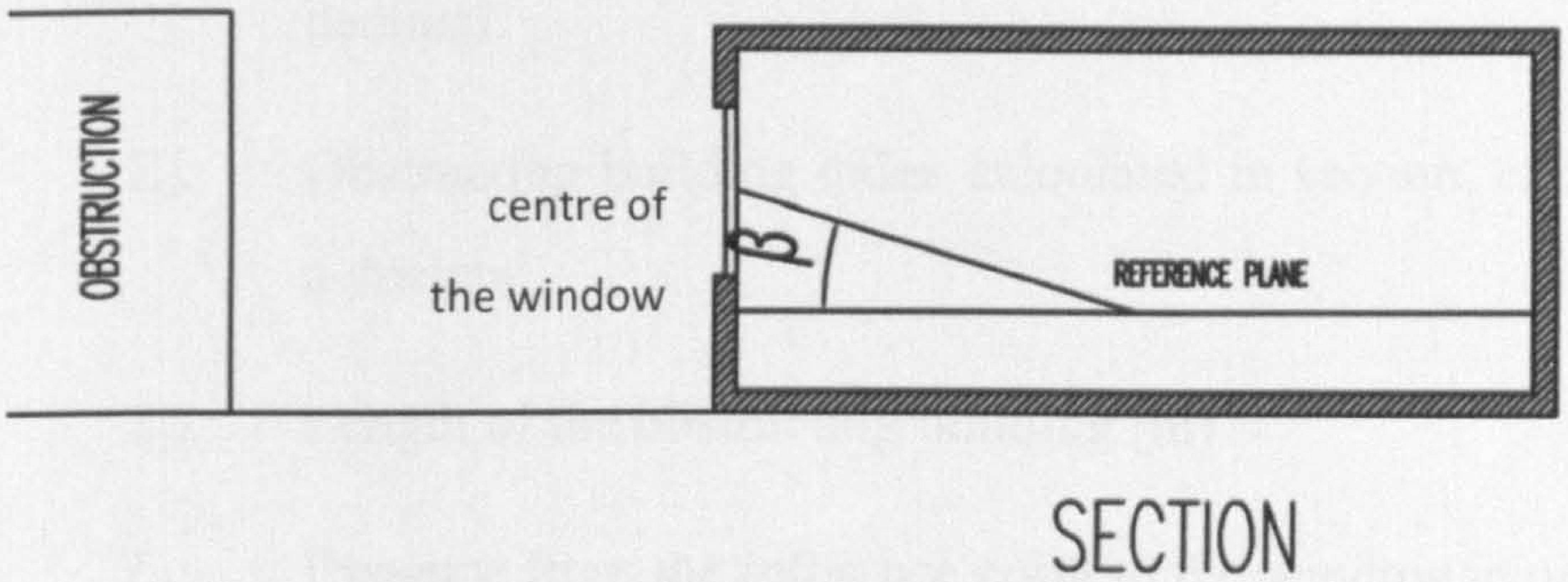


Figure 3.17 Defining the angle β of the luminance coefficient q

The *external reflected component* ε_{ch} [%] can be obtained by the same approach, using the principle that the luminance of the obstructed buildings is a fraction of the obstructed sky, scaled by the *external obstruction index (R)*. Therefore, ε_{ch} is obtained by:

$$\varepsilon_{ch} = \frac{n_1'.n_2'}{100}.R \tag{3.19}$$

Where R is the external obstruction index, expressed as a decimal, obtained from table J.8 of appendix J.

The n_1' and n_2' are calculated by the same process employed to obtain n_1 and n_2. Part (c) of figure 3.15 describes this principle in more detail.

It should be noted that the R index is a complex index that takes into account the consideration of several factors, e.g. geometry, distance and reflectance of the obstructing buildings. This R index is a revised version of the H.G Fruhling's Coefficient of Utilization C_e. It utilises both the reflectance of the obstructing buildings and the Coefficient of Utilization index *(C_e)*. This *R* index cannot be calculated directly, it is given in a table of values (table J.8 of appendix J). To obtain this *R* index, it is required to calculate the *building indices* (Z_1 and Z_2), obtained by:

$$Z_1 = \frac{L_{ob}.L_1}{(P + L_1).a} \tag{3.20}$$

$$Z_2 = \frac{H_{ob}.L_1}{(P + L_1).h_1} \tag{3.21}$$

Where: Z_1: Obstructing building index calculated in plan, expressed as a decimal.

Z_2: Obstructing building index calculated in section, expressed as a decimal.

L_{ob}: Length of the obstructing building [m].

L_1: Distance from the reference point to the window in plan [m].

H_{ob}: Height of the obstructing building [m].

h_1: Distance from the reference point to the head of the window [m].

a: Window width [m].

P: Distance from the obstructing building to window [m].

Once Z_1 and Z_2 index are defined from the above equations, the *R* index can be obtained from the table J.8 of appendix J. If an obstruction runs perpendicular to the window wall, the index *R* is further multiplied by 1.5.

The light entering the room is then reduced by window transmittance (defined by τ_{cs}, and *K*), and then partly reflected by the interior surface (defined by r_1). Finally the *ĐRASTN* at the calculating point is estimated by:

$$ĐRASTN = (\varepsilon_b + \varepsilon_{ch}).r_1.\frac{\tau_{cs}}{K} \tag{3.22}$$

Where: ε_b: Direct daylight component from the unobstructed sky [%], given by equation (3.18)

ε_{ch}: Reflected daylight component from external obstructions [%], given by equation (3.19)

r_1, τ_{cs}, and K are defined in equation (3.10).

All tables of values and indices used in this method are given in appendix J. The definitions of all the coefficient factors are illustrated in figure 3.18.

Overall, the principle of Danhiluc chart method is quite similar to the Waldram diagram. The main difference is that the Danhiluc chart method takes into consideration the internal reflected component. However, Pham (2006) comments that though this principle seems to be simple, accurate calculation of the long list of correction factors is quite complicated. Furthermore, as the code employs two independent methods of calculation, it remains unclear what should be done if the results obtained from step 1 and step 2 are not similar.

The principle of *ĐRASTN* is based on very early studies on daylight, dating back to the 1970s. Historically, Vietnamese academics could only exchange knowledge to countries in the Soviet Union block before the 1990s. Since then, there has been extensive development in studies in this area, to find simpler yet more accurate calculating methods. However, the code has not been changed after 1991. Moreover, after the end of Vietnam War in 1975, this code, developed for the North Vietnam regions was applied to the whole country. It remains unclear if any research has been conducted to confirm the validity of these methods when applied in larger regions with different climates. The code suggests that the design sky is 4000 lux. This means 2% *ĐRASTN* is equal to 80 lux. It should be noted that the outdated (but still valid) classroom lighting code TCVN:3978 (1984) recommends task illuminance *(Eih)* at 50-100 lux, therefore these values seem to fit to this recommendation. However, climatic data of HCMC shows that the average sky illuminance in the Wet season varies from 10 000 lux to 20 000 lux. Studies by Nguyen (1990) and Phan (1989) propose the design sky value at 15 000 lux , so 2% *ĐRASTN* equals to 300 lux, almost four times higher. This review reveals that the current Vietnamese daylight code is incompatible for HCMC, and thus it needs revision.

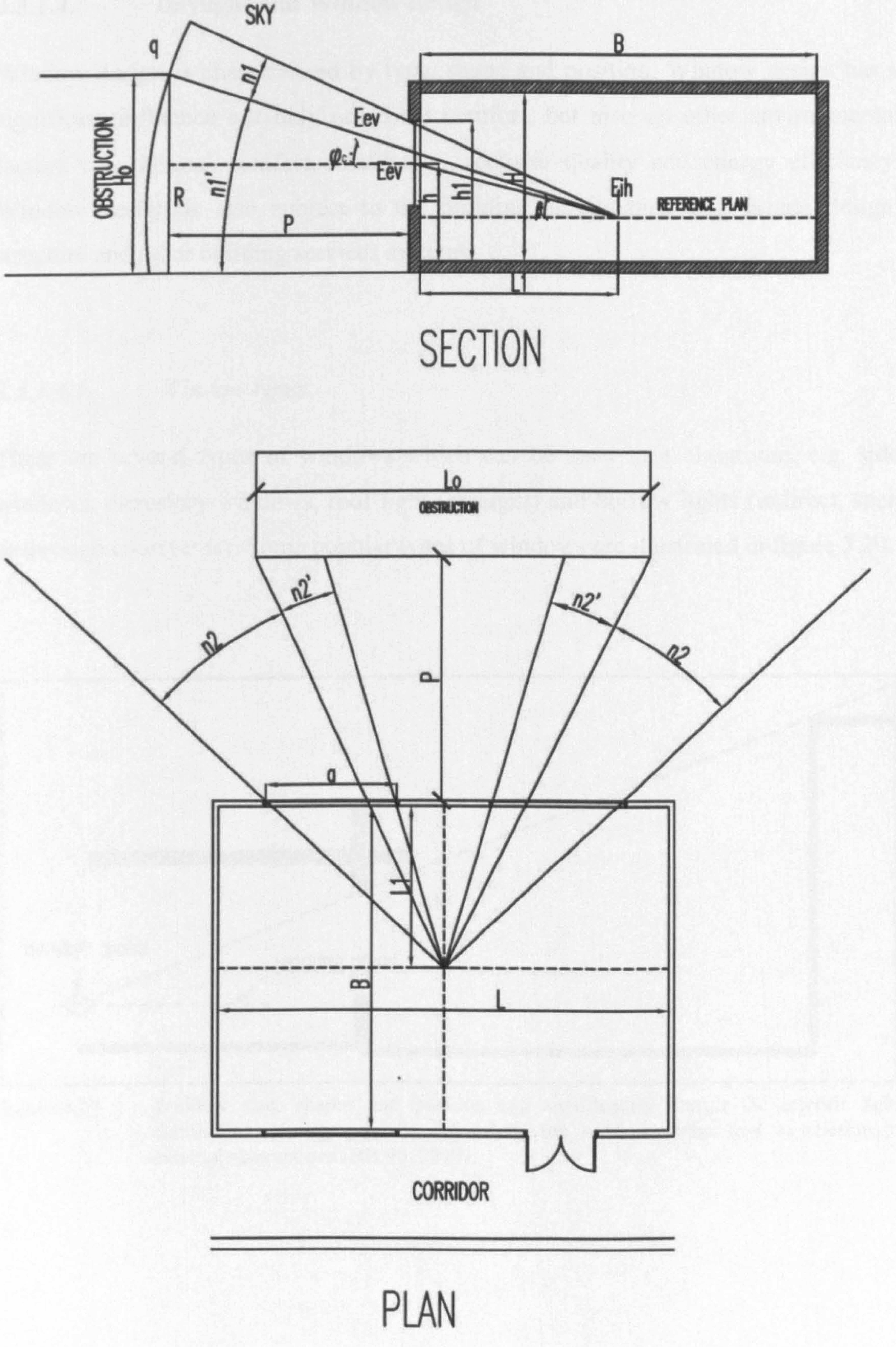


Figure 3.18 Definitions of design indices to be obtained in Danhiluc chart method

3.3.1.4. Daylight and Window design

Window design is characterised by type, shape and position. Window design has a significant influence not only on visual comfort, but also on other environmental factors e.g. thermal comfort, ventilation, acoustic quality and energy efficiency. Window design is also subject to the building architecture, e.g. facade design, structure and other building services systems.

3.3.1.4.1. Window types

There are several types of windows which can be used in a classroom, e.g. side windows, clerestory windows, roof light (skylight) and borrow lights (indirect, such as through courtyards). Some popular types of windows are illustrated in figure 3.20.

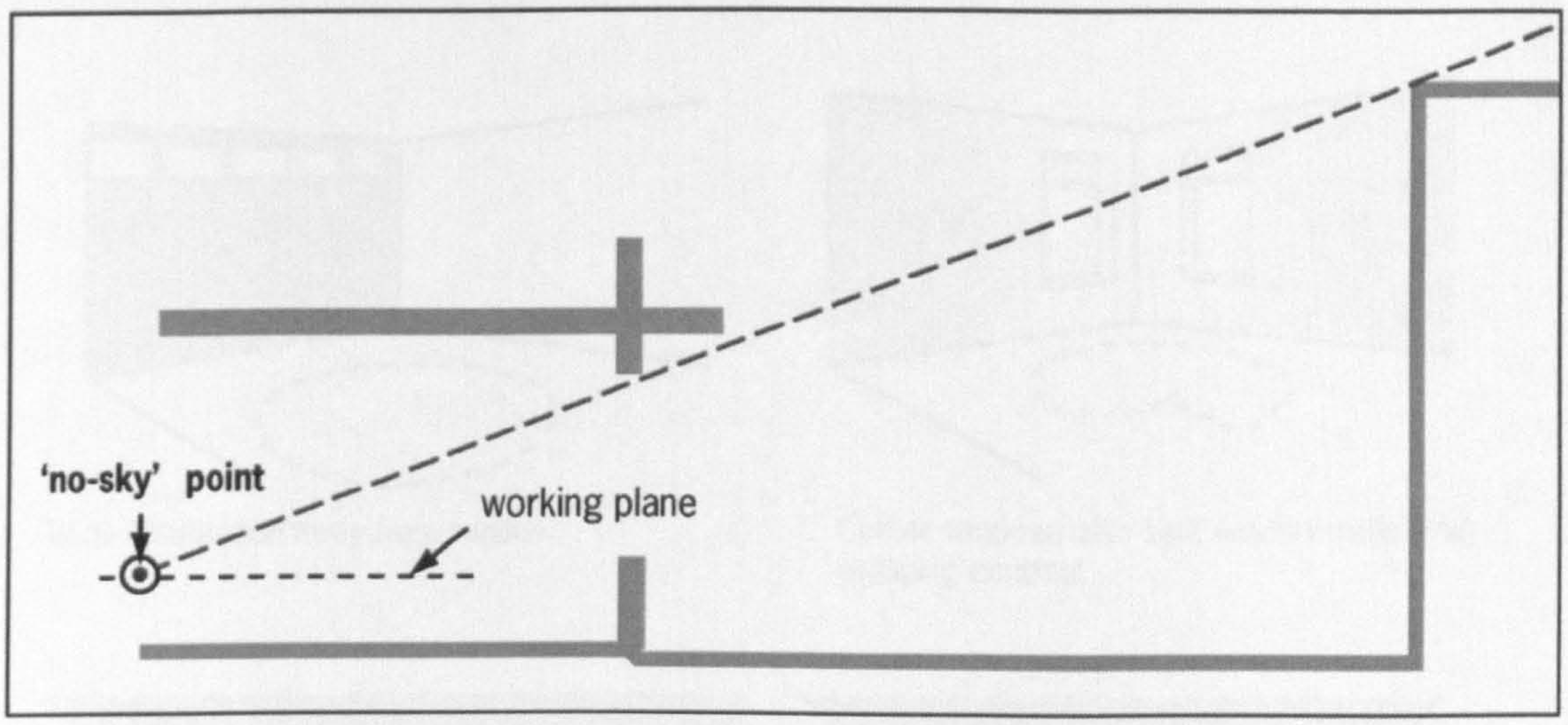


Figure 3.19 Window size, shapes and position can significantly impact the interior light distribution. No-sky point is defined by the window design and its relation to external obstructions (BB:90, 2010).

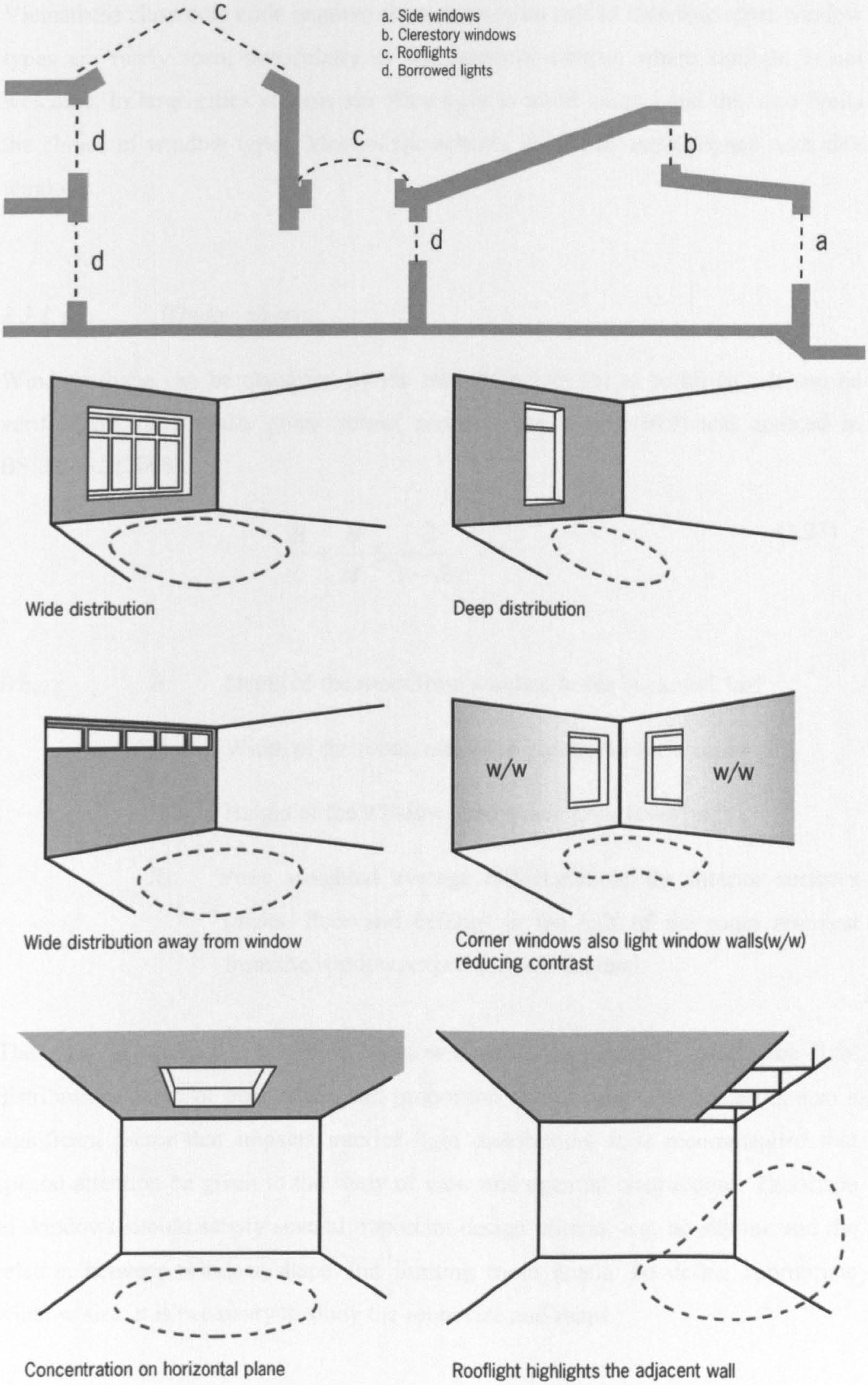


Figure 3.20 Popular classroom window types. (BB:90, 2010)

Vietnamese classroom code requires classrooms to be side lit therefore other window types are rarely seen, particularly in the Southern climate where sunlight is not welcome. In large cities schools are often built in multi storeys and this also limits the choice of window types. Most of the schools in HCMC are designed with side windows.

3.3.1.4.2. Window shape

Window shape can be classified by the ratio of height (h) to width (w). It can be verified by the formula given below, proposed by Lynes(1979) and adapted in BS:8206-2 (2008):

$$\frac{B}{L}+\frac{B}{H}\leq\frac{2}{1-Rb} \qquad (3.23)$$

Where

- B: Depth of the room from window to the back wall [m]
- L: Width of the room, measured parallel to the window [m]
- H: Height of the window head above floor level [m]
- R_b: Area weighted average reflectance of the interior surfaces (walls, floor and ceiling) in the half of the room remotest from the window, expressed as a decimal.

The ratio of window's height to window's width significantly affects the light distribution, depth of penetration and proportion of the view. Positioning is also a significant factor that impacts interior light distribution. It is recommended that special attention be given to the study of view and external obstructions. The shape of windows should satisfy several important design criteria, e.g. no-skyline and the relation between window shape and limiting room depth. To define appropriate window size, it is necessary to study the room size and shape.

3.3.1.4.3. *Window Size*

Window size can be determined by the net glazing area. It can be estimated from the *BRE ADF* equation (3.7):

$$\bar{D}_{BRE} = \frac{\tau A_w \theta}{A_r(1-\rho^2)} \rightarrow A_w = \frac{A_r(1-\rho^2)}{\tau\theta}\bar{D}_{BRE} \tag{3.24}$$

Or can be obtained from the *ĐRASTN* equation (3.10)

$$100.\frac{S_{cs}}{S_s} = \frac{ĐRASTN.K.\eta_{cs}}{\tau_{cs}.r_1} \rightarrow S_{cs} = \frac{ĐRASTN.K.\eta_{cs}S_s}{100.\tau_{cs}.r_1} \tag{3.25}$$

All definitions in equation (3.5), (3.7) and (3.10) are applied.

A Vietnamese standard classroom is about $48m^2$ to $54m^2$ (TCVN:3978, 1984), therefore net window area should be $9.6m^2$ to $13.5m^2$ for 2% *ĐRASTN*. Furthermore, BS:8206-2 (2008) provides requirements for minimum glazing area for adequate view out, based on the room depth and floor area. For classrooms with less than 8m deep, this code recommends a net window area of 20%, as given in table 3.6.

Table 3.6 Minimum glazed areas required for view when windows are restricted to one wall. This is for view requirement only, and does not ensure that adequate task illuminance is provided. As most of the classroom is not deeper than 8m, it is recommended that opening per floor ratio is about 20% (BS:8206-2, 2008;BB:90, 1999).

Depth of room from outside wall (max.) [m]	Percentage of window wall as seen from inside (min.) [%]
<8	**20**
8-11	**25**
11-14	**30**
>14	**35**

Note: Windows which are primarily designed for view may not provide adequate task illumination.

3.3.2. Recommendations for artificial lighting

It is recommended that daylight should be designed as the main source of classroom illuminance. However, at any place on earth, the amount of daylight varies during the year. Thus artificial light is required to provide sufficient operating illuminance.

3.3.2.1. Maintained Illuminance *(E_m)*

Maintained Illuminance ((E_m, in lux) is the minimum illuminance which should be provided at all times through the life of the installation, and it includes both the contribution of daylighting and electric lighting.

The selection of E_m is subject to the difficulty of the visual perfomance and other factors such as the background contrast, age and time. However, the exact relationship between the illuminance on the task and the performance achieved vary with the nature of the task and other factors such as ambience illuminance and contrast ratio (see figure 3.21 and figure 3.22).

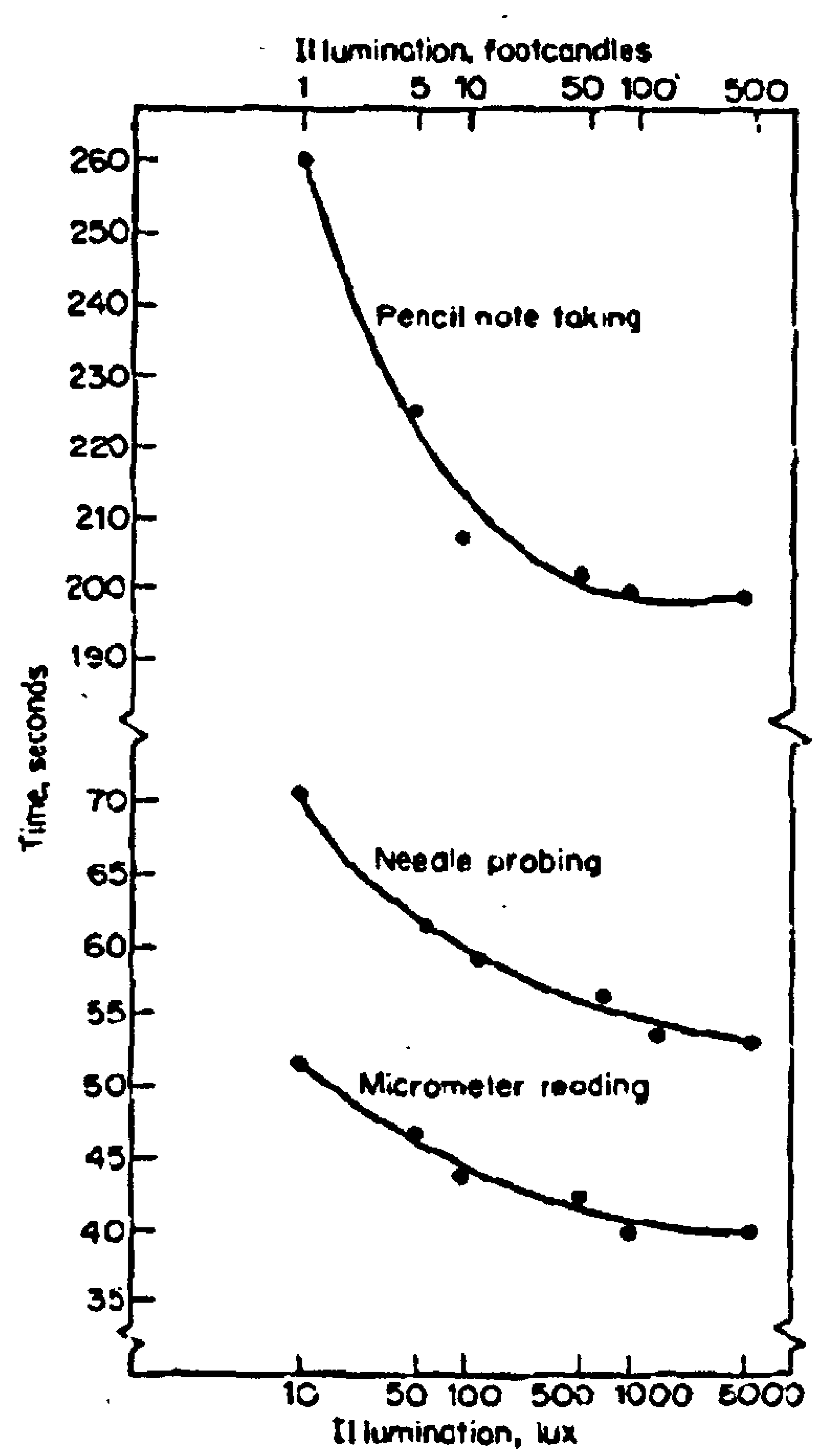


Figure 3.21. Relationship between amount of illumination and task complete time for representative industrial tasks (Sanders, Mccormick, 1992).

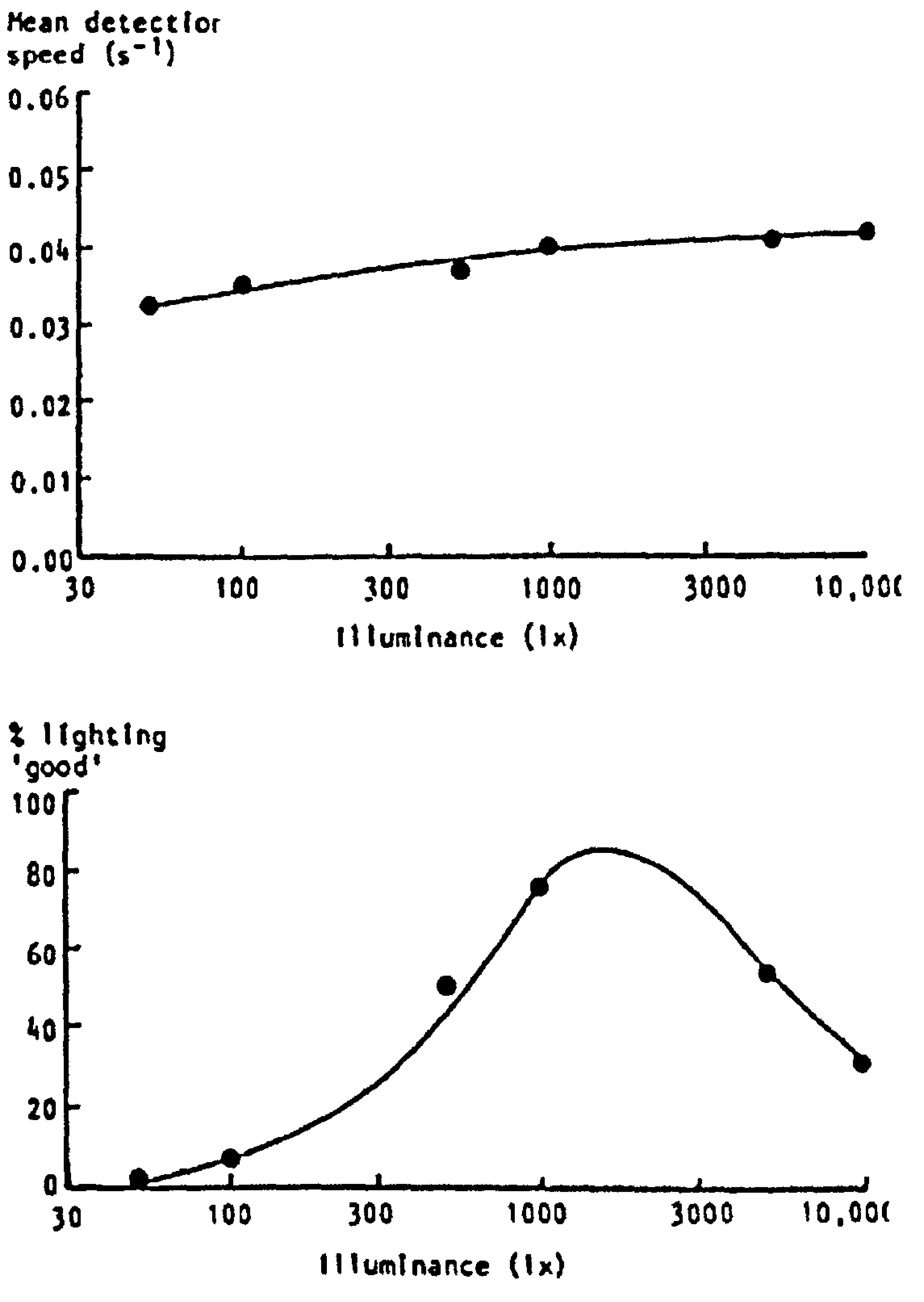


Figure 3.22 Relationship between the mean detecting speed and illuminances on the table; and percentage of subjects who consider "good" lighting plotted against illuminances on the table (Muck,Bodmann, 1961;Boyce, 1995)

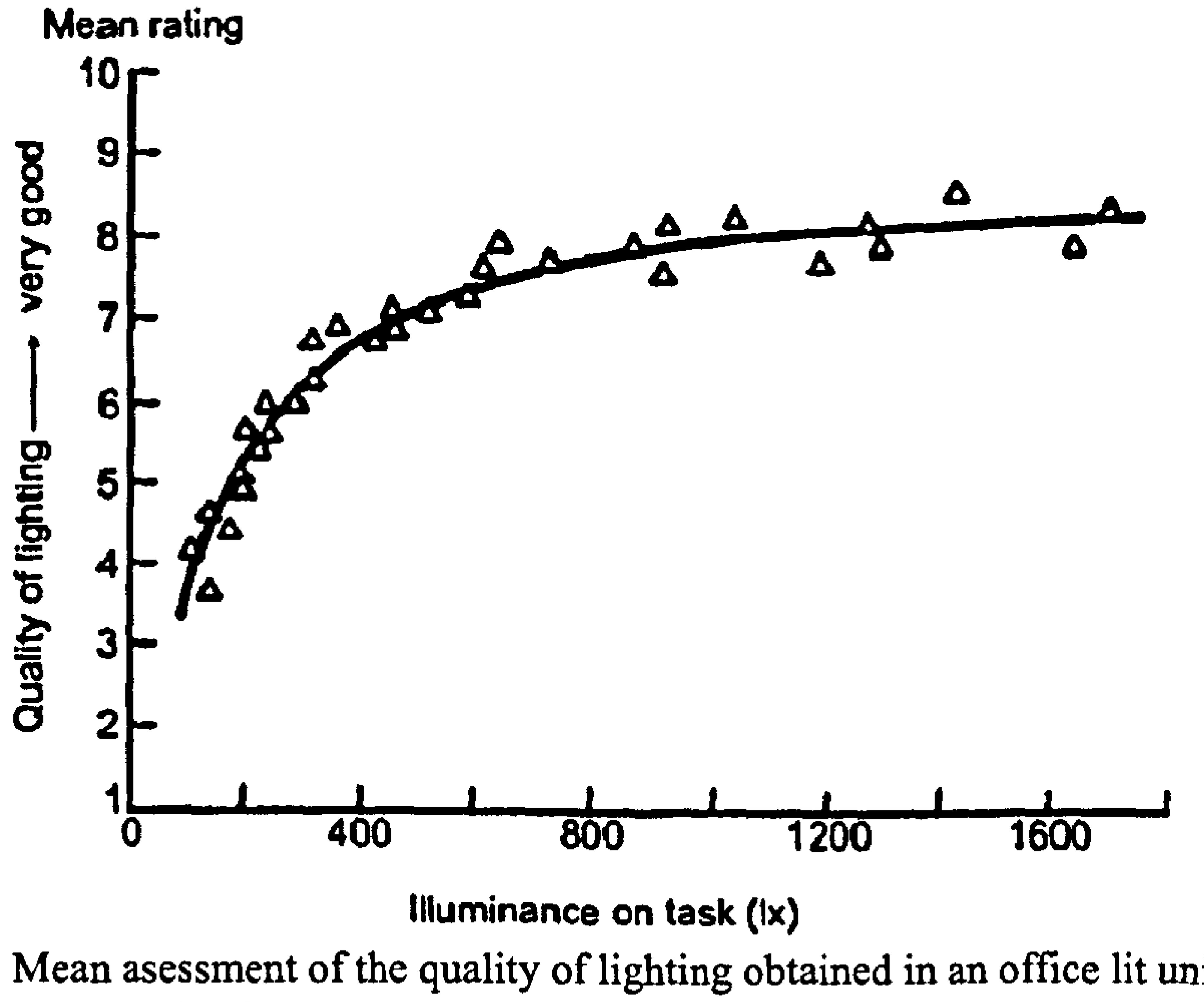


Figure 3.23 Mean asessment of the quality of lighting obtained in an office lit uniformly (CIBSE, 2002).

Table 3.7 Illuminance recommendations for reading in every edition of the IES (Illuminating Enginnering Society, US) Handbook. This shows the influence of lamp technologies and the economical/political position of the U.S on the illuminance recommendations. (Boyce, 1995).

IES Handbook	Visual task: Reading	Illuminance (lx)	Lamp type	Economic / Political State
1947	Regular Difficult	300 500	Incandescent	Moderate growth
1954	Regular Difficult	300 500	Incandescent /Fluorescent	Strong growth
1959	Regular Difficult	1000 2000	Fluorescent	Strong growth
1966	Regular Difficult	1000 1500	Fluorescent	Strong growth
1972	Regular Difficult	1000 1500	Fluorescent	Growth
1981	Regular Difficult	200-300-500 500-750-1000	Fluorescent	Post energy crisis
1987	Regular Difficult	200-300-500 500-750-1000	Fluorescent	Post energy crisis
1993	Regular Difficult	200-300-500 500-750-1000	Fluorescent	Environment concerns

It shoud be noted that the requirements for maintained illuminance are very different in the international codes. Internationally, the illuminance recommendations have also changed over the years. In 1917, an office in the U.S, which was lit at 100 lux, was regarded as exessive (Audel, 1917). In the 1960s, U.S offices were recommended to be lit at 1000 lux average. Then, it was reduced to 500 lux and further reduced to 300 lux as is currently prevalent. A possible anwer to explain this change is that the people's inherent visual performance capacities have changed. The nature of the task performed has also changed. Other possible anwers are that illuminance recommendations are not determined by visual comfort alone, but are subjected to many other factors, such as the influence of economy and technology. (Boyce, 1995).

3.3.2.1.1. The Vietnamese code

In the Vietnamese codes, E_m for classroom lighting is measured at two positions: student desktops and the teaching board. There are different E_m values applicable for a classroom illuminated by fluorescent lamp or by incandescent lamp. It is not clear why this difference is there for the types of lamp used and why only two types of lamp are applicable. Section 9.2 of TCVN: 3978 (1984) provides a brief note that says that a fluorescent lamp with *"white colour light spectrum,"* should be used but no further detail is provided. However, it has been discovered that different codes issued by various institutions recommend conflicting requirements (see table 3.8).

In 2000, the Ministry of Health issued the 1221/2000/QĐ-BYT directive which included a brief on E_m. This code addresses school hygiene requirements rather than provide a specific guidance on classroom lighting. It recommends the quantity of lighting fixtures required in a typical classroom. These requirements are very much similar to *MoC* TCVN: 3978 (1984) (Viet-Bao, 2001).

In 2005, the Ministry of Construction issued the TCXDVN:09 (2005) *Energy Efficiency Building Code (EEBC).* Although this code is prepared to directly address the energy efficiency issues, its "*Section 6: Lighting*" briefly provides similar *Em* recommendations to TCVN:7114 (2008), though it provides further details on min and max E_m.

It seems that there is little coordination between these codes as can be seen from the evidence found on the differences on illuminance recomendations. Several comments have been made on the fact that the 100 lux requirement by the TCVN3978 (1984) is too dim (SGTT, 2009; Hanoimoi, 2005). And it has recommended strongly that the codes need to be revised (Viet-Bao, 2001).

There have been high numbers of reports on a classroom's low visual comfort (VHO, 2004;Youthnews, 2008; ANTD, 2009; Vula, 2009). A recent survey from the Vietnam Urban Lighting Association (VULA) shows that in the city area 27.86% students are seriously short-sighted, of which 49.57% are secondary students (Vula, 2009). Main contributing factor for these numbers is the low maintained illuminance found in most of the school classrooms. In some classrooms, this value is as low as

80 lux. These surveys lead to further discussion on the need to revise the current codes (SGTT, 2009).

Some local goverments have taken steps to issue their own recommendations (Hanoimoi, 2005; SGTT, 2009). Another independent research carried by Vietnam Energy Efficient Public Lighting (VEEPL) developed their own guidance for classroom lighting; they suggested that a classroom should be lit to 300 lux (Tran, 2008). Summary of VEEPL proposal is shown in appendix H.

Table 3.8 Recommendations for task illuminance, excerpt from relevant Vietnamese codes.

Position	Standard Maintained Illuminance [lx]		Reference plan
	Fluorescent lamp	Incandescent lamp	
TCVN:3978 (1984)			
Student desk	100	50	Horizontal plan at 0.8m from floor.
Maintenance factor	1.5	1.3	
TCXD:16 (1986)			
Student desk	200	100	Horizontal plan at 0.8m from floor.
1221/2000/QĐ-BYT			
Classroom	From 6-8 fluorescent batten Type T10/T8 40W 1.2m	4 x lamp bulb, type 150-200W	Mounting height (2.8m from floor) Note: *Standard classroom WxDxH: 8.5x6.5x3.6m, or 1.10m^2 to 1.25m^2 per student. This is equal to 80-100 lux at working plan.* (Viet-Bao, 2001)

TCVN:09 (2005)					
School type	Lighting Power Density [W/m^2]	Illuminance [lx]			
		Average	Ambience	Min	Max
School	13	300	-	200	500

3.3.2.1.2. International codes

In most of the international codes, illuminance recommendation for a classroom is 300 lux. In case of US codes it is recommended that E_m, which is based on the task performances in the classrooms, should be more specific ranging from 300 lux to 500 lux (as in table 3.9 and appendix G).

Table 3.9 Classroom illuminance recommendations in international codes, in lux

Standard	CIE S008/E	DIN 5035-3	JIS Z9110	AS 1680.2.3	METP Guidelines for Energy Efficiency in Buildings	BB.90 CIBSE	IESNA RP-3	
Country	(Int')	(Germany)	(Japan)	(Australia)	(Malaysia)	(UK)	(U.S)	
							Normal (*)	A/V (**)
Task Area	**300**	**300**	**300-500**	**240**	**350**	**300**	**300-500**	**100**
Teaching board	**300**	**300**	**500**	**240**	-	**500**	-	-
Chalk board	-	-	-	-	-	-	**50**	<80 lx on screen
White board	-	-	-	-	-	-	**500**	

Note: (*): The US codes classifies the requirement based on the tasks rather than areas.

-Most tasks in the classroom are D=300 lux average (roughly 200-400 lux throughout the space).

-Some classroom tasks will still be E= 500 lux average (roughly 300-700lux throughout the space).

-A minimum criterion of 300 lux on any desk, is in the mid-range of "D"and just within the "E"range.

(**):A/V mode: e.g. screen presentation, use of projector. No more than 80lux vertically anywhere on screen surface (allows 8:1 video image with a projector <3000 lumens). Note provied by J.R.Benya(2007)

3.3.2.2. Brightness distribution

Because of long class hours, it is important that the lighting scheme is aesthetically pleasing and attractive. Many established works have shown that background brightness has an influence on alertness and mental health. Recent research proves that there is a correlation between background brightness and a student's academic performance (Govén et al, 2002; Govén et al, 2007; Govén, 2009).

Despite its significance, the spatial lighting distribution issue is discussed only briefly in the Vietnamese codes. Figure 3.24 shows the relationship between the mean performance scores for Weston's Landolt ring charts of different visual size and luminance contrast and task illuminance.

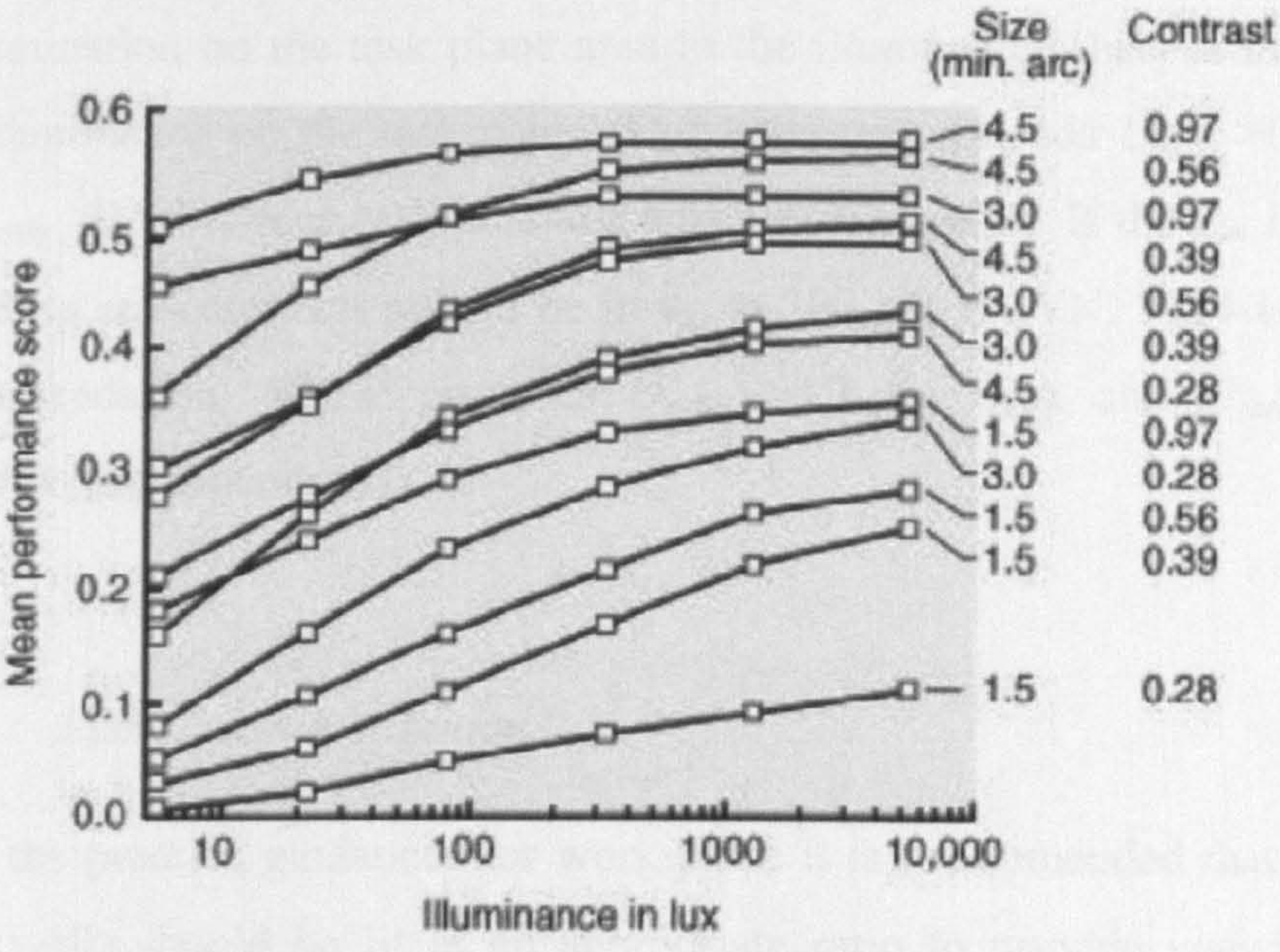


Figure 3.24 Mean performance scores for Weston's Landolt ring charts of different visual size and luminance contrast, plotted against illuminance (IESNA, 2000).

3.3.2.2.1. Uniformity

High uniformity ratio (U_{ratio}) is required in most of the international codes. Uniformity is calculated as the ratio of either minimum/average or minimum/maximum illuminance measured on relevant working plane. In the UK codes (e.g. Building Bulletins, CISBSE guides), it is required that minimum uniformity ratio should be 0.8 (i.e. minimum/average ratio). The US codes also recommend high uniformity ratio, it is measured as the ratio of minimum/maximum illuminance of relevant working plane and it is more spatially described:

> *"...to avoid high contrast. The brightest and darkest room surfaces should be no greater than 3 times or 1/3 as bright as the task (preferred) or 10 times or 1/10 as bright as the task (maximum)..."* (NEEP, 2002).

In Vietnamese codes, TCVN:3978 (1984) mentions that the luminaire layout should be linearly parallel to the main side wall where the windows are positioned. TCVN:

09 (2005) provides that the illuminance should be minimum 200 lux and maximum 500 lux. There is no information about uniformity and no further recommendations are given for the brightness ratio between surfaces; except illuminance level for the teaching board. TCVN: 7114-1(2008) provides more specific details of uniformity ratio (U_{ratio}). The code defines that uniformity is the ratio of the average illuminance [lux] of illumination on the task plane area to the illuminance [lux] at the point of minimum illuminance on the task plane. This code recommends U_{ratio} >0.7 at task area and U_{ratio} >0.5 between task area and surrounding spaces. If the E_m is 300 lux, the surrounding environments should be lit up to 200 lux. TCVN: 7114-1(2008). In their recommendation, VEEP proposes U_{ratio} >0.7 for desk and U_{ratio}>0.6 for teaching board (see appendix H).

3.3.2.2.2. Luminance distribution

In most of the practice guidances for work place it is recommended that the room ceiling and walls should be lit in an appropriate ratio to provide visual comfort. TCVN: 7114-1(2008) recommends that the the comfort brightness ratio be 1.5 times, as shown in table 3.10. However, TCVN: 7114-1 (2008) does not provide clear description of *"surrounding areas"*, and whether it includes all furniture, wall, floor and ceiling. In other international codes, this requirement is usually described in more detail, with specific requirements for different surfaces.

Table 3.10 Recommendations for lighting distribution at work places, excerpt from the Vietnamese code TCVN 7114-1(2008).

Task Area [lx]	Surrounding Areas [lx]
≥700	500
500	300
300	200
≤200	Same of task area

Figure 3.25 Suggestions by Pham (2006) for comfort luminance distribution ratio. The interior luminance distribution ratio can be the representation of exterior luminance distribution ratio, which is climate based. The left illustration is the ratio for temperate climate, and the right illustration is for tropical climate.

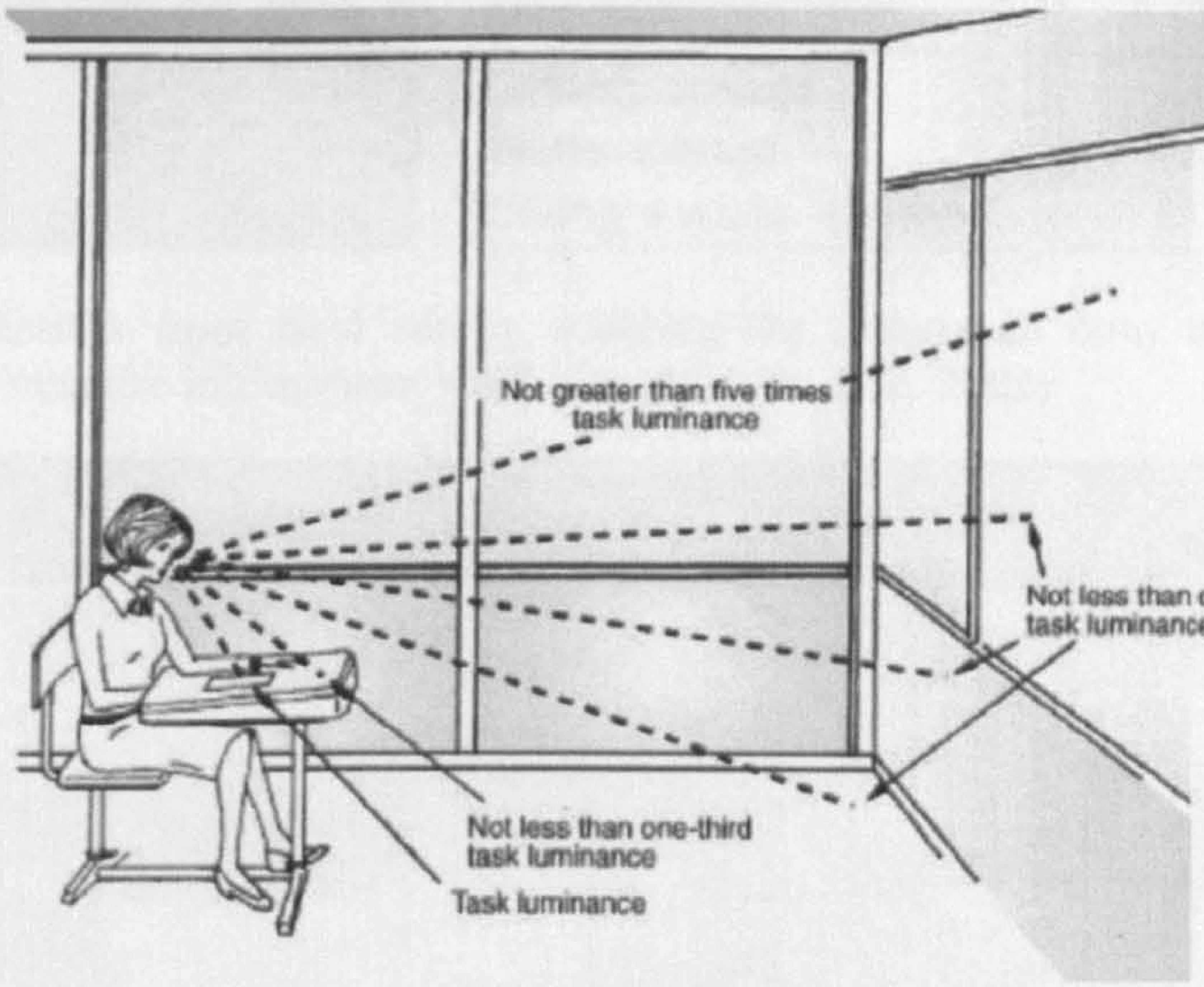
Table 3.11 Recommendations for illuminance distribution in UK codes.

UK codes (BB90)	*Task area*	*Walls*	*Ceiling*
%	*100%*	*50%*	*30%*
Illuminance	300 lux	200 lux	100 lux

Table 3.12 Preferred luminance ratios of room surfaces. (IESNA, 2000)

Experimenter	Area					
	Immediate Surround	Front wall	Rear wall	Right wall	Left wall	Ceiling
(Touw, 1951)	0.3	-	-	-	-	-
(Bean, Hopkins, 1980)	1	-	-	-	-	-
(Tregenza et al, 1974)	-	0.52	0.64	0.51	0.55	0.85
(Van Ooyen et al, 1987)	0.4			0.3		
(Roll, Hentschel, 1987)	0.1-0.6					0.1-3

In the British codes, e.g. CIBSE guide LG7 and BB:90, the specific descriptions on background brightness requirements are summarized in table 3.11. Other reseaches also suggest different ratios, which are summarized in table 3.12. The US codes require very specific spatial distribution of light in a classroom (shown in figure 3.26). It recommends the use of direct/indirect lighting scheme, with 50% artfificial light flux upward (NEEP, 2002).



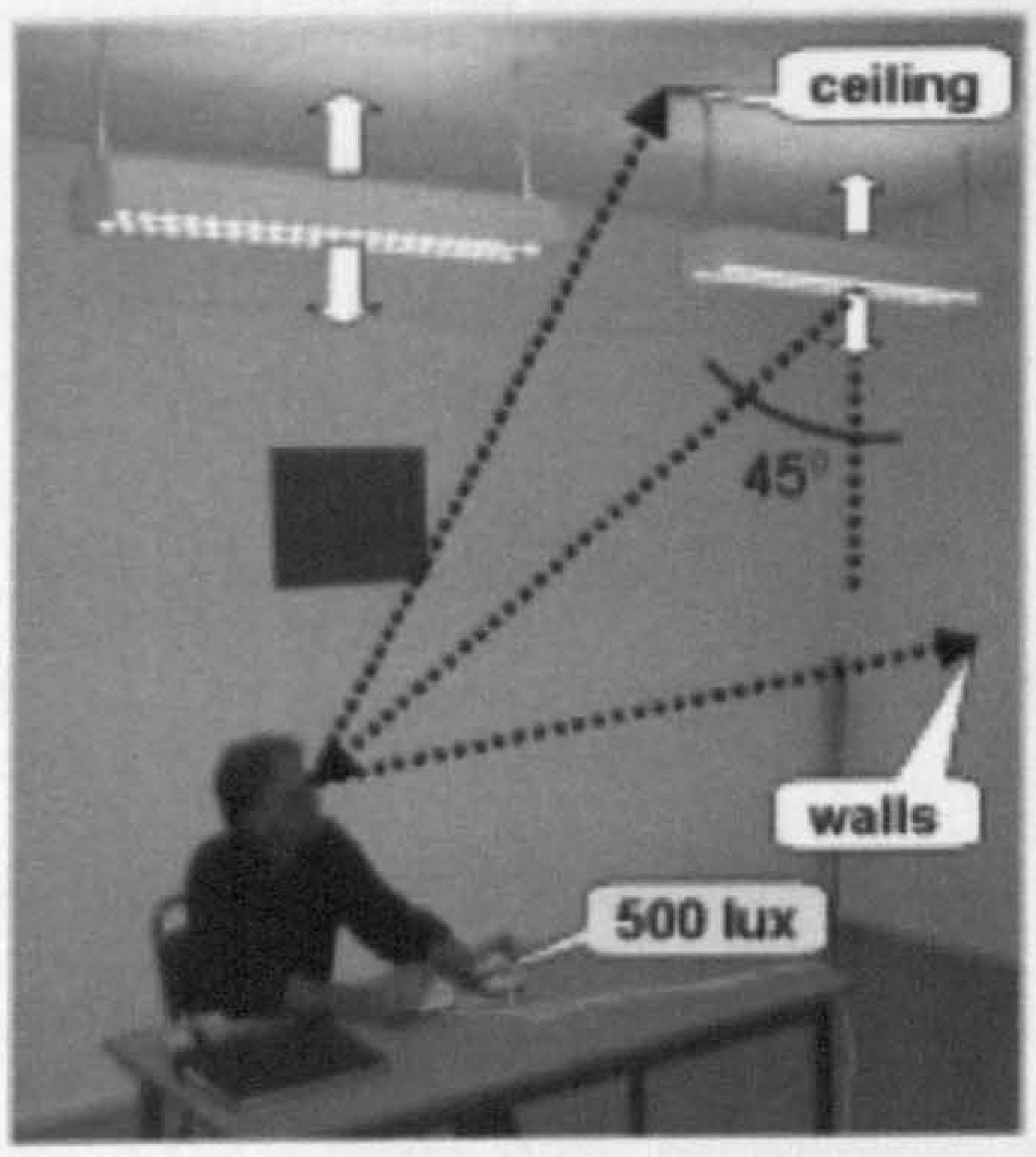
In a classroom the luminance of significant surfaces should not differ greatly from that of the visual task. The luminance of the surface immediately surrounding the task should be less than the task luminance, but not less than one-third the task luminance. The lowest luminance of any significant surface should not be less than one-third the task luminance. The highest luminance should not be greater than five times the task luminance. (IESNA, 2000) & (NEEP, 2002).

US codes	Working plan	Walls	Focal walls*	Windows	Teaching board**	
					White	Green/Black
Luminance ratio between task area and other surfaces	3:1	3:1	1:1	10:1	1:1	2:1

(*) For rooms where desks face one direction, provide focal lighting on the front wall or board. For multi-purpose spaces, provide focal lighting on two or three walls.

(**) For uniformity, the edges of the board should not be less than 1/3 the brightness of the centre.

Figure 3.26 Recommendations for classroom luminance distribution. Excerpt from IESNA Lighting Handbook (IESNA, 2000).



Conclusion / Results

Prefered lightdistribution Average value of position 1-4	Downward flux (%)	Upward flux (%)
Test-luminaire	44	56

Luminance ratio Luminaire in 45°/ surrounding Measured values based on prefered light distribution 44% / 56%	Luminaire Average luminance	Luminaire Spot luminance
Ceiling -average	8:1	12:1
Walls -average	13:1	20:1
Celing + walls -average	11:1	17:1

Figure 3.27 Results from field survey studying the luminance ratio between task area and luminaire in European work place (Govén et al, 2002)

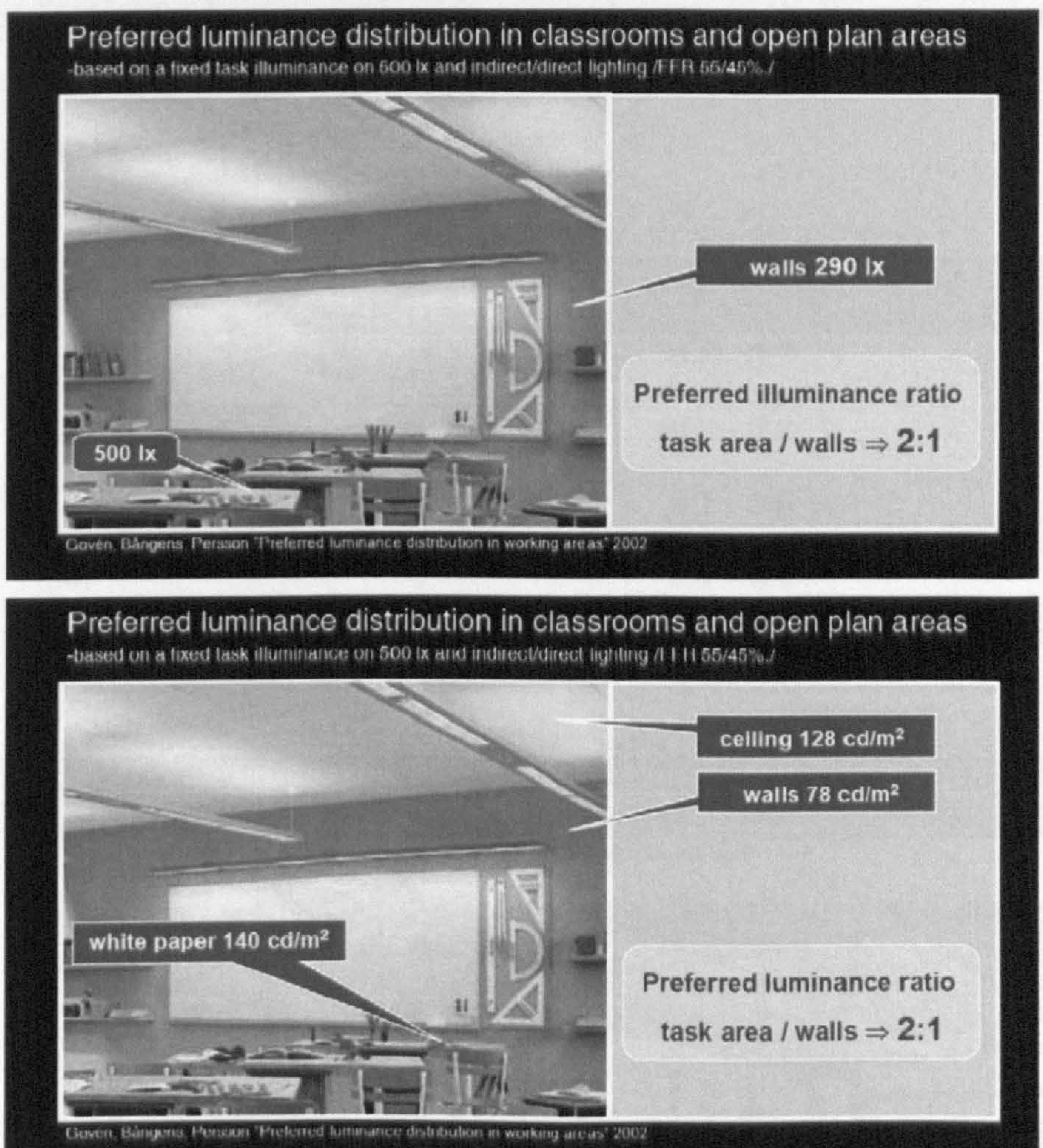


Figure 3.28 Results from Field studies of T.Govén (2002), (Rayham, 2007).

These requirements are set up to provide appropiate luminance ratio variations for the entire visual field. Findings from T.Góven's (2002) field studies in European school classrooms shows that a brightness ratio of 2:1 between task area and walls is preferable. Furthermore, in 2002, T.Govén conducted a study on preferable luminance ratio between the task area and the luminaires. His results are shown in figure 3.27 and figure 3.28.

3.3.2.2.3 Surface reflectance

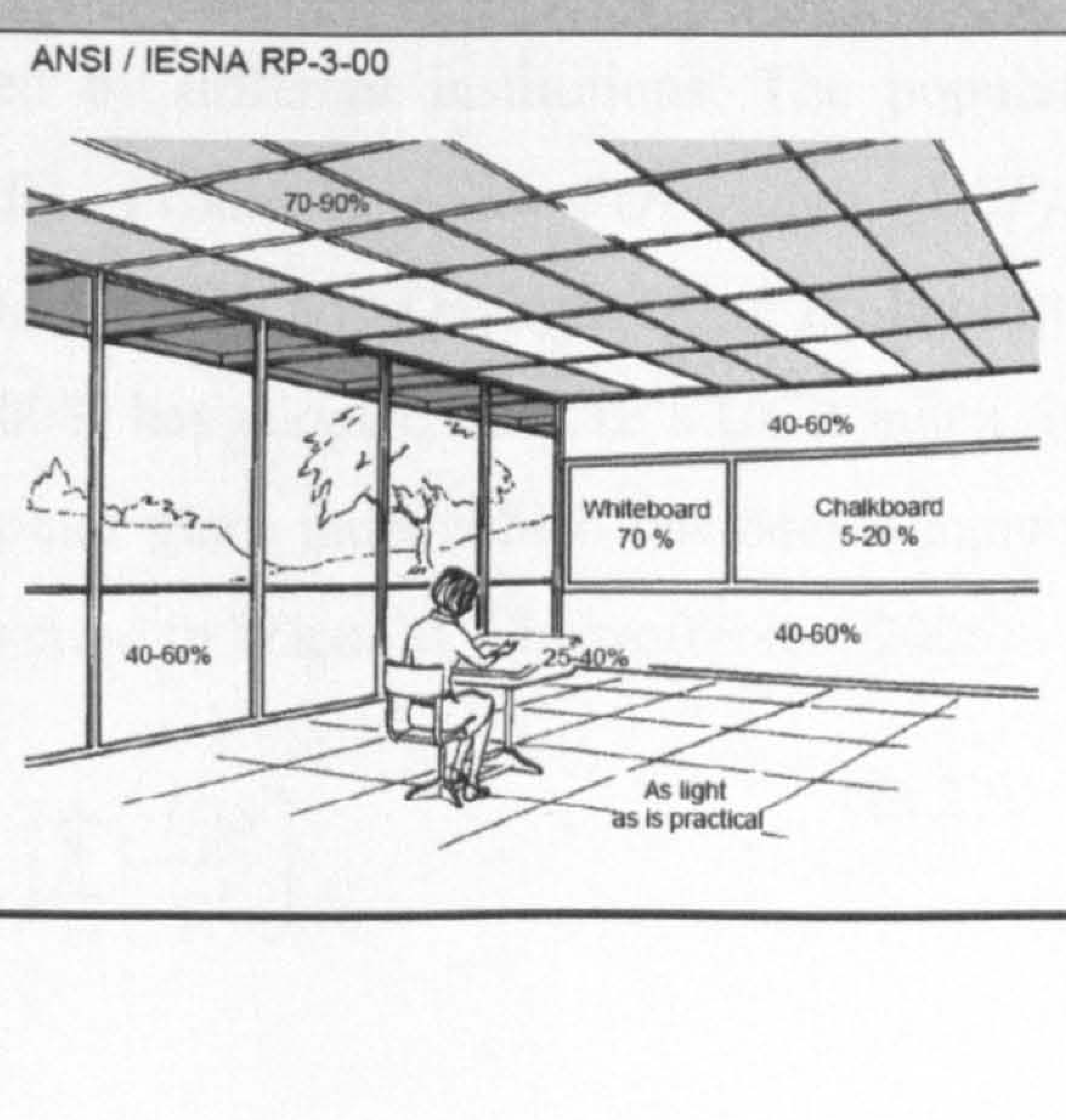
A good lighting distribution can be achieved by controlling the light falling on the surfaces and manipulating the surface reflectance properties. TCVN:7114-1(2008) provides a table with recommendations for surface reflectance factors, shown in table 3.12. Review of other international codes shows the same recommended range for reflectance factors for best visual comfort in a classroom. Walls and ceilings should have light colour finish with high reflectance factors, whilst desk top should be less reflective (matt) (see table 3.13).

Table 3.13 Recommendations for surface reflectance. (TCVN:7114-1,2008)

Surface	Reflectance
Ceiling	**0.6 - 0.9**
Wall	**0.3 - 0.8**
Task area	**0.2 - 0.6**
Floor	**0.1 – 0.5**

Table 3.14 Recomendation of surface reflectances in the U.K and U.S codes.

Surface	U.K Codes (BB90)	U.S Code (IESNA RP-3-00)
Ceiling	0.7	0.7-0.9
Wall	0.6	0.4-0.6
Desk area	-	0.25-0.4
Floor	-	As light as practical



3.3.2.3. Glare

Glare describes the difficultly of seeing in the presence of bright light. In CIBSE lighting handbook (CIBSE, 2002) it is suggested that glare occurs when one part of an interior is much brighter than the general brightness in the interior. In a classroom, luminaires and windows are the most common sources of excessive brightness. Glare can be quantified by using glare indices. Generally, glare indices often contain four physical quantities (CIE, 1983; as cited in Wienold, Christoffersen, 2006):

$$G = \left(\frac{L_s^e \omega_s^f}{L_b^g f(\phi)} \right) \qquad (3.26)$$

Where	e, f and g:	Weighting exponents.
	$f(\phi)$:	Complex function of the displacement angle, which can be expressed using the Guth's position index.
	L_s:	Luminance of the glare source [cd/m^2]
	L_b:	Luminance of the background [cd/m^2]
	ω_s:	Solid angle subtended by this source [sr].

There are several glare indices developed by different institutions. The popular indices are *Unified Glare Rating (UGR), Visual Comfort Percentage (VCP), Daylight Glare index (DGI), CIE Glare Index (CGI)* and Daylight Glare Probability (DGP). Vietnemase code TCVN:7114-1(2008) has adopted the CIE's UGR index. It should be noted that UGR is the most popular glare index,which has been adopted worldwide. It is obtained by (CIE, 1992; as cited in Wienold, Christoffersen, 2006):

$$UGR = 8.\log\left(\frac{0.25}{L_{Background}} \right) \sum_{ni} \left(\frac{L^2 \omega}{p^2} \right) \qquad (3.27)$$

Where: $L_{Background}$: Background luminance [cd/m²]

L: Luminance of the luminous area [cd/m²]

ω: Size of the luminous area [*sr*]

p: Guth Position index of the glare source.

ni: Number of luminaire

The *UGR* values typically range from 13 to 30, the lower the value, the less the discomfort. For classrooms, most of the codes (i.e. TCVN:7114-1, BB90, and EN 12464-1), recommend *UGR* =19.

The *Visual Comfort Probability* (VCP) index is popularly used in the U.S. The VCP is a ratio expressed as a percentage of people who, when viewing from a specific location and in a specified direction, find the system acceptable in terms of glare. A 'VCP' of 70% or more is considered to be satisfactory. Further information about VCP is given in the IESNA Lighting Handbook (2000).

The *Daylight Glare Index (DGI)* provides another alternative method to predict the discomfort glare from large sources, experienced by an observer. *DGI* is obtained by (Hopkinson, 1972; as cited in Wienold, Christoffersen, 2006):

$$DGI = 10\log_{10} 0.478 \sum_{i=1}^{n} \frac{L_{s_i}^{1.6}\Omega_{s_i}^{0.8}}{L_b + 0.07\omega_s^{0.5} L_{s_i}} \quad (3.28)$$

Where: L_s: Source luminance [cd/m²]

L_b: Average background luminance [cd/m²]

ω_s: Angular size of the source in steradians as seen by the eye [sr]

Ω_s: Solid angle subtended by the source, modified for the effect of the position of the observer in relation to the source in steradians [sr]

The glare evaluation using *DGI* is based on the index presented in table 3.15 below. An *UGR 19* is equivalent to *DGI 22*. In summary, the requirements for glare in classroom lighting codes are shown in table 3.16 below.

Table 3.15 DGI glare regions and their related glare index. (CLEAR, 2004; Wienold, Christoffersen, 2006)

Zone	Region	DGI	UGR
Discomfort zone	*Intolerable*	>28	>28
	Just intolerable	28	28
	Uncomfortable	26	25
	Just uncomfortable	24	22
Comfort zone	***Acceptable***	***22***	***19***
	Just acceptable	20	16
	Noticeable	18	13
	Just perceptible	16	10

Table 3.16 Glare indices for classroom lighting.

Code	TCVN: 7114-1 (2008)	BB:90 (2010)	EN:12464-1 (2002)	US CODES (ANSI/IESNA:RP3, 2000)
Glare Index	UGR	UGR	DGI	VCP
Recommendation	19	19	22	>70%

3.3.2.4. The Lighting system

The effectiveness of a lighting system is dependent on several factors such as the luminaire, the controlling, lighting layout and the classroom environment (room shape, surface and furniture). Thus, in selection process of an appropriate lighting system, a designer should consider all these related issues carefully.

3.3.2.4.1. *The Luminaire*

Classroom lighting system may consist of more than one type of luminaire. The typical construction of standard luminaire includes the lamp, ballast, and optical systems.

(i) Choice of lamp

In most of the Vietnamese codes,the use of fluorescent lamps is recommended. It is understandable why the fluorescent lamp is popular, since it gets a high score in most of the above mentioned categories. The choice of lamps is based on many parameters. Some of the most important lamp criteria to consider are:

- Luminous efficacy (lumen per watt, LPW)
- Lumen output and lumen maintenance,
- Lamp colour characteristics (colour rendering, colour rendering index)
- Lamp size and shape
- Lamp life, size,
- Controlling flexibility
- Cost (capital cost and operation cost)

It is also important to note that fluorescent battens are extremely popular in the large cities of Vietnam. The shortage of electricity in the country contributes to this popularity, as well as low cost, long life and simple installation. The characteristics of commonly used light sources are given in appendix I.

(ii)Luminous efficacy

Using high efficient light source plays a significant role in enabling the lighting scheme to meet new requirements on energy saving. High efficient lamps generate more lumen per watt than others. In terms of luminous efficacy (lumen per watt, LPW), discharged lamps have the highest LPW (High pressure sodium lamp, 104 lm/w). However, its poor colour rendering (Colour Rendering Index, *CRI*<21, mono-chromatic: yellow colour) makes it unsuitable. Metal halide lamp has a better *CRI*, but it has several disadvantages such as the warm up time, high capital cost, poor lumen maintenance and limited control flexibility. Fluorescent lamp does not have the highest luminous efficacy as an available light source; but it has the best balance of all features economically and practically.

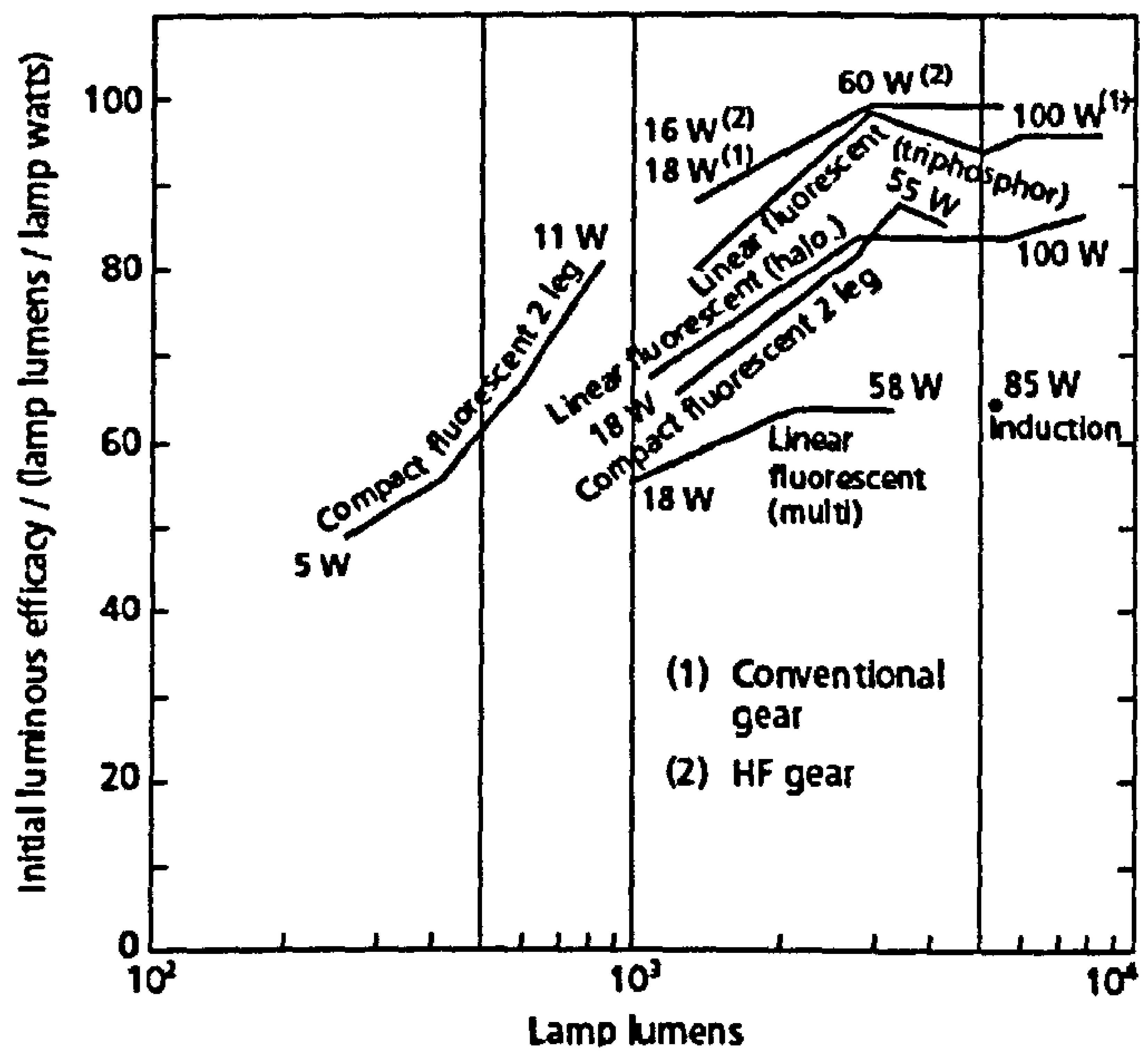


Figure 3.29 Initial luminous efficacies of fluorescent lamps (CIBSE, 2004)

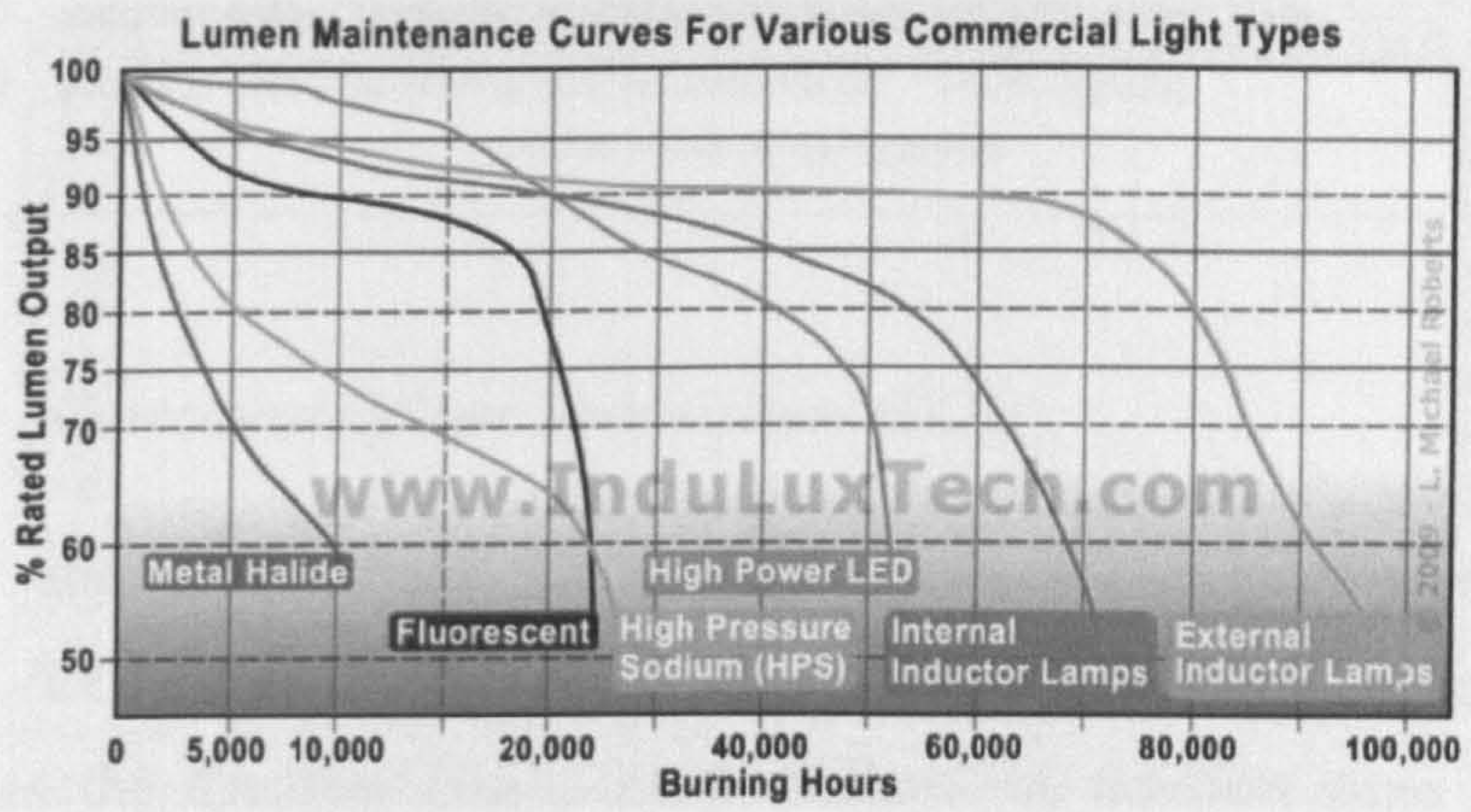
(iii) Lumen output and lumen maintenance

Lumen output is the luminous output of the lamp. To achieve the given illuminance, the number of luminaires needed, can be reduced by using a lamp with higher lumen output. However, if there are too few luminaires arranged in the lighting layout, it is difficult to maintain good light distribution and controlling flexibility. Another important factor affecting the lamp selection is lumen maintenance, because the luminous output of a lamp changes over its life. Furthermore, in some types of lamps, the light quality also changes. For example, end of life metal halide lamp cannot keep its original colour rendering; it has a good luminous efficacy but has poor lumen maintenance characteristics. Flickering is often seen in old fluorescent lamps.

There is no specific recommendation in Vietnameses code for this issue. The 1221/2000/QĐ-BYT suggests a standard lighting layout consisting of six to eight T10/T8 40W fluorescent tube lamps for a typical 8.5 x 6.5 x 3.6m classroom. In most of the international codes, fluorescent lamps are also recommended.

(iv)Lamp colour characteristics

The colour of illumination can be described by two independent properties: chromaticity, or *Correlated Colour Temperature* (*CCT*) and colour rendering.



Figures 3.30 Lumen maintenance curves for various commercial lamp types (Induluxtech, 2009)

3.3.2.4.2. Colour Rendering Index (CRI)

Vietnamese codes do not provide any specific detail on colour rendering requirements for classroom lighting. The *CIE* (Commission Internationale de l'Eclairage) has established a measuring scale called the *Colour Rendering Index (CRI)*. Lamps with higher *CRI* provide better visual perception of the object colour. *CIE* rates lamps in terms of a *Colour Rendering Index* (*Ra*) that represents the degree of resultant colour shift of a test object under a test lamp, in comparison with its colour under a standard lamp of the same correlated colour temperature.

For classroom lighting, VEEP suggests $R_a \geq 83$. The UK codes (BB90) recommend $R_a \geq 80$ (group 1A-1B). The U.S code IESNA RP-3-00 also suggests that lamp with $R_a \geq 80$ should be used, although $R_a \geq 70$ is also sufficient. Fluorescent lamp (either T8 or T5) can be a good candidate, although its quality is dependent on the manufacturer (varying from 73 to 98).Further information is given in appendix I.

Table 3.17 The CIE colour rendering groups, and their recommended applications. (CLEAR,2004)

Group	R_a	Importance	Typical application
1A	90...100	accurate colour matching	Galleries, medical examinations, colour mixing
1B	80...90	accurate colour judgement	Home, hotels, offices, schools
2	60...80	moderate colour rendering	Industry, offices, schools
3	40...60	accurate colour rendering is of little importance	Industry, sports halls
4	20...40	accurate colour rendering is of no importance	Traffic lighting

The CIE colour rendering groups

3.3.2.4.3. *Correlated Colour Temperature (CCT)*

Experiments show that there is a relationship between *Correlated Colour Temperature (CCT)* and illuminance level on users' psychological effects. Figure 3.31 illustrates the *Kruithof chart*, which defines the comfort zone (in white) of preferred combination of the colour temperature of the light source and the colour temperature. According to the *Kruithof chart*, if E_m = 200 lux-500 lux, the preferred *CCT* will be within the range of 2700° K to 7500 °K. However, it is important to note that visual adaptation plays an importance role in room perception. Studies have found that the perception of rooms lit with lamps of different colour temperature was dominated by illuminance and there is scepticism on the trade off between illuminance and colour temperature (IESNA, 2000).

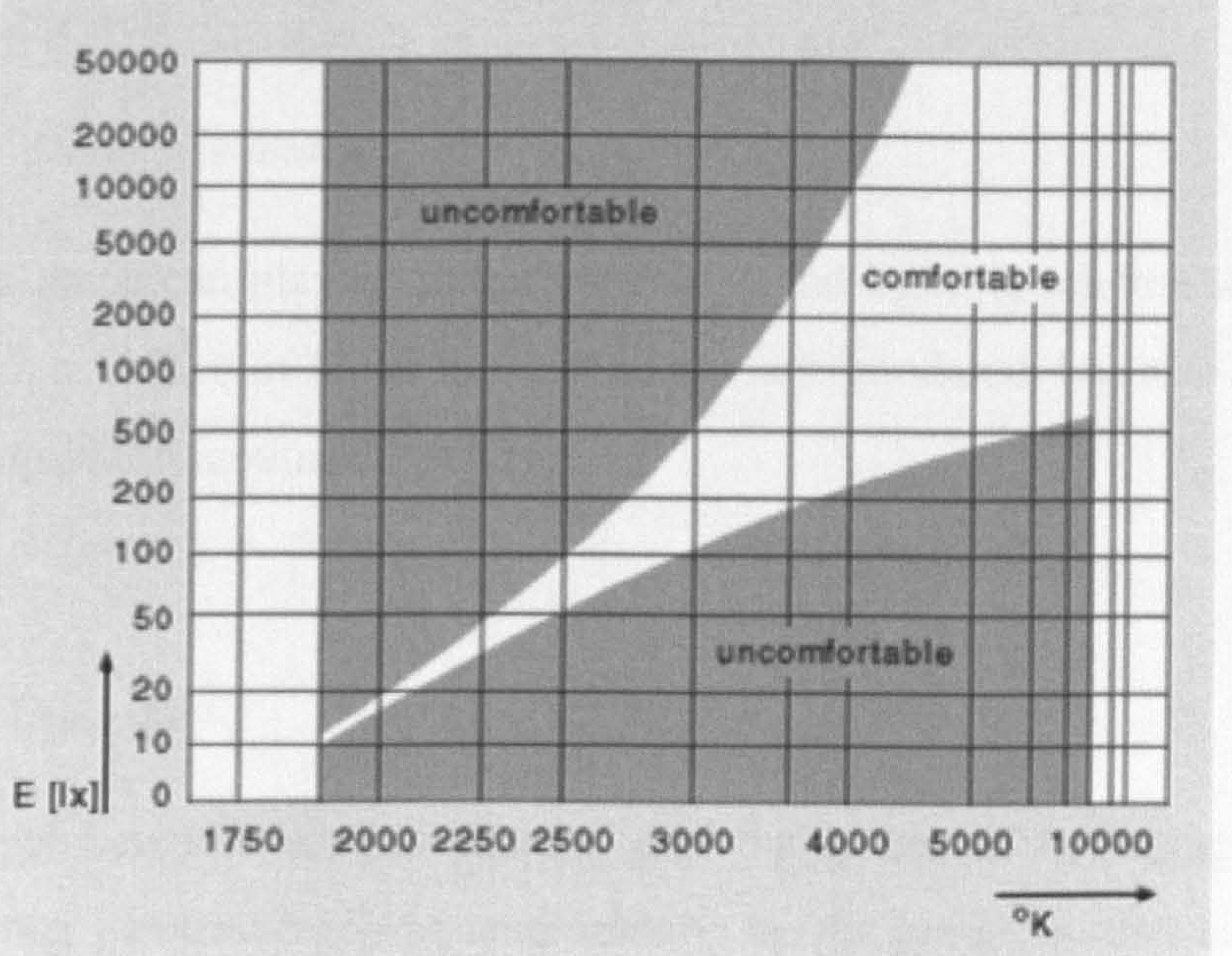


Figure 3.31 The Kruithof effect chart defines the comfort zone as a combination of illuminance and colour temperature of the light source (Osram, 2009)

Photobiological studies have demonstrated the effect of colour temperature on human well being. A number of recent researches confirm that light does not simply affect the human body through our sense of vision. Study on a healthy human suggests that we also possess a so-called "third eye", a unique non-visual photo-receptor cell in the retina directly linked to the pineal gland, which in turn regulates our bodily cycles (LRC, 2004). Dr. George C. Brainard (2009) suggests that the human "third eye" is sensitive to the wavelength of 446-477nm as the most potential wavelength region for melatonin suppression (which makes us sleep). Therefore, exposure to blue, or "cool" blue-tinted light can improve alertness (Brainard, 2009). There have been experiments where an electrical lighting system with changing colour temperatures is installed and the response as the user's change in biological moods and rythm is recorded. The results are quite positive, however it is limited to experimental installation rather than as per recommendations.

Both TCVN: 3978 (1984) and TCVN: 7114-1(2008) recommend using cool white light source (4200°K) to illuminate classroom. BB90 (1999) suggests using lamps with a Warm to Intermediate colour appearance classification (3300K to 5300K) ; where the electric lighting supplements the daylighting and a *CCT* above 4000 Kelvin is recommended. The SLL handbook (2009) also recommends something similar, further explaining that higher *CCT* is required to blend the electrical lighting to the daylighting well.

3.3.2.4.4 Lamp size and shape

Lamp size and shape can play an important role in the lighting scheme selection. It not only limits the choice of luminaire that can be accomodated, but also affects the light distribution of the luminaire.

3.3.2.4.5. Lamp life

Lamp life is subjected to several factors, e.g. the issues of operating heat, the durability of other electronic components making up the luminaire and capital cost. LED currently has the longest lamp life (50 000 hours) available in the market; although it does not have good colour rendering index (*CRI*<80). Other light sources are high pressure discharge lamps and fluorescent lamps (lamp life ~20 000 hours).

However, discharge lamps have some practical and economical disadvantages as discussed above. At present, fluorescent lamps are still the best available light source for classroom lighting (see appendix I for lamp life comparisons).

3.3.2.4.6. Controlling flexibility

The classroom lighting codes provide no specific requirement for lamp dimming capacity. However, the recommendation on using daylight – artificial light linked systems make up the requirement for controlling the lamp. Therefore, dimming capacity is among the important factors that affect the choice of lamps for classroom lighting.

In classroom lighting, there are often not too many lighting scenes required (only on occasions such as video display or on-screen presentation). However, it is recommended that a highly flexible lighting scheme be designed. Simple controlling can be individual switching, dimming and integration of daylight-artificial lighting linked system. Recent research in the US discovered that providing individual access in lighting control can improve the work productivity (LightRight, 2003).

Figure 3.32 Luminaire appearance should be simple and friendly to minimize visual distraction (Licht.de, 2010)

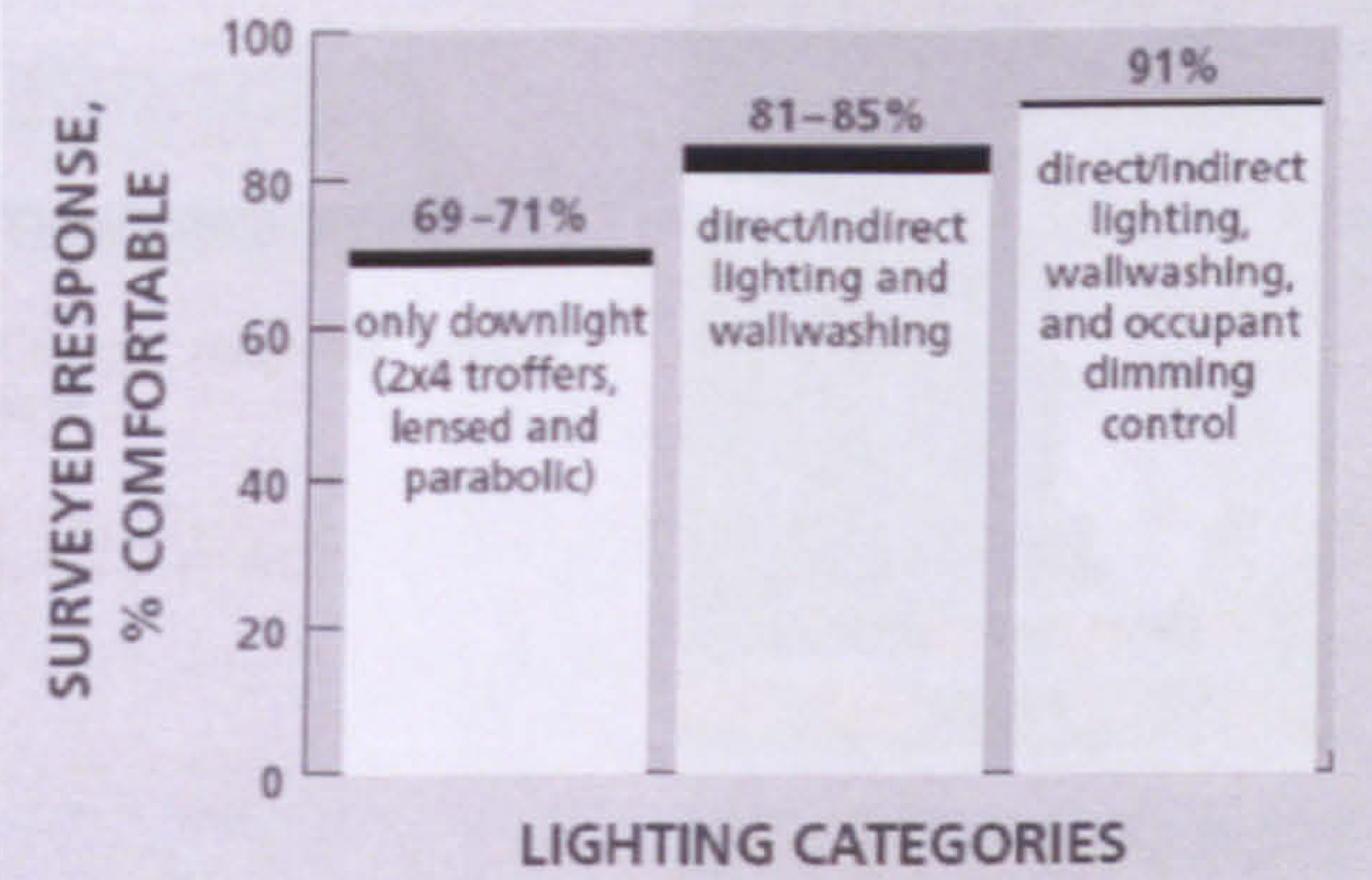
3.3.2.4.7. Choice of Luminaire

According to IESNA:RP-3(2000) guide, the selection of luminaire may be based on the appearance, performance, mounting and maintainability. Capital cost is also among the important issues. The UK guide BB:90 (1999) suggests that the choice of luminaire is subjected to the luminous efficiency and light distribution. These are characterised by the Light Output Ratio values (total, downward and upward) and the shape of the luminous intensity distribution (polar curve). In secondary school classrooms, it is important that luminaire should have a nice and friendly appearance in both on and off mode. Badly designed luminaire can be a source of visual distraction; good designed luminaire can aesthestically complement the architecture.

Other important factors for the choice of lighting fixture is the luminaire photometric characteristics. Both UK codes and US codes discuss using different luminaire types in the classroom: direct, indirect-direct and indirect lighting systems. BB90 suggests that the most effective electric lighting installations are those comprising of different elements which combine task and appearance.

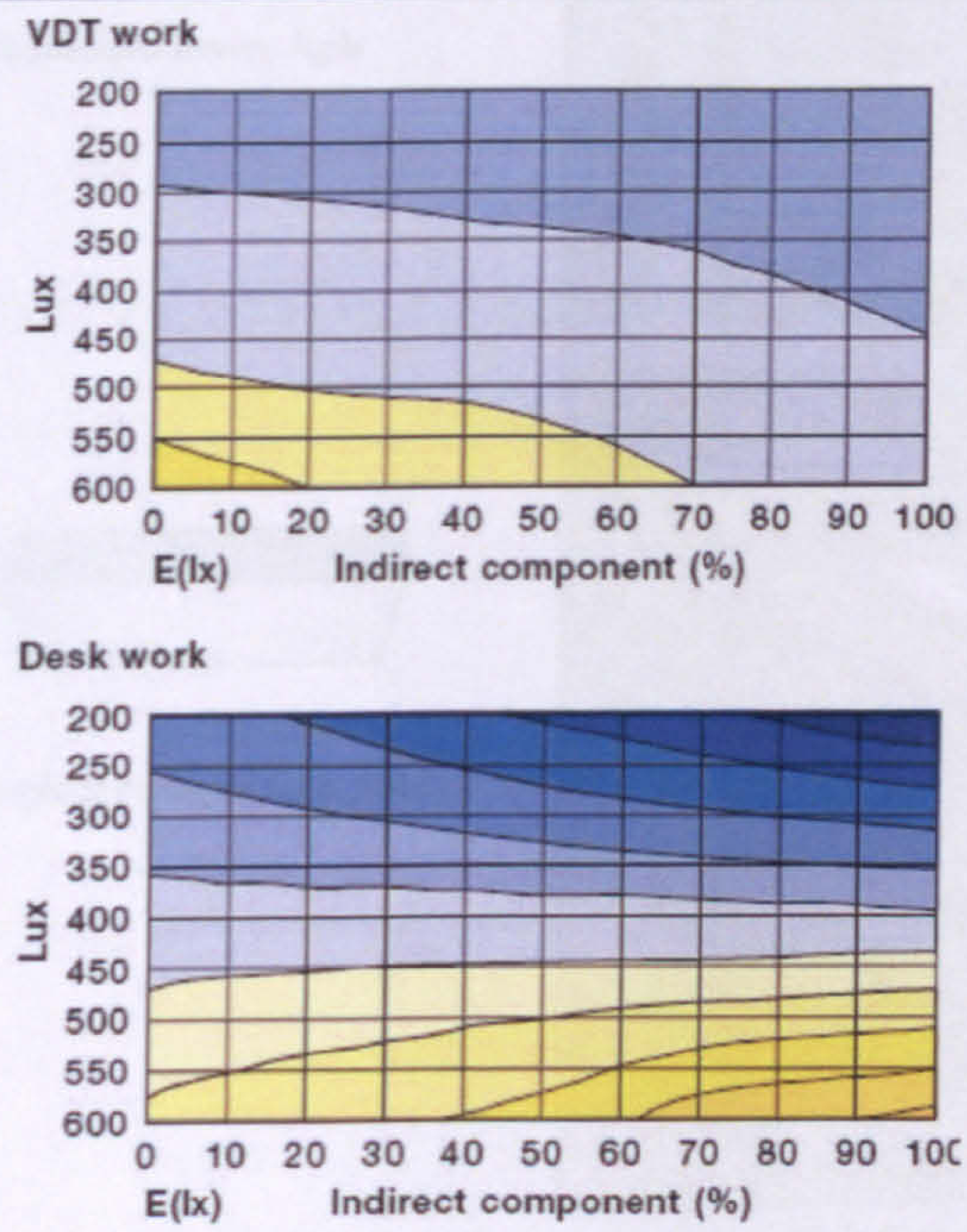
Category	**Upward Light**
Direct	0 - 10%
Semi-direct	10 - 40%
General diffusing	40 - 60%
Direct-Indirect	40 - 60%
Semi-indirect	60 - 90%
Indirect	90 - 100%

Table 3.18 Luminaires for general lighting are classified in accordance with the percentage of total light output emitted above and below the horizontal. (BB:90, 2010)



Six conditions were provided and rated by comfort level. The addition of room surface brightness and personal control improved occupant comfort.

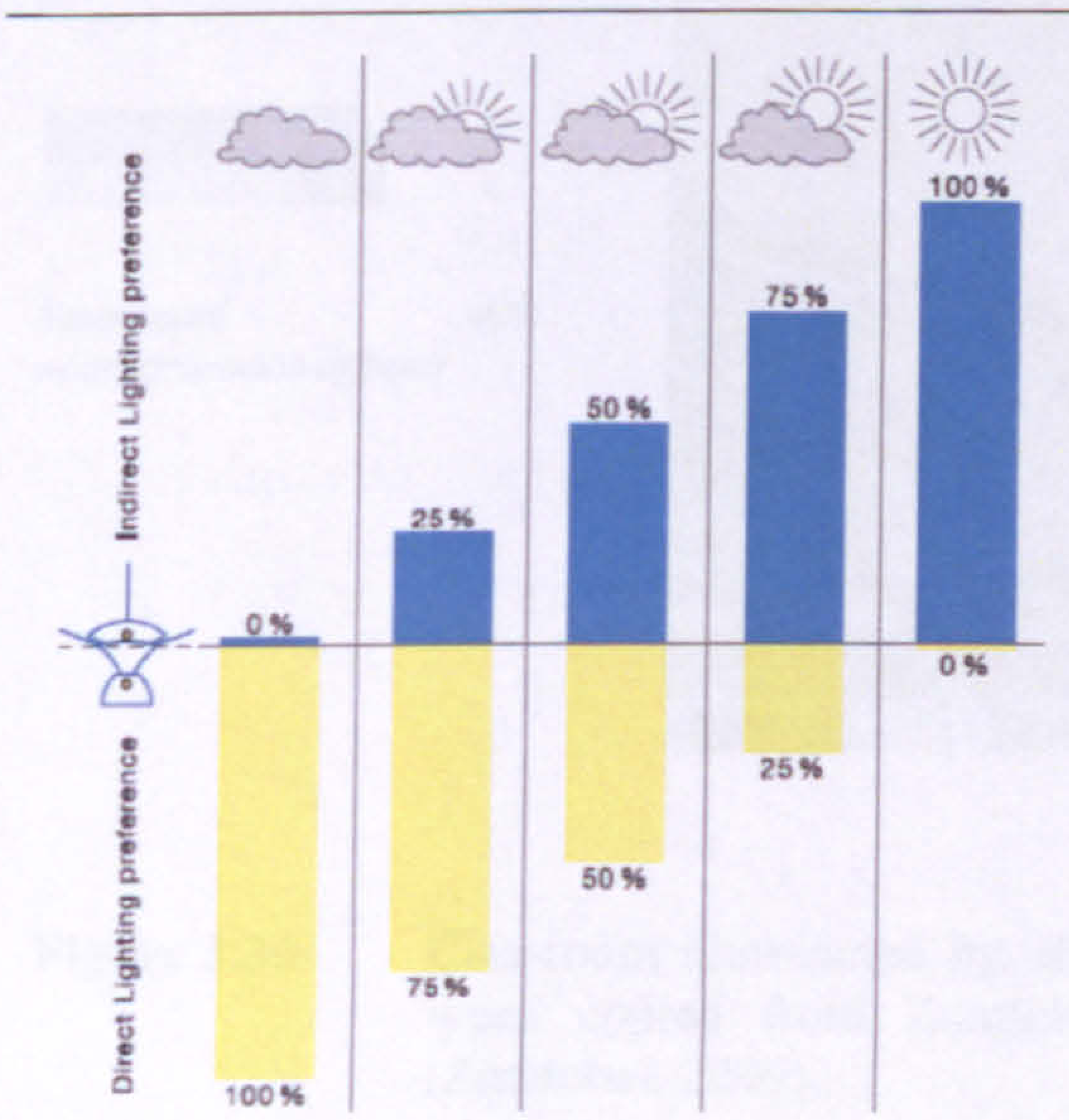
Figure 3.33
Results from LightRight's study: Lighting designs that provided direct / indirect lighting and wallwashing were rated as comfortable by 81%–85% of participants. In comparison, designs that provided only downlight (2x4 troffers) were rated as comfortable by 69 – 71% of participants. The most preferred design provided direct/indirect lighting, wallwashing and occupant dimming control of the overhead lighting for their workstation. This design was rated as comfortable by 91%, the highest percentage of the six conditions (LightRight, 2003).



Key

- low satisfaction
- high satisfaction

Figure 3.34
S. Fleischer (2004) discovered that preferred lighting intensity and its indirect component are very different, depending on application area. For screen-based work, direct light is preferable and for desk-based work, higher indirect component is preferable (Zumtobel, 2004).



- low satisfaction
- high satisfaction

Figure 3.35
Results from S. Fleischer (2004) study found a clear relationship between lighting conditions outside and inside. People prefer warm direct lighting when the sky is overcast, and indirect cool lighting when sunny. (Zumtobel, 2004)

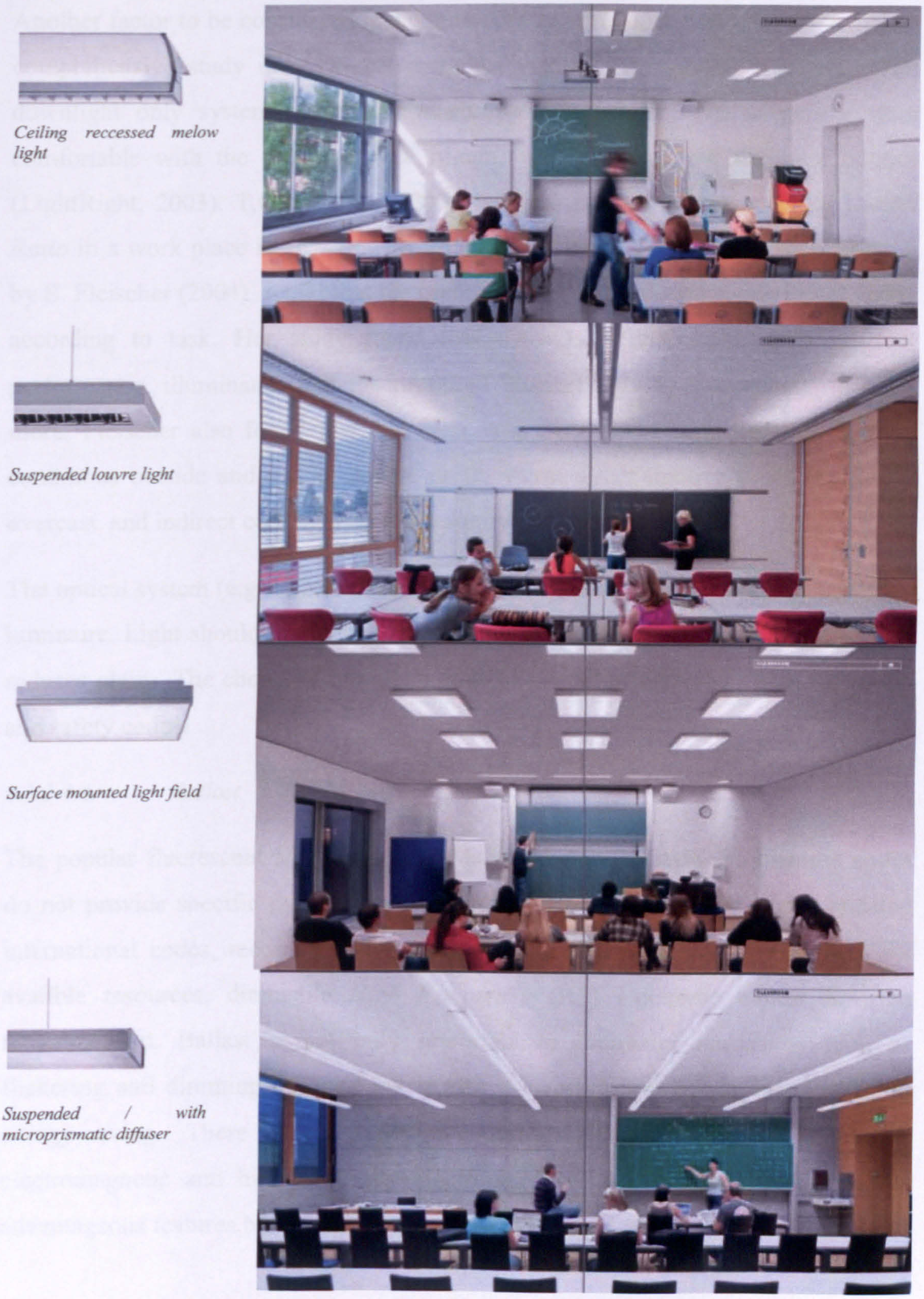


Figure 3.36 Classroom illuminated by different types of luminaire. Illustrations and luminaire types copied from Zumtobel handbook : Light for education and Science. (Zumtobel, 2009)

Another factor to be considered is the luminaire *Light Output Ratio (LOR)*. A recent comprehensive study in a US office shows that 29% to 31% of people under downlight only system rated them uncomfortable, whilst 91% of people were comfortable with the direct-indirect system, wall washing and dimming control (LightRight, 2003). T.Govén et al (2002) suggest that the preferred *Light Output Ratio* in a work place is 44% downward and 56% upward (*flux*). Another research by S. Fleischer (2004) found that the preference for quantity and type of light varies according to task. Her study found that there is a relationship between task performance, illuminance and the preffered indirect lighting component. Further more, Fleischer also found that that there is a clear relationship between lighting conditions outside and inside. People prefer warm direct lighting when the sky is overcast, and indirect cool lighting when sunny (Fleischer, 2004).

The optical system (e.g reflector, refractor, diffuser) is an important component for a luminaire. Light should be directed to where it is needed. Good optical system also reduces glare. The choice of luminaire must of course be compliant with the health and safety codes.

3.3.2.4.8. Ballast

The popular fluorescent and metal halide lamps require ballasts. Vietnamese codes do not provide specific requirements for ballast. However, in most of the updated international codes, recommendation for ballast is discussed briefly. If there are availble resources, dimmable *High Frequency* (HF) electronic ballast is often recommended. Ballast is not only important to luminaire operations such as flickering and dimming capacity but is also a significant factor in contributing to energy saving. There are two types of common ballast available in the market: electromagnetic and high-frequency electronic. The electronic version has more advantageous features,but it is more expensive.

3.3.2.5. Controlling

The strategy of controlling for classroom lighting has not been discussed much in the past. The development of mordern technologies allows simple on/off switching controller in the complex *Building Management System (BMS)*. In addition, the teaching methodology and facilites have also changed over years. For example, lectures with the aid of media materials (videos, films, on screen presentations) are often seen in modern classrooms. Thus, modern classroom lighting should have high flexibility to allow the occupants to customize the lighting scheme. Good controlling strategies can also help to save energy. For example, the use of occupancy sensor and timing switch are often seen in modern classroom. Another key issue for saving energy is maximizing the advantage of daylight-artificial light integration system.

Vietnamese codes do not address the need for a controlling strategy.There are some popular control types such as time-switch controls, photocell controls, occupancy controls, dimmers and in-luminaire controls. In general, automatic controls are required by most updated energy efficiency codes. In the US, automatic daylighting stepped switching or continuous dimming controls are required by code for classrooms in Oregon and Seattle (Benya, 2007).

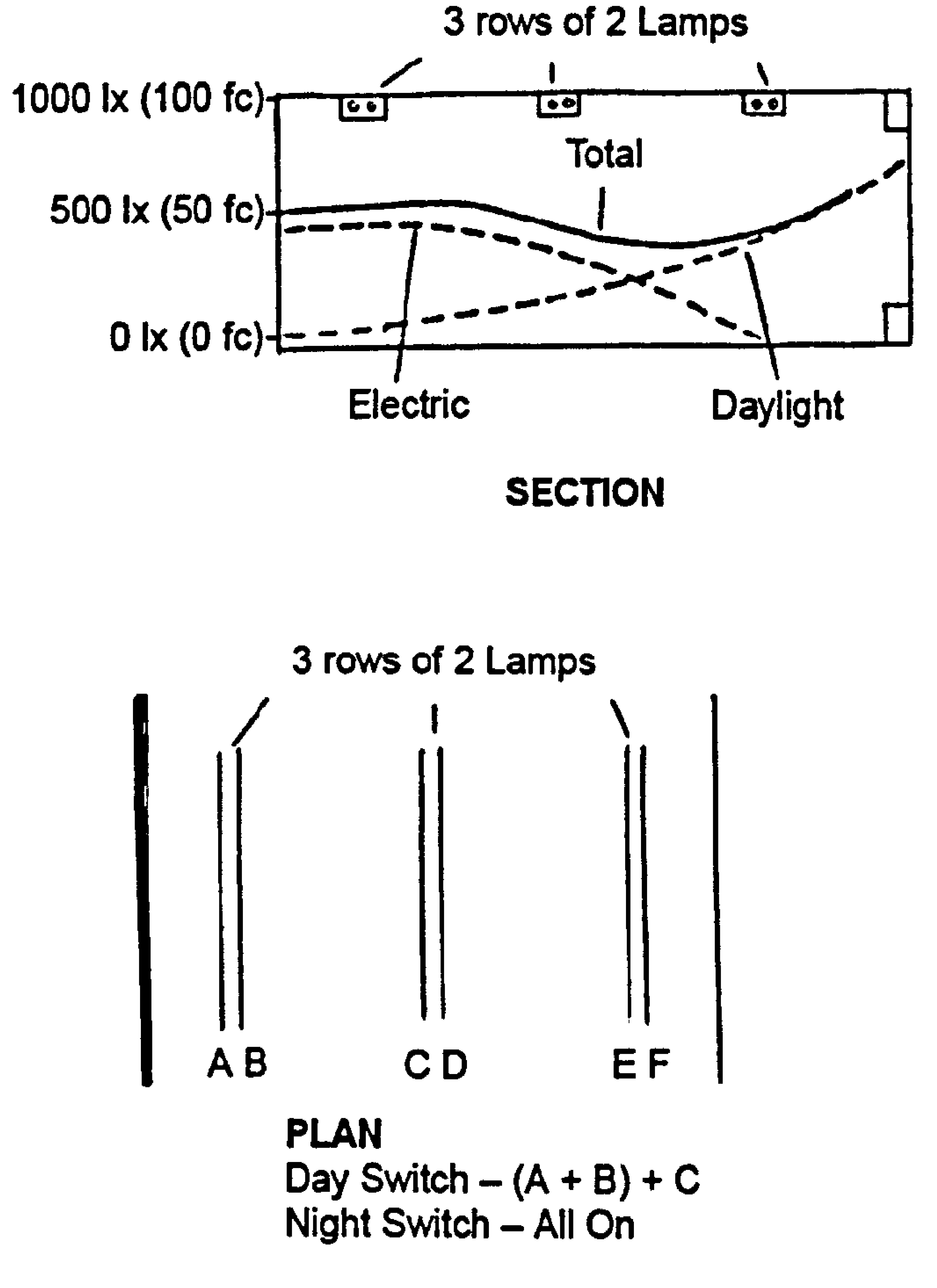


Figure 3.37 Example of daylight combined with electric light scheme. Luminaires near the windows can be switched off when there is sufficient daylight. (ANSI/IESNA:RP3, 2000).

Table 3.19 Classroom controlling strategies. (ANSI/IESNA:RP3, 2000)

Manual Controls	Automatic Controls
• In large open spaces, work areas should be grouped and switched independently. • When single, or two-lamp luminaires are used, adjacent luminaires should be placed on alternate circuit. • When three-lamp or four-lamp luminaires are used with multiple ballasts, central lamps may be connected to a separate circuit with the outside lamps to provide light level flexibility. • Task areas with special |(higher) light levels should be on separate circuits. • Luminaires along window walls should be placed in seperately switched group.	• Time switches to turn off some (or all) lighting on a predetermined schedule. • Timers that turn lighting off after a specific period. • Occupancy sensors to turn off lighting automatically in empty classrooms and turn on lighting when students return. • Photosensor controls that regulate lighting in conjunction with available daylighting. They are also available in control systems that maintain a specified light level, saving energy when lamps are new and dirt depreciation is minimal. • Relays that permit the selective operation of individual luminaires or groups of luminaires. • Energy management systems that customize the amount of light and the time the light is on and off, in individual spaces throughout the facility.

3.3.2.6. Energy efficiency

The energy efficiency of artificial light sources can be assessed by *Lighting Power Density (LPD)*, which is the energy used per area to light the space at a given light level. These requirements are now addressed in all the latest codes. In school classrooms, lighting accounts for a significant part of energy use which can be as much as 25% (Thorn, 2010). A design study in Sonhofe, Germany shows that the installation of intelligent lighting control systems can save up to 53% energy (Zumtobel, 2009). Another indicator, which is *Lighting Energy Numeric Indicator (LENI)* , is also commonly used in the lighting codes.

Recommendations for *LPD* and *LENI* in school classrooms are summarised in table 3.20 and table 3.21.

Table 3.20 Recommendations for *Lighting Power Density (LPD,* in W/m^2*)*. (Zumtobel, 2009)

TCVN:09:2005 (Vietnam)	CIBSE Guide F and BCO guide (UK) (at 300 lux)	AS/NZ 1680.2.3 (Australia)	ASHRAE/IESNA 90.1-2004 and IECC-2004 (U.S)	California Title 24 (US)	PIER 4.5 (California Energy Comssion, US)
13 W/m^2	Fluorescent: 7 W/m^2 Compact Fl. 7 W/m^2 Metal halide: 11 W/m^2 BCO: 12 W/m^2	12W/ m^2	1.4 W/sf (15.7 W/m^2)	1.2 W/sf (12.9 W/m^2)	0.82-0.89 W/sf (8.8-9.57 W/m^2)

Table 3.21 Recommendations for *Lighting Energy Numeric Indicator* (LENI, in kWh/m^{2}a) excerpt from various codes. (Zumtobel, 2009)

EN 15193 (European)	**H 5059 (Austrian)**	**DIN 18599 (German)**	**Minergy (Swiss)**
24.8 kWh/m^{2}a	24.8 kWh/m^{2}a	8.49 kWh/m^{2}a	8.81 kWh/m^{2}a

3.4. Recommendations for Thermal Comfort

The benefit of daylight in classrooms is highlighted in most of the lighting codes. However, daylight is the only visible part of the solar radiation, which can also be transferred into heat. As HCMC is located within the tropical belt where solar radiation availability is high, inappropriate improvement of daylight quality in classrooms may lead to worsening thermal comfort. Therefore, it is important to review the thermal comfort consequences. The relevant literatures of thermal comfort are school classrooms are introduced in this section.

In most of the international codes, thermal comfort is defined as *'the condition of mind which expresses satisfaction with the thermal environment'* (CIBSE, 2006; ASHRAE:55, 2007). It seems that the assessment of thermal comfort is based on the user's satisfaction rather than numeric physical measurement. According to CIBSE Guide A (2006), the human body heat balance is given below:

$$M - W = C_{res} + E_{res} + K_h + R_h + C_h + E_h + S_h \quad (3.29)$$

Where: M: Metabolic rate [met, or w/m^2]

W: Rate of performance of external work.

C_{res}: Heat exchange by convection in the respiratory tract.

E_{res}: Heat exchange by evaporation in the respiratory tract.

K_h: Heat flow by conduction from the surface of the clothed body.

R_h: Heat loss by radiation from the surface of the clothed body.

C_h: Heat loss by convection from the surface of the clothed body.

E_h: Heat loss by evaporation from the surface of the clothed body

S_h: Body heat storage.

Study of this heat balance equation leads to the common suggestion that a person's heat balance and thermal comfort sensation are affected by six factors, which are both environmental and personal. The environmental factors are *Air temperature, Radiant temperature, Relative air speed* (or air velocity) and *Humidity*. The personal factors are *Metabolic rate* [met], and *Clothing Insulation* [clo]. They may be independent of each other, but together contribute to the user's thermal comfort.

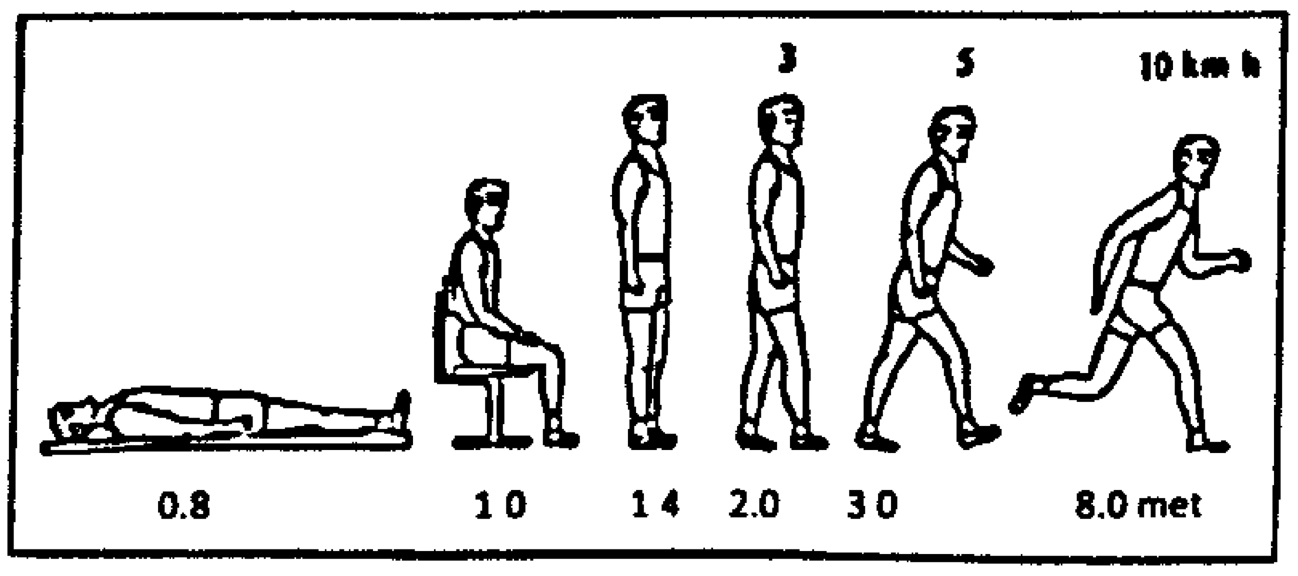


Figure 3.38 Metabolic rates of different activities [met] (Fanger, 1986)

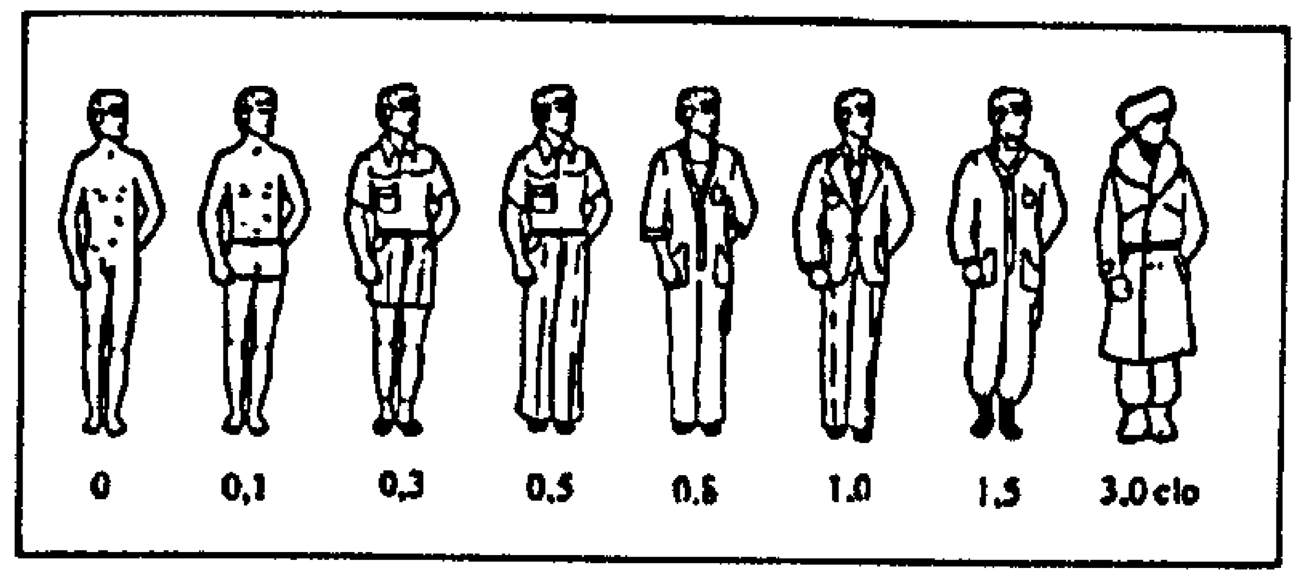


Figure 3.39 Insulation of typical clothing ensembles [clo] (Fanger, 1986)

3.4.2. The Vietnamese codes

TCXDVN: 306 (2004) covers most of the thermal comfort requirements in dwellings and public buildings. It was developed from other codes such as TCVN: 4605 (1988), TCVN: 5687 (1992) and former Soviet Union code 30494-96 (Trinh, 2003). TCXDVN: 306 (2004) defines neutral comfort state as *"if 80% of users feel comfortable"*. Thus this index is based on the predicted user's comfort assessment. The code adopted three indices which are considered *"suitable and applicable for Vietnamese"* (Trinh, 2003). These indices are *Condition Index* ΣH [%] by Zuilen-Korenkov, its modification *thermal sensation scale* and the C.G. Webb *Effective Temperature* T_{eff} [°C] . The code proposes a thermal sensation scale based on these indices .This scale was derived from a field study on 1100 people living in North Vietnam. The *Condition Index* (ΣH) of Zuilen- Korenkov is obtained by:

$$(\Sigma H) = 0.24(t_d + t_r) + 0.1d - 0.09(37.8t_d)\sqrt{v} \qquad (3.30)$$

Where: t_d: Dry bulb temperature, [^{0}C]

t_r: Mean radiant temperature of internal surfaces [^{0}C]

d: Humidity ratio [g/kg]

v: Air velocity [m/s]

The *Effective Temperature,* t_{eff} [^{0}C] of C.G. Webb is obtained by the following equation :

$$T_{eff} = 0.5(t_d + t_w) - 1.94\sqrt{v} \quad (3.31)$$

Where: T_{eff}: Effective temperature, [^{0}C]

t_d: Dry bulb temperature, [^{0}C]

t_w: Wet bulb temperature [^{0}C]

v: Air velocity [m/s]

Table 3.22 Recommendations for thermal sensation scale and neutral comfort temperature. TCXDVN: 306 (2004)

TCXDVN 306 (2004) **THERMAL SENSATION SCALE FOR VIETNAMESE**

Comfort Scale	Thermal Sensation **Scale**	Condition Index (ΣH)		Effective Temperature [^{0}C] (Teff)		Air temperature [^{0}C]	
						j=80%	v=0.3-0.5m/s
		Cold season	Hot season	Cold season	Hot season	Cold season	Hot season
COLD	Cold	7.1	-	≤17.3	-	≤19.8	-
	Slightly cold		-	18.5	-	-	-
COMFORT	Lower comfort limit	11.1	-	20.0	-	21.5	
	Neutral comfort	12.7	13.8	23.3	24.4	24.5	25.5
	Upper comfort limit	14.9	16.3	26.5	27.0	29.0	29.5
HOT	Slightly hot	15.0	17.5	-	28.5	-	-
	Hot	-	19.1	-	≥29.2	-	≥31.5

Note: The cold season is defined as the period where average daily temperature is lower than 19.8^{0}C; hot season is the period where average daily temperature is higher than 25.5^{0}C.

The calculation methods introduced by the code are quite complicated and they require professional measuring equipments. The equation is dependent on several correction factors; the description and derivation of which is unclear. Furthermore, it is noted that these recommendations were based on a survey of 1100 people living in the North of Vietnam and it is unclear if they are valid for the Southern tropical climate. Findings from other researchers in this field also point out that this code does not take into consideration several significant issues of adaptive users' comfort, e.g. adaptability, structure under skin related to age and nationality and influence of working intensity or working stress (Trinh, 2003; Pham et al, 2006). As TCXDVN: 306 (2004) describes *"hot season is the period where average daily temperature is higher than 25.5^{0}C "*, HCMC climate can be classified as "hot season" for most of the year.

According to the code, neutral operative temperature (T_{op}) for HCMC is therefore, within the range of 25.5^{0}C to 29.5^{0}C. The Vietnam National Institute for Labour Protection (NILP) proposes another index called the *Predicted Thermal Sensation SN* developed from the project NILP99, and is referred to –as the NILP99 index. NILP99's SN index is obtained by:

$$SN = K_{hc} - a(t_k + t_r)^n - b.P_{hm} + c(37.8 - t_k)\sqrt{v} \quad (3.32)$$

Where:	K_{hc} *=7.965*	Correction factor for the hot season in Vietnam
	t_k:	Dry air temperature in workplace [^{0}C].
	t_r:	Mean radiant temperature of internal surfaces [^{0}C]
	n = 0.92	Ethological correction factor
	P_{hm}:	Partial water pressure at work place [mmHg]
	a=0.1:	Correction factor for air and surface temperature effect.
	b = 0.033	Correction factor, to be calculated as b=0.0362 x n
	37.8:	Maximum skin temperature [^{0}C] when body is exposed to hot source
	v:	Air velocity at work place [m/s]
	c= 0.04:	Cloth correction factor for Vietnam, c= 0.0362 x 10%

Table 3.23 NILP's recommendations for thermal sensation scale *SN* (NILP99) (Trinh, 2003)

SN index	≤ 0.8	≤ 1.4	≤ 2.0	≤ 2.6	≤ 3.2	≤ 3.8	≤ 4.4
Sensation	Too hot	Very hot	Hot	Considerable hot	Slightly hot	Normal	Comfort
Temperature [^{0}C]	>40	40-37	37-35	35-31	31-29	29-25	25-23

Table 3.24 Recommended neutral comfort temperature [°C], obtained from other studies in the North Vietnam . (Hoang, 1986)

	Location	Authors	Seasons	Air temperature [°C]			Humidity	Air velocity	Effective temperature *Temp* [°C]		
				Upper limit	Comfort	Lower limit	[%]	[m/s]	Upper limit	Comfort	Lower limit
1	North	Pham Ngoc Dang	Summer	29.5	25.5	-	80	0.3-0.5	27.0	24.0	-
			Winter	29.0	24.5	21.5	80	0.3-0.5	26.0	23.3	20.0
2	North	Nguyen Huy Con & Do Bao Toan	-	28.5	27.0	25.0	90	0.5-0.6	26.0	24.0	23.0
3	North	Nguyen Huy Con &Trinh Xuan Minh	Summer	27.0	25.0	23.0	80	<0.5	27.3	23.0	18.6
			Winter	25.0	23.0	21.0	80	<0.2	24.6	21.0	16.8
4	Vinh(*)	Dao Ngoc Phong &Le Thanh Uyen	-	28.9	-	-	84	-	-	-	-
5	Vinh(*)	Ngo Huy Anh	-	-	-	-	-	-	27.5	23.7	20.0
6	North	University of Hanoi	-	-	-	-	-	-	26.2	23.0	-
7	North	Tu Huu Thiem	-	26-27	24-25	23.0	60-80	0.1	-	-	-

(*) Vinh City is located in Nghe An province, North Centre of Vietnam

There are many correction factors involved in the calculation of NILP99's SN index. These correction factors are numerically provided by the codes, though NILP99 does not explain clearly where these numbers are derived from. The *SN* comfort range is shown in table 3.26. The comfort temperature is recommended to be within the range of 23 ^{0}C to 25 ^{0}C; although the upper limit of the *"normal condition"* may be as high as 29 ^{0}C.

There have been several other studies that have established the range of comfort temperature for Vietnam. The results are summarized in table 3.22. Although surveyed in the North, the studies reveal differing ranges of comfort air temperature and effective temperature, expanding over a scale of 10^0 C.

3.4.3. The International Codes

Several studies and researches have attempted to develop some kinds of indices which can express the effect of the thermal environment on the human body. Popular indices that are used worldwide are *Fanger's Predicted Mean Vote (PMV)*, *Gagge's Effective Temperature (ET*)* and *Standard Effective Temperature (SET*)*. However, a study by Humpreys et al. (2007) suggests that increasing the complexness of the indices may introduce more error. Nicol and Humpreys (2010) suggest that a simple index such as the *Operative Temperature* (*Top*, ^{0}C) can be used to effectively assess the environmental comfort conditions. The following discussion will introduce some of the most common and relevant methods for determining acceptable thermal conditions in occupied spaces.

3.4.3.1. The Operative Temperature

Among the six factors, if the values of humidity, air speed, metabolic rate and clothing insulation are known, a comfort zone may be determined by the combination of the two other factors, which are air temperature and mean radiant temperature. Furthering this concept, Nicol and Humpreys (2010) suggest using *the Operative Temperature* (T_{op}, ^{0}C), which is a simple index including both air temperature and mean radiant temperature.

The *Operative Temperature* is calculated as:

$$T_{op} = A_h\, T_{ai} + (1\text{-}A)T_r \quad (3.33)$$

Where: T_{ai} : Indoor air temperature [°C]

T_r: Mean radian temperature [°C]

A_h: The ratio $h_c/(h_c+h_r)$, and $(1\text{-}A)$ is the ratio of $h_r/(h_c+h_r)$

h_c, h_r: are the surface heat transfer coefficients of the clothed body by convection and radiation respectively.

If the indoor air speed is not greater than 0.1 m/s, Operative Temperature is given by:

$$T_{op} = \frac{1}{2}T_{ai} + \frac{1}{2}\,T_r \quad (3.34)$$

All the definitions above applied.

3.4.3.2. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfaction (PPD)

The *Predicted Mean Vote (PMV) - Predicted Percentage of Dissatisfaction (PPD)* Indices present "*methods for predicting the general thermal sensation and degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments*". (ISO:7730, 2005). Therefore, the assessment is based on the subjective users' comfort satisfaction rather than numeric physical measurement. *PMV* is defined as an index that predicts the mean value of the votes of a large group of users on a seven-point thermal sensation scale (see table 3.25).

From this PMV concept, Fanger extends his study to the development of the PPD index to predict the percentage of thermally dissatisfied people. The users' dissatisfaction is defined by their seven-point thermal sensation comfort vote. The people that vote within the three central categories (+1: slightly warm, 0: neutral, and -1: slightly cool) are considered thermally satisfied. The correlation between *PMV* and *PPD* is illustrated in the figure 3.40, which is an excerpt from the international code ISO: 7730 (2005) . However, it should be noted that the distribution of PPD is based on observations from climate chamber experiments and not from field measurements. (CLEAR, 2004).

The PMV can be obtained by using the equations given in appendix N. Both ISO: 7730 (2005) and ASHRAE: 55 (2004) provide further details on obtaining PMV values using a computer software to simplify the process. The PPD is calculated from PMV by:

$$PPD = 100 - 95.exp(-0.03353.PMV^4 - 0.2179.PMV^2) \tag{3.35}$$

Table 3.25 Fanger's thermal sensation scale.

Sensation Scale	Numeric Scale
Hot	+3
Warm	+2
Slightly warm	+1
Neutral	0
Slightly cool	-1
Cool	-2
Cold	-3

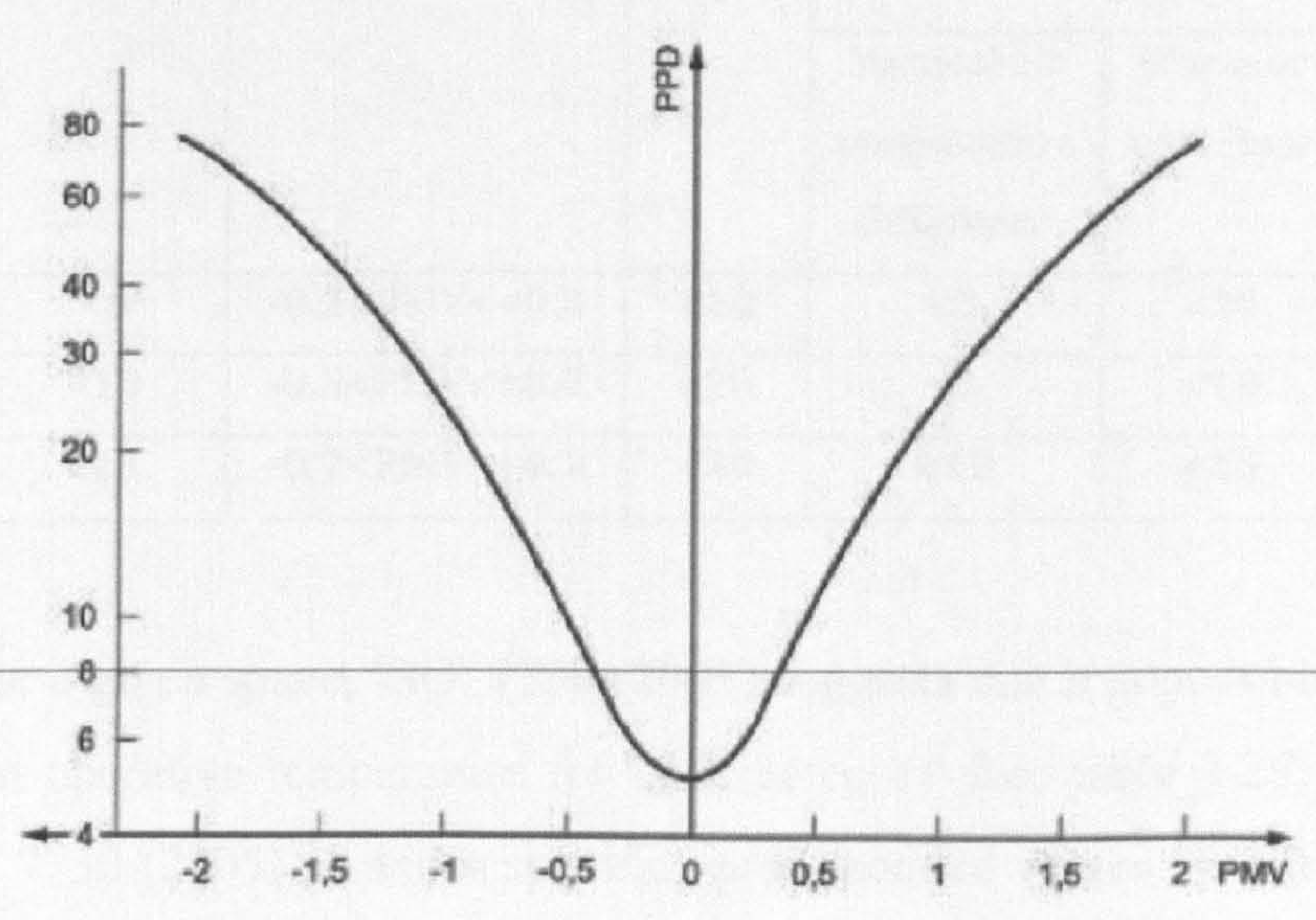


Figure 3.40 Correlations between PPD and PMV (ISO:7730, 2005)

3.4.3.3. The International Standard ISO: 7730 (2005)

3.4.3.3.1. PMV and PPD methods

ISO:7730 (2005): *Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort* provides the method developed from Fanger's concept. ISO: 7730 (2005) also provides an assessment method for local discomfort caused by draughts, asymmetric radiation and temperature gradients. It suggests using one of the following three methods to calculate the *PMV*:

a) Using digital computer software provided in Annex D of the code.
b) Using directly provided values of PMV, given for different combination of activities, clothing, operative temperature and relative velocity.
c) By direct measurement and using integrating sensor.

Table 3.26 Recommendations for thermal comfort requirements. (ISO: 7730, 2005)

Category	Thermal state of the body as a whole		Local Discomfort			
	PPD (%)	PMV	DR(%)	PD(%) caused by		
				Vertical air temperature difference	Warm or cool floor	Radiant asymmetry
A	**<6**	**-0.2<PMV<+0.2**	**<10**	**<3**	**<10**	**<5**
B	**<10**	**-0.5<PMV<+0.5**	**<20**	**<5**	**<10**	**<5**
C	**<15**	**-0.7<PMV<+0.7**	**<30**	**<10**	**<15**	**<10**

If *PMV*=0 for a given space, ISO: 7730 (2005) suggests that it is possible to calculate the optimum operative temperature for each category (see table 3.26). From these charts, ISO: 7730 (2005) provides specific recommended values for various types of buildings including school classrooms. If a classroom is classified as category A, the code suggests, the *operative temperature* is in the range of 24.5±1.0 (°C) for summer and 22.0±1.0 (°C) for winter (see table 3.27).

Table 3.27 Recommendations of different design criteria for spaces in various types of building. (ISO:7730, 2005).

Type of building/space	Activity W/m²	Category	Operative temperature °C		Maximum mean air velocity [a] m/s	
			Summer (cooling season)	Winter (heating season)	Summer (cooling season)	Winter (heating season)
Single office Landscape office Conference room Auditorium Cafeteria/restaurant Classroom	70	A	24,5 ± 1,0	22,0 ± 1,0	0,12	0,10
		B	24,5 ± 1,5	22,0 ± 2,0	0,19	0,16
		C	24,5 ± 2,5	22,0 ± 3,0	0,24	0,21 [b]
Kindergarten	81	A	23,5 ± 1,0	20,0 ± 1,0	0,11	0,10 [b]
		B	23,5 ± 2,0	22,0 ± 2,5	0,18	0,15 [b]
		C	23,5 ± 2,5	22,0 ± 3,5	0,23	0,19 [b]
Department store	93	A	23,0 ± 1,0	19,0 ± 1,5	0,16	0,13 [b]
		B	23,0 ± 2,0	19,0 ± 3,0	0,20	0,15 [b]
		C	23,0 ± 3,0	19,0 ± 4,0	0,23	0,18 [b]

[a] The maximum mean air velocity is based on a turbulence intensity of 40 % and air temperature equal to the operative temperature according to 6.2 and Figure A.2. A relative humidity of 60 % and 40 % is used for summer and winter, respectively. For both summer and winter a lower temperature in the range is used to determine the maximum mean air velocity.

[b] Below 20 °C limit (see Figure A.2).

3.4.3.3.2. *Validity, Reliability and Usability of ISO: 7730 (2005)*

There have been some critical comments on ISO: 7730 (2005). Laboratory studies often support the validity of this code, while field studies do not (Olesen and Parson, 2002). Olesen and Parson (2002) have criticized the lack of thereotical validity e.g. the recent improvement of the human balance heat equation and the prediction of sensation is based on thermal load. Olesen and Parson (2002) also indicate that ISO:7730 (2005) does not take into acount the people and their local and cultural adaptation ability. Results found from a field survey of the SCATs Project (Nicol and Pagliano, 2006) also found several errors in ISO:7730 regarding *PMV, PPD* and operative temperature. Differences are also seen between free-running buildings and mechanically heated-cooled buildings (see figure 3.41-3.43).

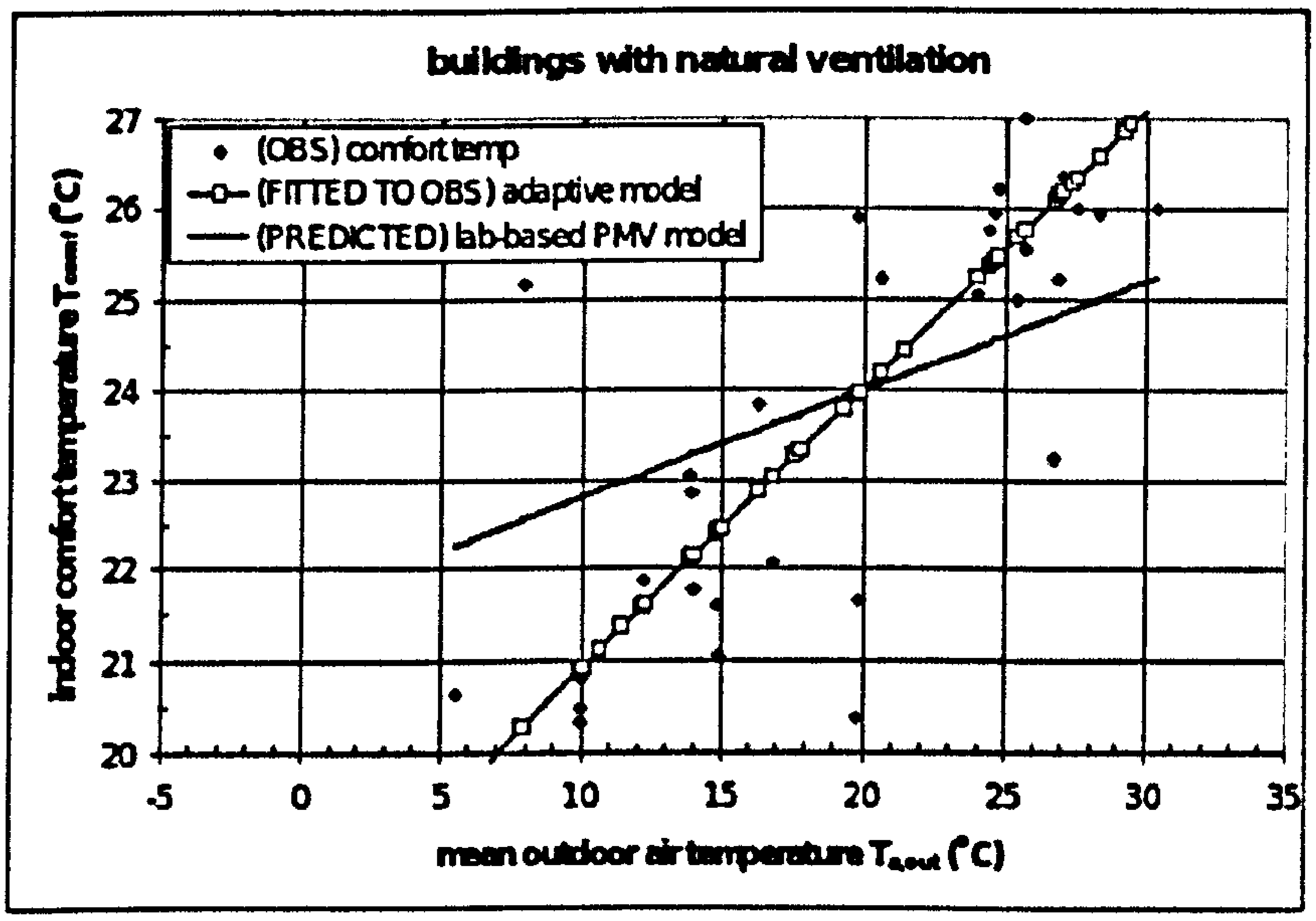


Figure 3.41 The PMV errors found between the predicted lab-based model and the field survey. (Nicol and Pagliano, 2006)

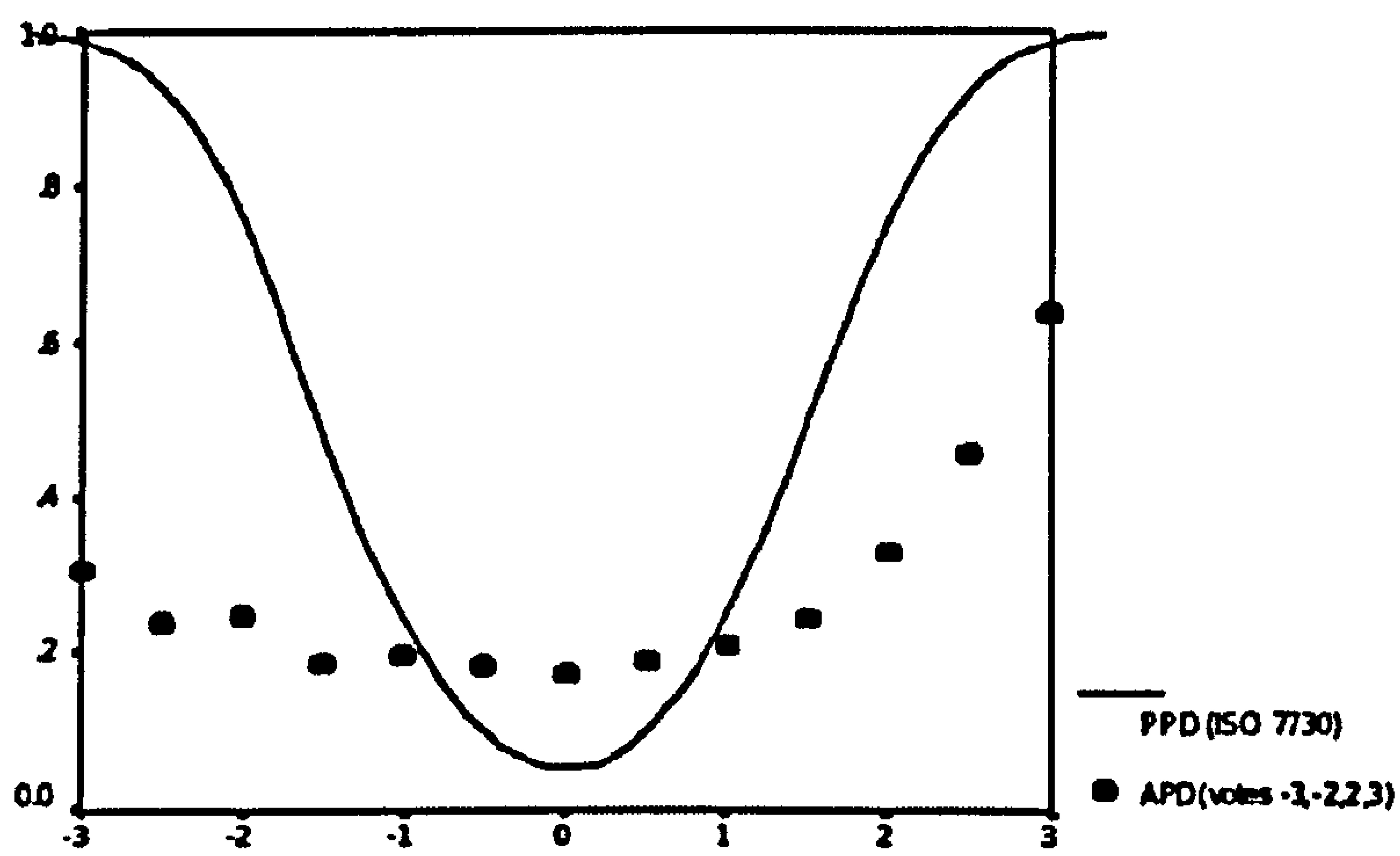


Figure 3.42 The PPD errors found between the predicted lab-based model and the field survey. (Nicoland Pagliano, 2006)

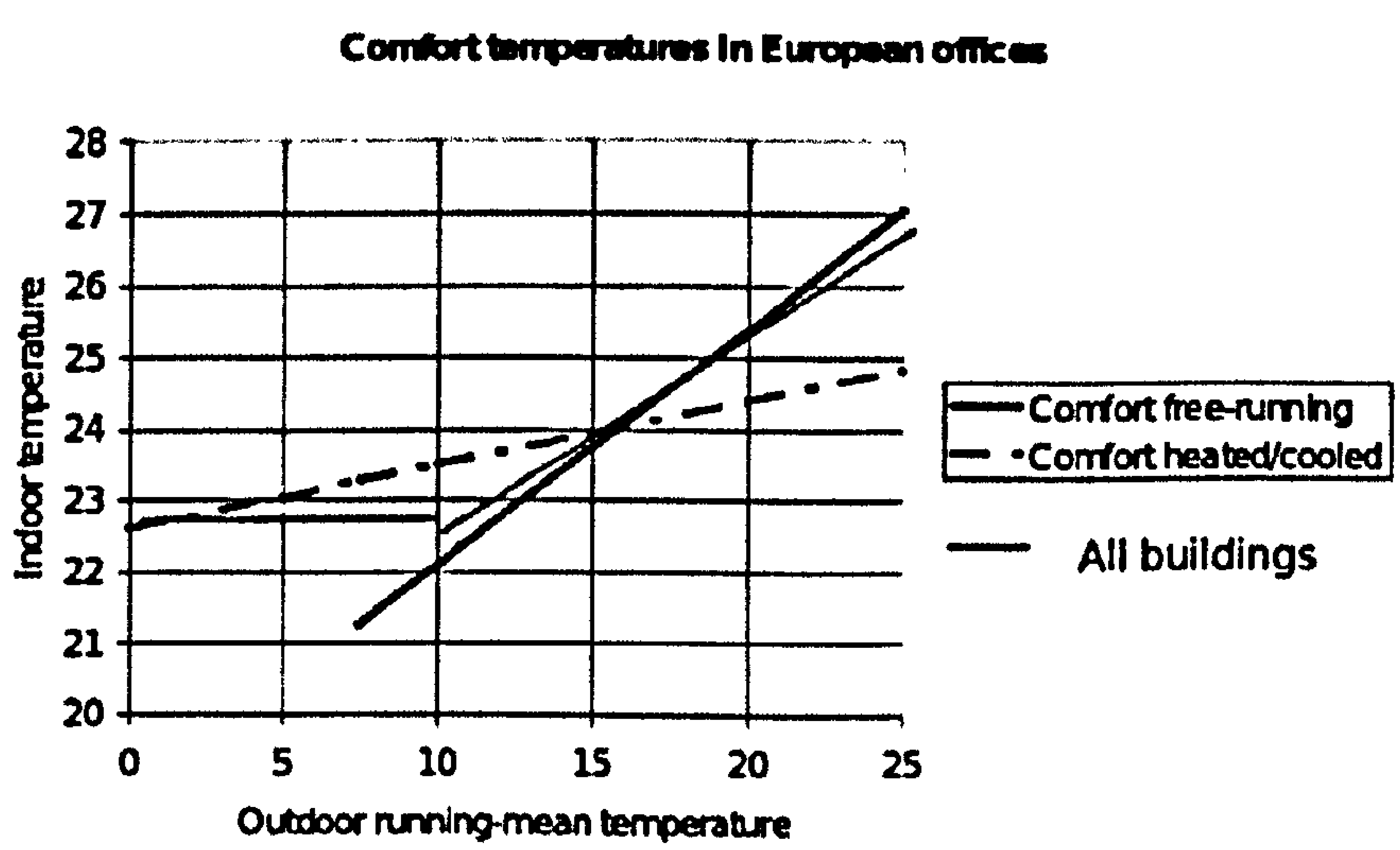


Figure 3.43 The plotted correlation between outdoor running-mean temperature and indoor comfort temperature. This chart is developed from the data collected by SCATS projects. (Nicol and Pagliano, 2006)

3.4.3.4. The European Standard EN: 15251 (2004)

The European standard EN: 15251(2004): *"Indoor Environment Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Quality, Thermal Environment, Lighting and Acoustics"* provides guidance on calculating an acceptable indoor environment including thermal comfort.

EN:15251(2004) uses the data derived from a recent European Project, *Smart Controls and Thermal Comfort (SCATS)*, which studied the environmental conditions of 26 European offices. Thus it is more applicable to European buildings. EN: 15251 (2004) classifies buildings into four categories; for each category, it provides associated acceptable limit range for *Operative temperature* for free-running buildings and Predicted Mean Vote (PMV) for mechanically cooled buildings (see table 3.30).

EN: 15251 (2004) suggests different requirements for free-running buildings (without mechanical cooling systems) and mechanically cooled/heated buildings. Buildings with mechanical fans are still classified as free-running under this code. For free running buildings, EN: 15251 uses Operative Temperature to assess thermal comfort conditions, with a comfort zone for each building category. The *indoor operative temperature* (*Θo*, °C) is generated from the *outdoor mean running temperature* (*Θrm*, °C). Table 3.29 shows the categorization of *indoor operative temperature* in correlation with *outdoor mean running temperature*. The neutral comfort temperatures should fall within a category defined by an upper and lower temperature limit. The limit offset differs with buildings classifications.

Table 3.28 EN15251 recommendations for building categories and associated acceptable limit range for Operative Temperature for free-running buildings and Predicted Mean Vote PMV for mechanically cooled buildings (EN:15251, 2004)

Category	Explanation	Limit (T_n, °K)	Limit of the predicted mean vote (PMV)
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	±2	±0.2
II	Normal expectation for new buildings and renovations	±3	±0.5
III	Moderate expectation (used for existing buildings)	±4	±0.7
IV	Values outside the criteria for the above categories (only acceptable for a limited periods)		

Table 3.29 EN 15251 Calculating Operative Temperature for free-running buildings. (EN:15251, 2004)

EN:15251 Calculating Operative Temperature		
Category I	Upper limit	$\Theta imax = 0.33\ \Theta rm + 18.8 + 2$
	Lower limit	$\Theta imin = 0.33\ \Theta rm + 18.8 - 2$
Category II	Upper limit	$\Theta imax = 0.33\ \Theta rm + 18.8 + 3$
	Lower limit	$\Theta imin = 0.33\ \Theta rm + 18.8 - 3$
Category III	Upper limit	$\Theta imax = 0.33\ \Theta rm + 18.8 + 4$
	Lower limit	$\Theta imin = 0.33\ \Theta rm + 18.8 - 4$
Key: Θ_o: **Operative temperature (°C)**	Θ_{rm} **: Outdoor running mean temperature (°C)**	

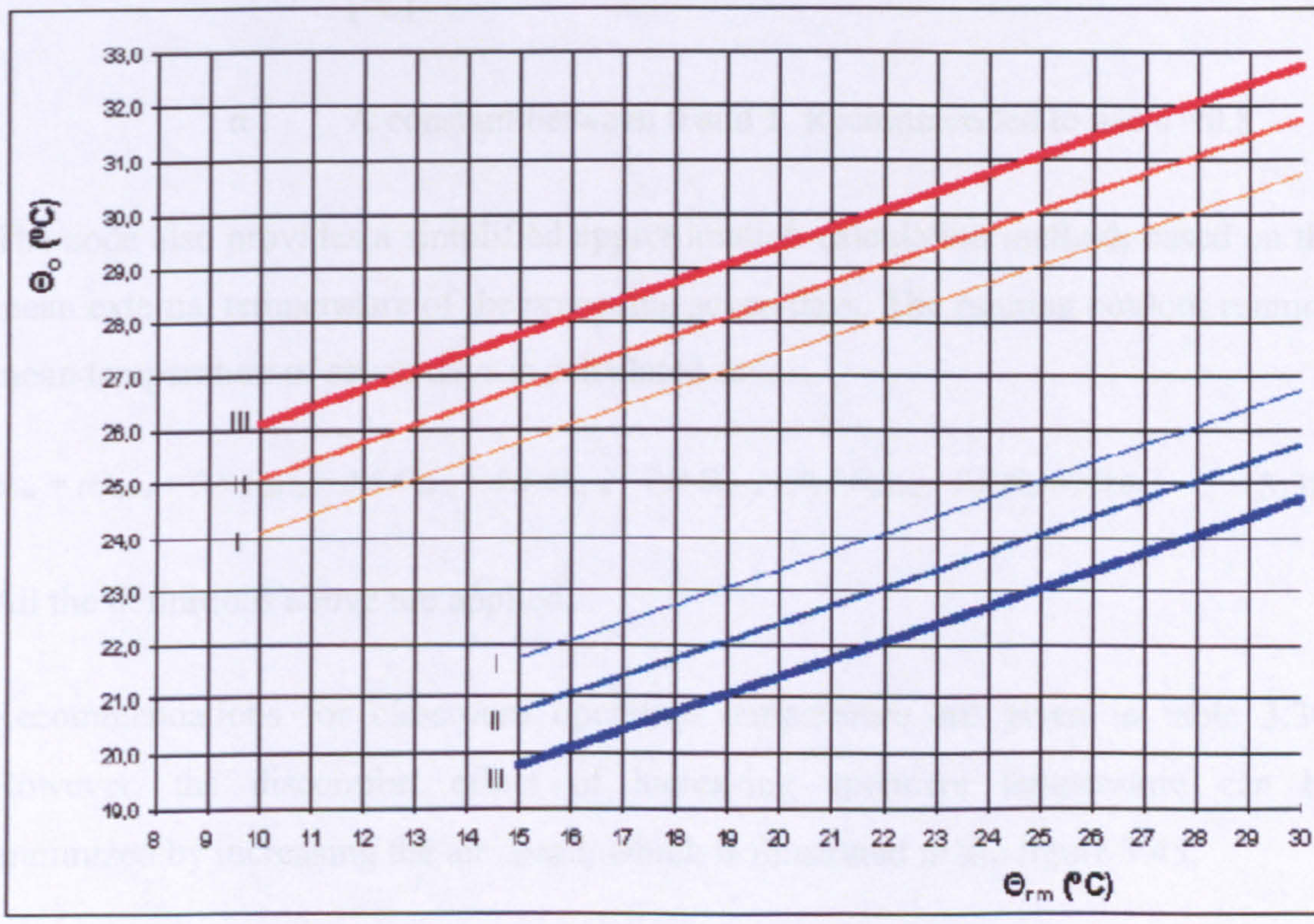


Figure 3.44 EN 15251 Design values for the indoor operative temperature for buildings without mechanical cooling systems, as a function of the exponentially-weighted running mean of the outdoor temperature (CEN, 2009).

The running mean temperature Θ_{rm} is calculated from:

$$\Theta_{rm} = (1-\alpha).\{\Theta_{ed\,-1} + \alpha.\,\Theta_{ed\,-2} + \alpha_2\,\Theta_{ed\,-3}.....\} \tag{3.36}$$

This can be simplified to:

$$\Theta_{rm} = (1-\alpha)\Theta_{ed\,-1} + \alpha.\,\Theta_{rm-1} \tag{3.37}$$

Where: Θ_{rm}: Running mean temperature for today [°C]

Θ_{rm-1}: Running mean temperature for the previous day [°C]

Θ_{ed-1}: Daily mean external temperature for the previous day [°C]

$\Theta_{ed\,-2}$: Daily mean external temperature for the day before and so on. [°C]

α : A constant between 0 and 1. Recommended to use α =0.8

The code also provides a simplified approximation calculation method, based on the mean external temperature of the preceding seven days. The running outdoor running mean temperature of seven days is calculated as:

$$\Theta_{rm} = (\Theta_{ed\,-1} + 0{,}8\,\Theta_{ed\,-2} + 0{,}6\,\Theta_{ed\,-3} + 0{,}5\,\Theta_{ed\,-4} + 0{,}4\,\Theta_{ed\,-5} + 0{,}3\,\Theta_{ed\,-6} + 0{,}2\,\Theta_{ed\,.7})/3{,}8 \tag{3.38}$$

All the definitions above are applied.

Recommendations for classroom operative temperature are given in table 3.30. However, the discomfort effect of increasing operative temperature can be minimized by increasing the air speed, which is illustrated in the figure 3.45.

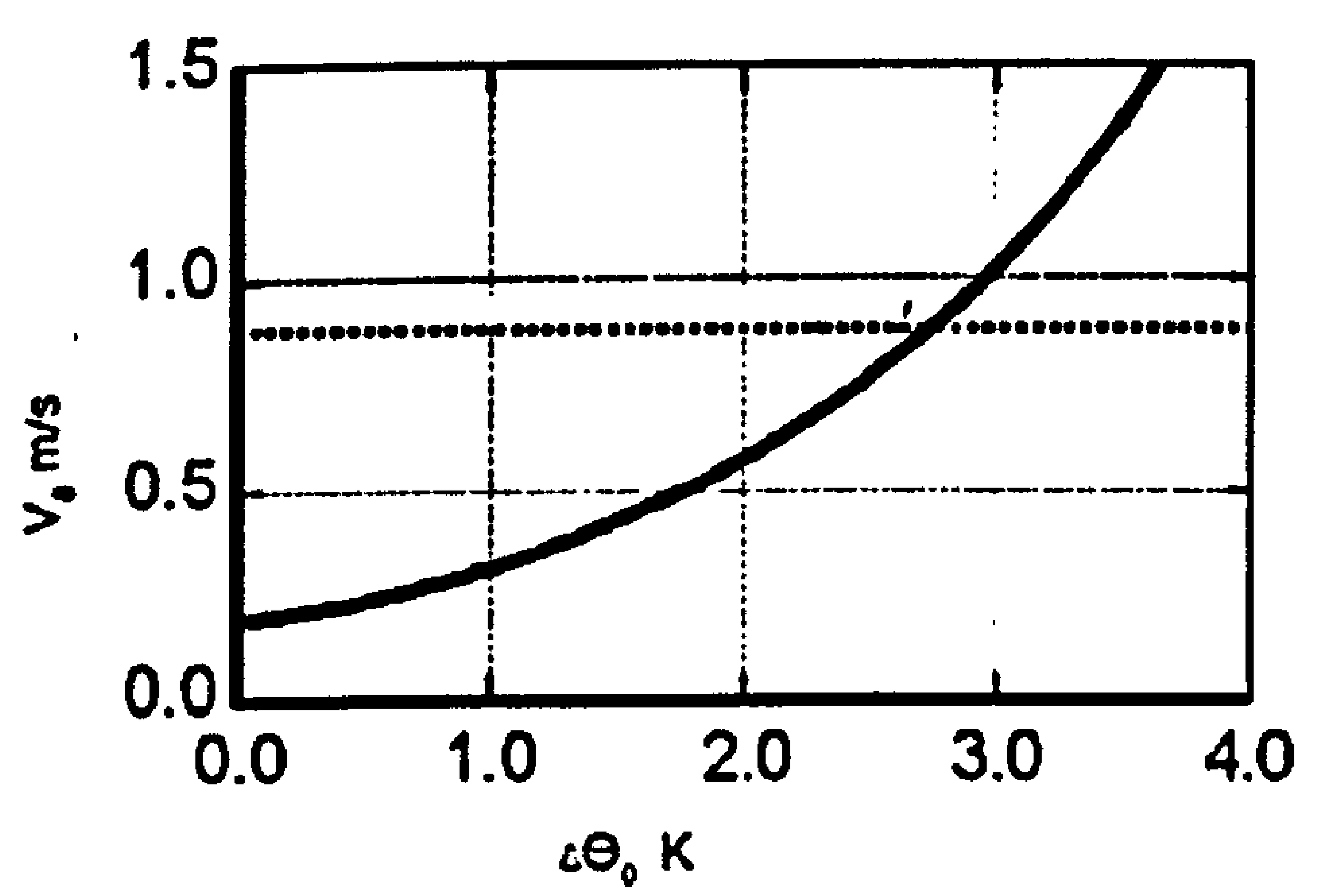
For mechanically cooled or heated buildings, EN: 15251(2004) suggests using the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfaction (PDD), which similar to ISO:7730 (2004) (see table 3.31) .

Table 3.30 EN: 15251 recommended design values of indoor temperature for the design of buildings. (EN: 15251,2004)

EN:15251 Recommended design values of indoor temperature for the design of buildings		
Category	Operative temperature [^{0}C]	
	Minimum for heating (winter season), ~ 1,0 clo	Maximum for cooling (summer season), ~ 0,5 clo
I	**21.0**	**25.0**
II	**20.0**	**26.0**
III	**19.0**	**27.0**

Table 3.31 Recommended categories for the design of mechanically heated and cooled buildings. (EN: 15251,2004)

Category	Thermal State of the body as a whole	
	PPD (%)	**PMV**
I	<6	-0.2 < PMV < + 0.2
II	<10	-0.5 < PMV < + 0.5
III	<15	-0.7 < PMV < + 0.7
IV	>15	PMV<-0.7; or +0.7<PMV



ΔΘo : Increase in operative temperature, K

*V*a = Air speed, m/s

Figure 3.45 Air speed required for offsetting increased temperature.

3.4.3.5. The U.S Standard ASHRAE: 55 (2004)

The U.S standard ASHRAE: 55 (2004) *"Thermal Environment Conditions for Human Occupancy"* is widely used in the U.S as well as worldwide, as a reference for defining conditions for thermal comfort. The data base of ASHRAE: 55(2004) was originally collected by the researcher *de Dear* through worldwide experiments, including those from more temperate climates such as Japan, to hot and humid tropical climates e.g. Brazil, Singapore, Thailand, Malaysia and Indonesia (Nicol and Humpreys, 2010).

The concept of ASHRAE: 55 (2004) is very similar to EN: 15251(2004) and ISO: 7730 (2005) index of PMV and PPD, however, its approach is different as it is applicable for naturally ventilated buildings only.

Table 3.32 ASHRAE: 55 (2004) Recommendations

PPD	PMV
<10	-0.5<PMV<+0.5

ASHRAE: 55 (2004) suggests that the conditions for neutral thermal comfort are a combination of several requirements. It introduces two methods of determining acceptable *Operative Temperature.* The first method takes into account the impact of air velocity, humidity and clothing factor. The acceptable comfortable zone is defined as when 80% occupants feel comfort. ASHRAE:55 (2004) states that:

"it is based on the PMV-PPD index plus an additional 10% dissatisfaction that may occur on average from local (partial body) thermal discomfort and 10% dissatisfaction criteria for general (whole body) thermal discomfort".

If air speed is not greater than 0.2m/s, the comfort zone can be specified from the chart shown in figure 3.46. If air speed is greater than 0.2 m/s, it should take into account adjustments that allow incremental upper comfort limit (see figure 3.47).

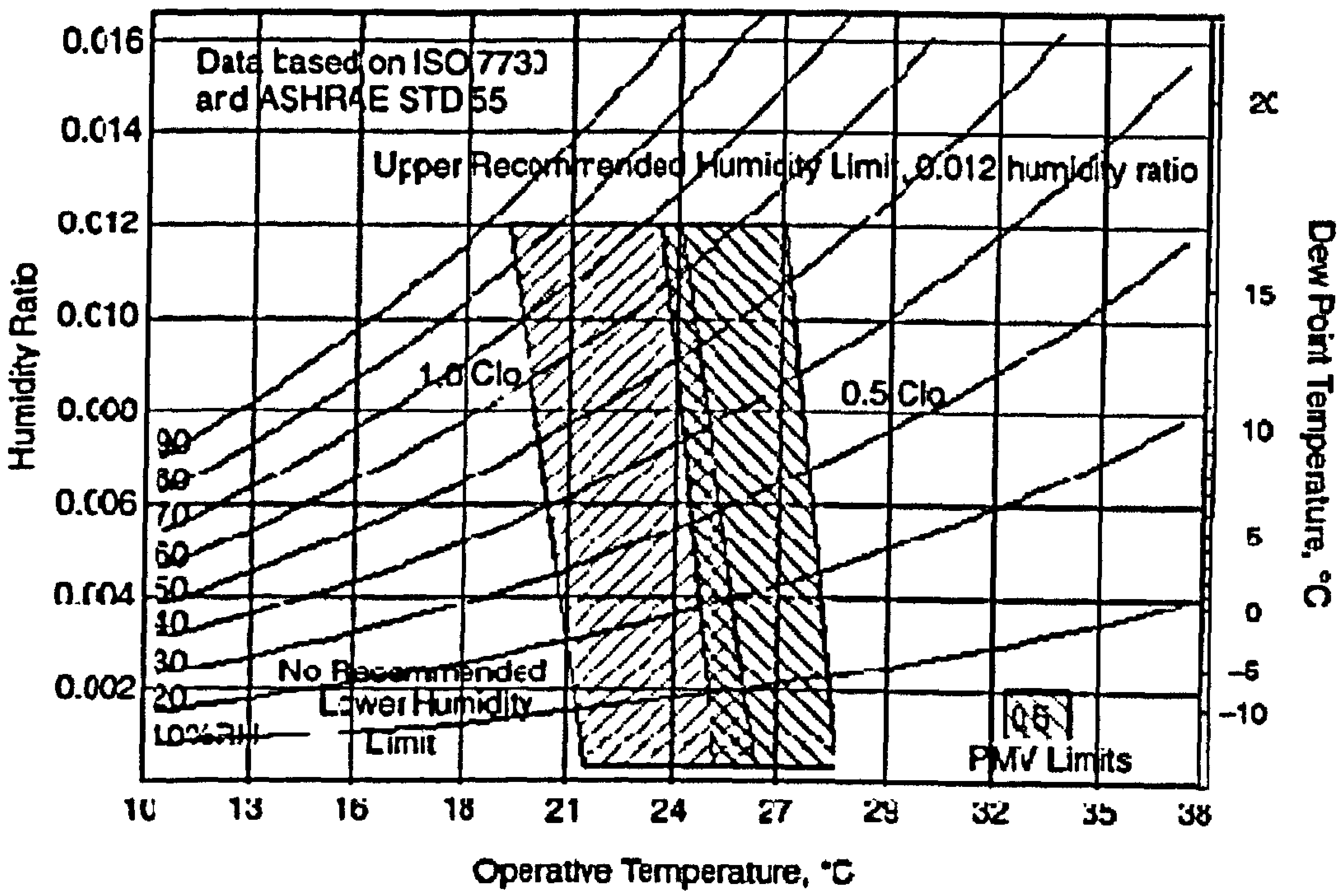


Figure 3.46 Acceptable range of operative temperatures and humidity for spaces. (ASHRAE:55,2007)

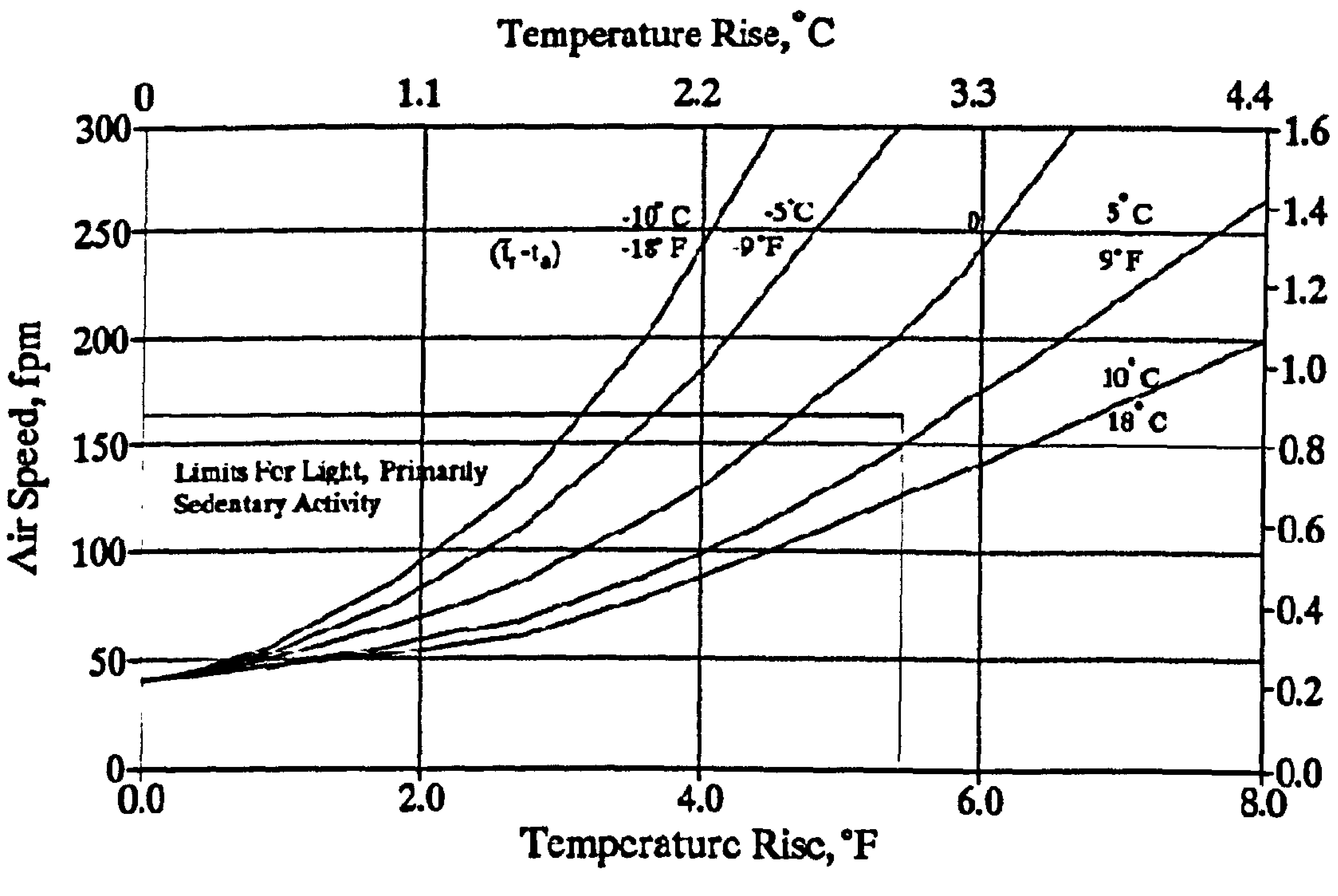


Figure 3.47 Air speed required to offset increased temperature (ASHRAE:55, 2007)

ASHRAE: 55 (2007) introduces another method for defining neutral comfort temperature (T_{comf}, °C), which is derived from the *monthly mean outdoor temperature* (T_{om}, °C). This method does not consider air speed, humidity or local discomfort factors. The *neutral comfort temperature* (T_{comf}, °C) is derived by:

$$T_{comf} = 0.31T_{om} + 17.8 \quad (3.39)$$

Where: T_{comf}: Neutral comfort temperature [°C]

T_{om}: Monthly mean outdoor temperature [°C]

The correlation between the indoor neutral comfort temperature and outdoor mean running temperature is illustrated in figure 3.49, showing the comfort zone and acceptable limits. However, the monthly mean temperature T*om* is not clearly defined in the code either as the historical monthly mean or as the mean for the month of investigation.

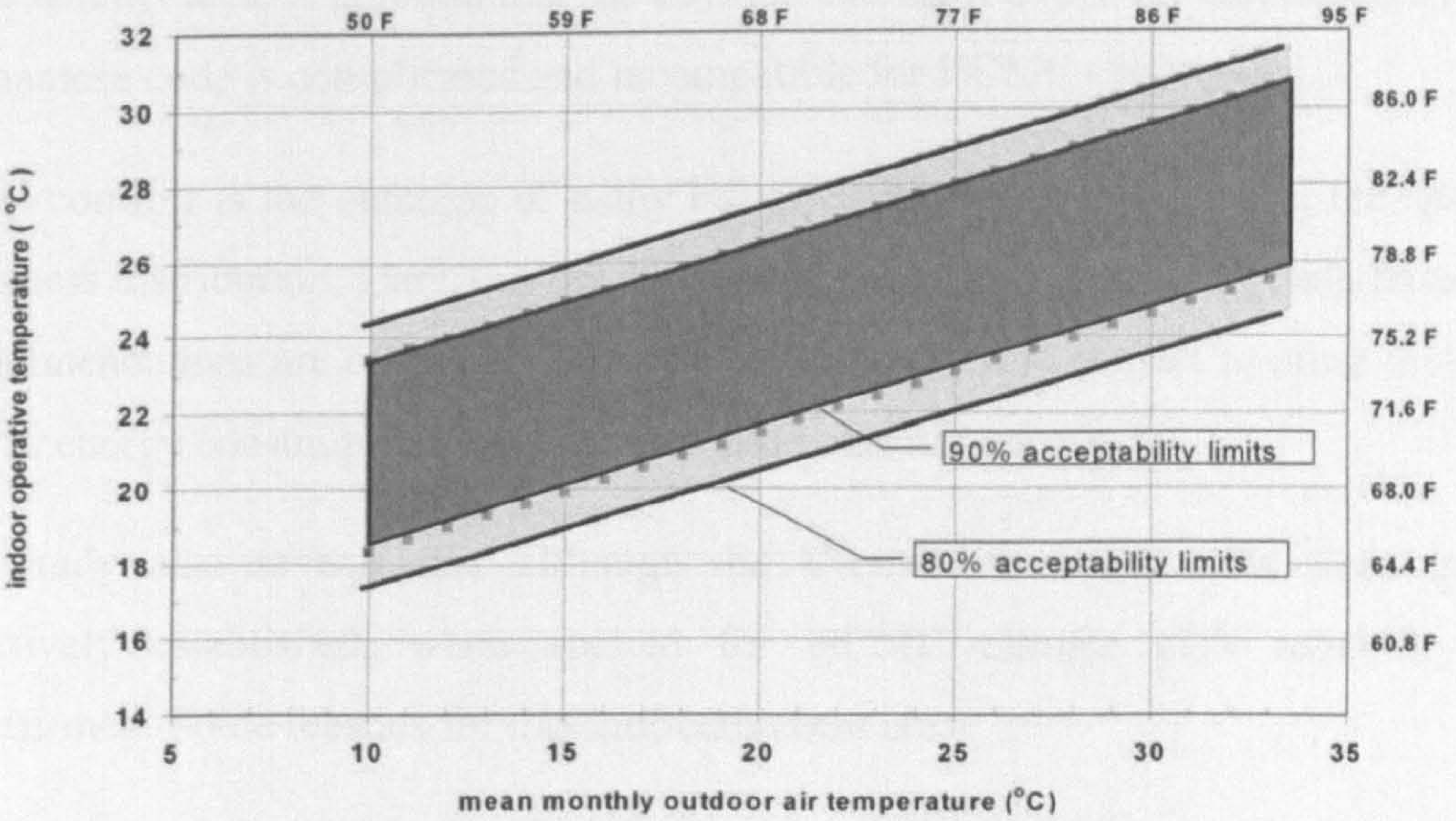


Figure 3.48 Acceptable operative temperature ranges for naturally conditioned spaces. (ASHRAE:55, 2007)

3.5. Conclusions

The main function of the codes regarding school classrooms is to ensure quality of the teaching-learning environment. However, these requirements recommended by the codes are constrained by many factors which may not be numerically defined. It would be rational to take a step back and review in context where, when and how these recommendations were established. This applies to both national and international standards.

The task of designing a good lighting scheme for classrooms goes beyond the architectural space, limited by the classrooms' walls. It requires an extensive study of both the natural and the social setting of the external site. These are indicated by the significance of site planning, access to sunlight and daylight, providing interesting view of the external while maintaining privacy and security.

The code review shows that most of the methods of predicting daylight contribution in the current codes are based on overcast sky which perhaps is not appropriate for HCMC. Optimizing window and shading design are the key tools for introducing good daylight and sunlight contribution to the interior. Most of the methods used for calculating daylight, are dependent on the window properties such as type, size, shape and net area. It is found that the daylight calculation method introduced by the Vietnamese code is complicated and incompatible for HCMC classrooms.

Visual comfort is the outcome of many issues, such as task illuminance, the spatial brightness distribution, glare, uniformity and the performance of the lighting fixtures. Recommendations are often based on task performance and subject to other factors, such as energy consumption, maintenance and controlling strategy.

This study also reveals that although the Vietnamese codes have been quite extensively established, when applied for HCMC climate their reliability is unconfirmed. Some reasons for this ineffectiveness are:

- The databases are out of date and not applicable for HCMC
- There are conflicts on the codes' requirements
- The details provided are insufficient
- The definition for the domain of its applicability is not clear
- The methods of testing-calculating are complicated

Similar problems are found in the thermal comfort codes. Therefore, both the Vietnamese lighting and thermal comfort codes require revisions.

Chapter 4

Review of existing schools and classrooms in HCMC

4.1. Introduction

This chapter provides a critical review of existing school types in HCMC and how the architecture of schools and classrooms has evolved through time influenced by climate, culture and society. Emphasis is given to the description of lighting strategies. The second part of this chapter focuses on the architectural cross-examination of four surveys conducted in HCMC city and presents some user opinions on current conditions.

4.2. Overview of existing school types in HCMC

HCMC has an extensive network of schools. There are many types of school architecture existing in the city, which were established through different periods of the city's history. Three types of school architecture are prevalent currently: The French colonial schools built before 1945, modern schools built during the 1945-1990 period and schools built after 1990. Although traditional schools no longer exist a review of their architecture can provide useful learning for future school design.

4.2.1. Traditional school architecture (before 19th)

Before the 19th century, formal education was established only in big cities and was exclusively for royals, nobles and the wealthy. Local education existed, but it was self-established and usually consisted of groups of local students studying with private tutors at his or her house. Schools and classrooms established in big cities also had no formal design. Study could take place in any informal type of space, e.g. in a private library, reading rooms or in a garden pavilion. These spaces featured traditional Vietnamese wooden architecture.

Although the cultural and social life of HCMC was influenced by different groups of immigrants, the Vietnamese-Kinh culture of the Red River Delta was the most dominant and well established. The influence of other cultures on local architecture was limited to religious buildings and private residences rather than public buildings. The original architecture brought by the immigrants was somehow not suitable to the local environmental conditions and characteristics. Only unique and advantageous architectural features of each culture were adopted, others were blended or faded out over the time. For instance, late French Indochina colonial architecture featured Western construction technologies, roofs and shading design from traditional Vietnamese architecture and decorative motifs borrowed from Indian-Khmer architecture (see figure 4.1).

The traditional Viet-Kinh wooden buildings were considered as the main traditional architecture. Although very few traditionally built buildings still exist and are functional today it is worth doing a brief review to see how they developed over thousand years to cope with the local environmental conditions.

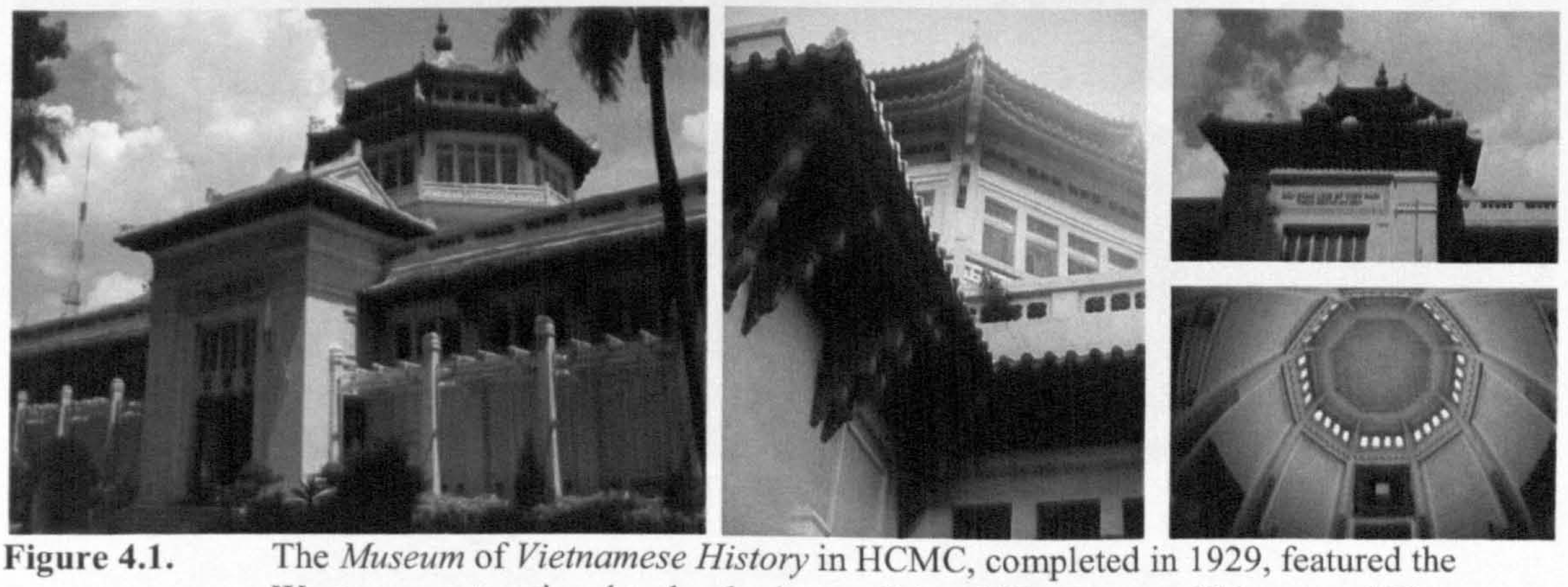


Figure 4.1. The *Museum* of *Vietnamese History* in HCMC, completed in 1929, featured the Western constructional technologies, traditional Vietnamese, Chinese and Khmer architectural elements. (Nguyen, 2010).

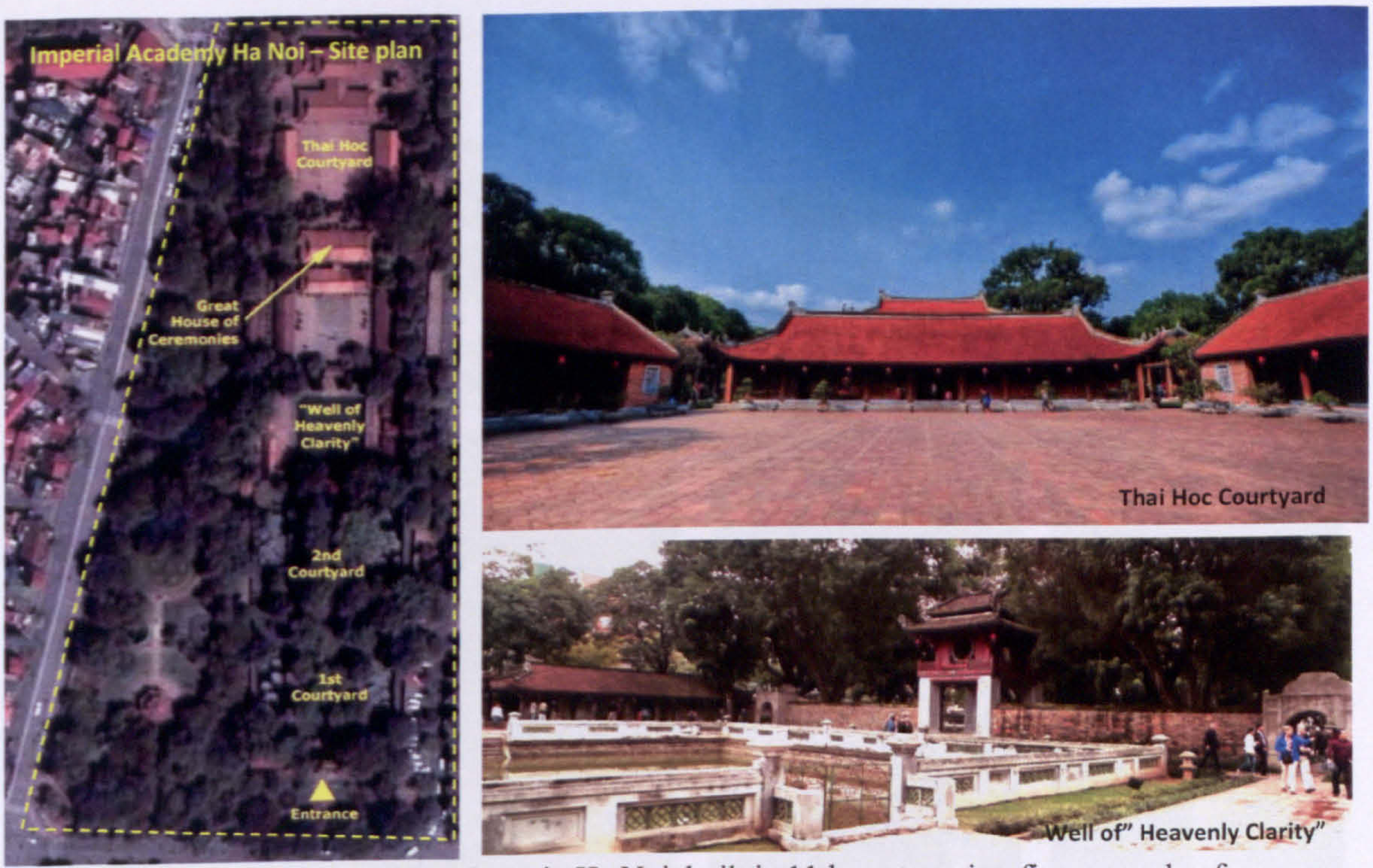


Figure 4.2 The Imperial Academy in Ha Noi, built in 11th century, is a fine example of traditional Vietnamese architecture featuring low rise wooden buildings surrounded by several courtyards in a symmetrical layout. (Nguyen, 2007)

Figure 4.3 Daylight strategies in traditional architecture feature large veranda and flexible openings (Nguyen, 2007)

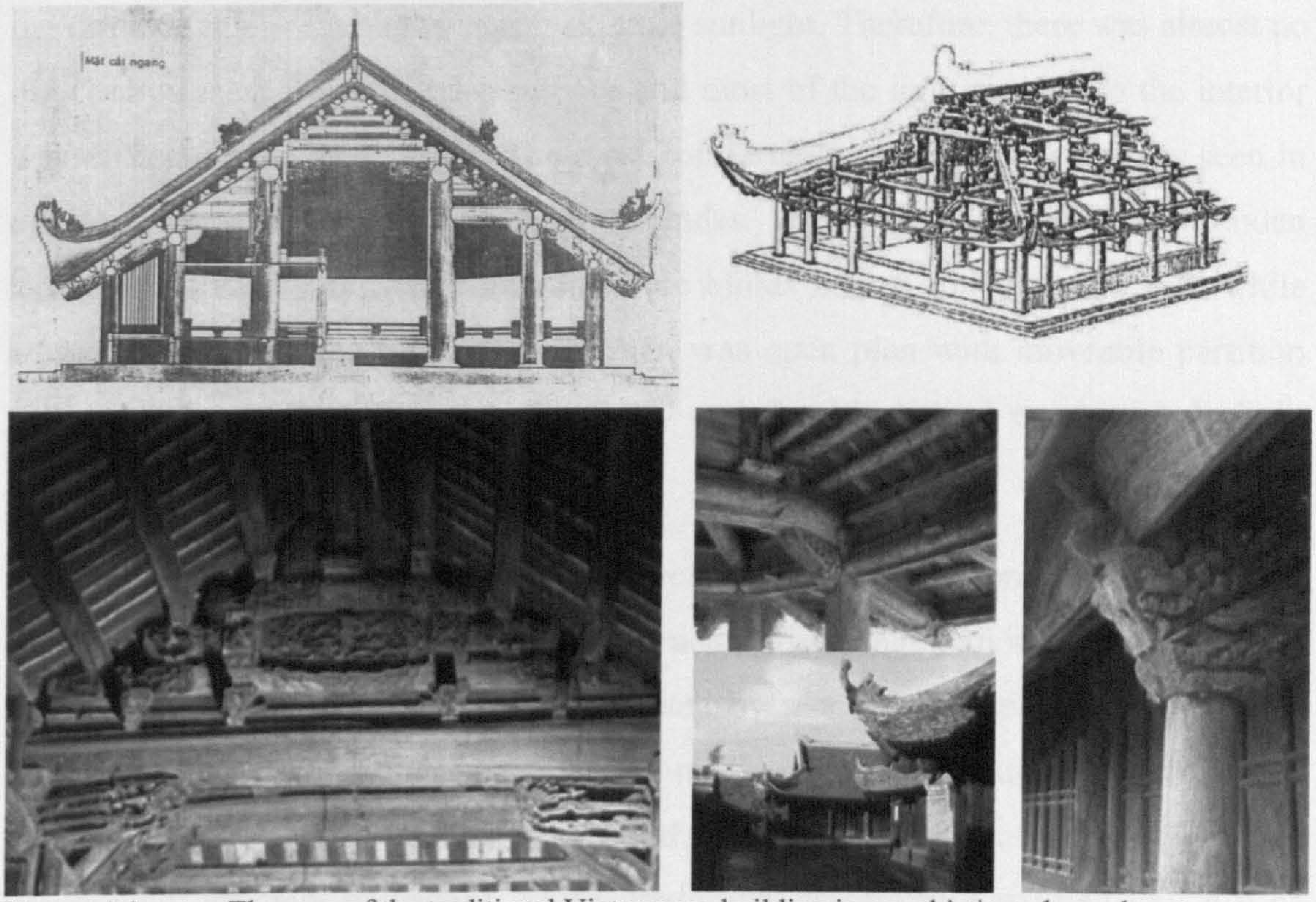


Figure 4.4 The core of the traditional Vietnamese building is a sophisticated wooden structure. (Nguyen, 2007)

Traditional architecture in Vietnam was usually designed with an open plan layout. Buildings were often low-rise with a maximum of one to two levels, linked by corridors and surrounded by a courtyard. The layout was symmetrical and the main facade opened to the South or the South-East. The landscape had large water surfaces and green spaces. Trees of short or medium height were planted in front of the main façade whilst higher trees with bigger canopies were planted at the rear. The water surfaces helped to soften, reflect and diffuse daylight while the trees provided shading and interesting views. Landscape features also helped to shade the building from strong sunlight.

Traditional Vietnamese architecture was constructed mainly from wood components. The core of the building was a sophisticated wooden structure consisting of the roof truss system and symmetrical wooden pillars. Walls and partitions did not bear any load, so they were moveable and thus promoted natural ventilation and access to natural lighting. Empirically in hot and humid climate, natural cooling and ventilation and avoiding direct sunlight penetration are effective strategies for a comfortable indoor environment. Buildings get access to daylight through the courtyard. The roof structure was often extended to become a large veranda buffering the dimmed interior with the strong external sunlight. Therefore, there was almost no direct sky access from the deep interior and most of the light coming to the interior was diffuse and reflected light. The most comfortable place for teaching, as seen in old documents, was under these large verandas. Windows with bamboo or wooden lattice movable blinds were common; these blinds helped to soften the light while allowing air flow. The building plan often was open plan with moveable partition walls and doors, these features effectively and flexibly helped to control daylight access from the interior.

It seems that the traditional wooden architecture is no longer appropriate for modern classroom requirements. First, modern teaching-learning activities require better formal established classroom space regulated by many requirements of visual and thermal comfort. Second, there has been so much revolution in building and material sciences since the 19th century and wooden architecture is not cost efficient or functionally efficient nowadays. Third, traditional architecture is often low rise of one to two storeys high, and this type of architecture is not feasible for modern schools in high density urban spaces. However, some of the architectural elements can be employed in future design, such as large overhangs, the window design and landscape settings.

4.2.2. The French Colonial Schools (early 20th century to 1945)

Since Saigon was once the most important city of the colonial French Indochina, the French established in the city a system of Westernized schools. The architecture of these schools was a mixture of French and local influences. Many of the schools built during this period are located within the present city centre and are still functioning today. Originally they were built when the city was not so densely populated, so the schools occupied a vast area of land with lot of trees and open spaces, thus they have low land plot ratio.

Schools often comprised of several medium rise buildings of two or three storeys, arranged symmetrically around several courtyards and linked by long and wide side corridors. Although this design provides good access to daylight and natural ventilation, the layout is too stretched.

School buildings were constructed of brick masonry. Classrooms were standardized in rectangular modules of 7x7m, aligned along long corridors running on the North-South axis. In early periods, daylight was the main source of illumination. Electric light was installed only in late 20th century. Windows were often very tall and narrow and they were positioned on the main external wall. The window doors often featured wooden louvers similar to those in Mediterranean regions in Southern France. They allowed daylight to enter deeply in the room and there is a threat of direct sunlight and glare, therefore the top part of these tall and narrow windows are often inoperable. Apart from original Western architecture, large overhangs were added in, and the side corridors were widened so they shaded the windows and facades against strong sunlight efficiently. The window-to-floor ratio was quite small as compared to modern standards.

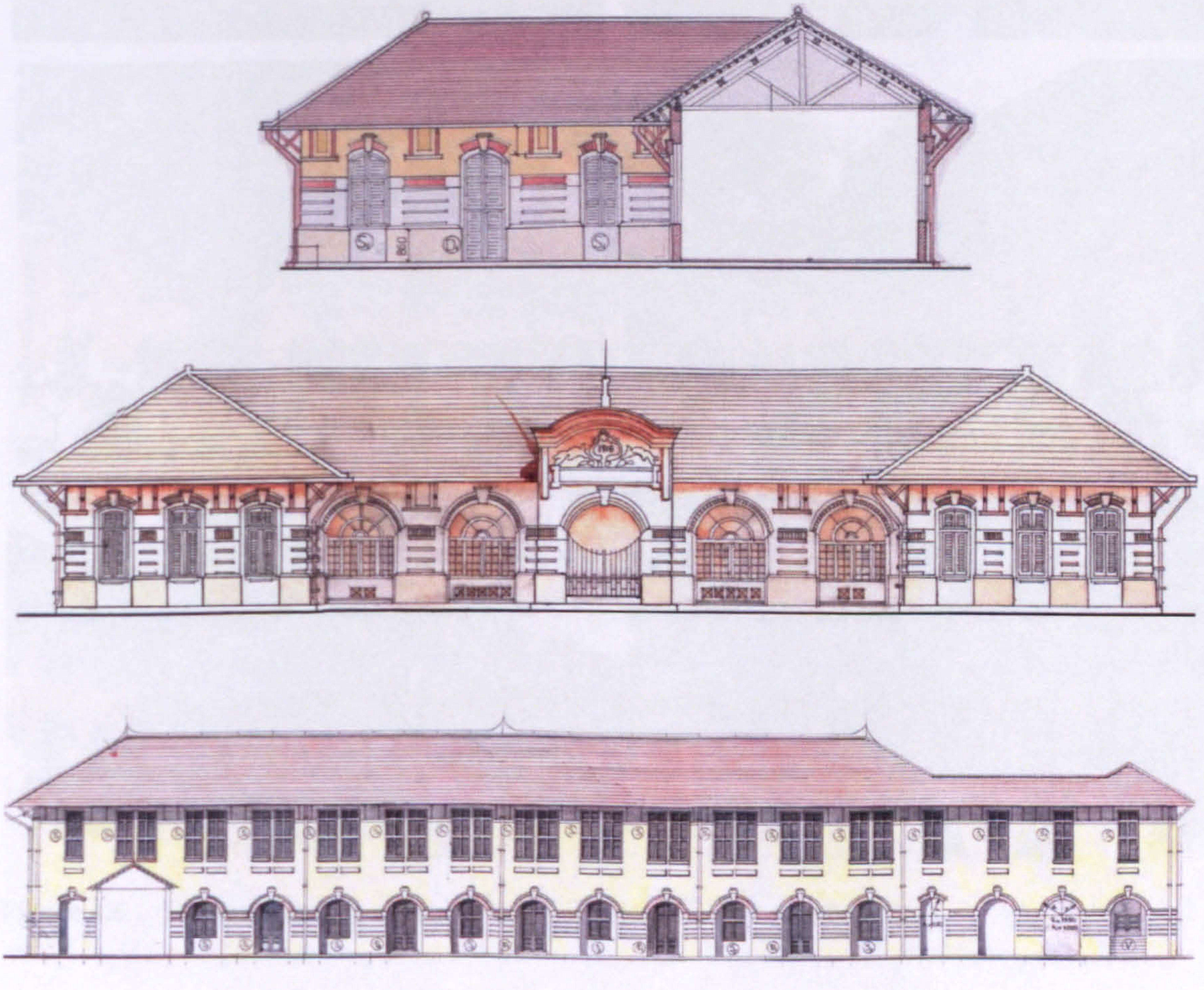


Figure 4.5 Marie Curie College, an example of colonial French architecture in early 20th.

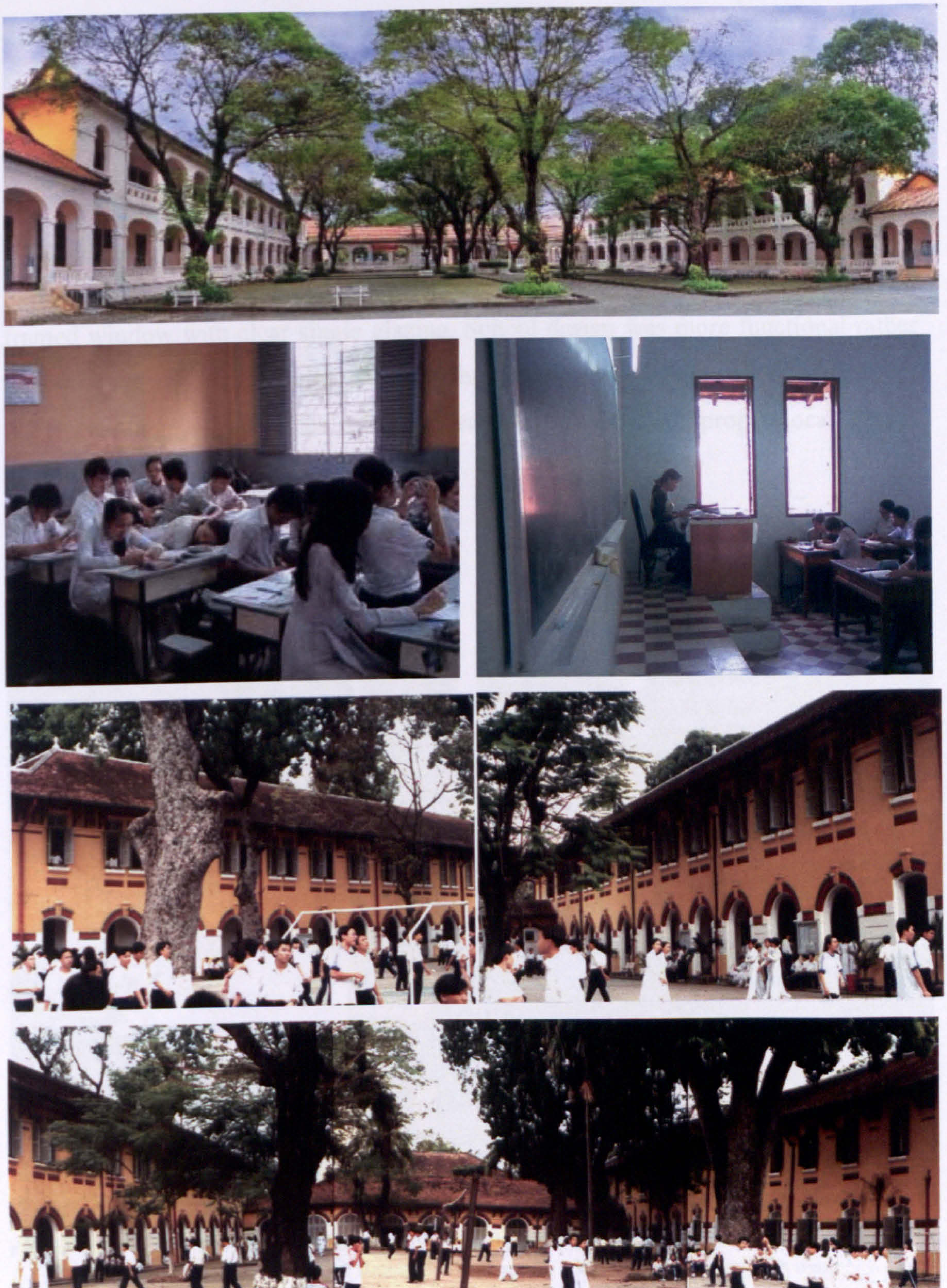


Figure 4.6 Some images of French colonial schools in HCMC. (Le, 2010)

4.2.3. Schools built in the 1945-1990 period

Because of the impact of the Vietnam War (1945-1975), schools built in this period had very simple architecture. The layout was more flexible and more functional and more floors were built to accommodate a higher number of students. Reinforced concrete structure was widely used. Classrooms were still designed in the 7x7m module. Basic type of shading was added, such as concrete overhang, wood or metal framed window with clear single glazing. School design was more functional rather than an inspiring learning environment. The situation was not improved after 1975, due to shortage of resources after the war and also lack of proper local design guidance for HCMC.

Figure 4.7 Schools built in the 1945-1990 period have simple architecture, based on concrete structure and feature standardized elements such as concrete shadings over windows.

4.2.4. Schools built after 1990

After 1990, many new schools have been built in the city, especially through private investment. There have been efforts to design schools with more inspiring architecture and a comfortable environment. However, the lack of land has lead to a more constrained design, as schools are often located within populated residential areas. Therefore, the layout is much more functionally compact. In some cases, the ground floor is left empty since the playground is too small. Schools were being developed vertically, with more floors added to accommodate more students, despite the codes. Classrooms were still built in a fixed module of 7x7m. Advance materials were introduced. However, shading devices are still in the very basic form of concrete overhang and single glazing. Air-conditioned classrooms are more popular. Media equipments such as projectors and computers have been introduced and have transformed the classrooms functionally. But the lack of appropriate design guidance and the rapid expansion of urban space have compromised the school design.

Figure 4.8 Examples of schools built after 1990s.

Table 4.1

Comparisionsof site layout

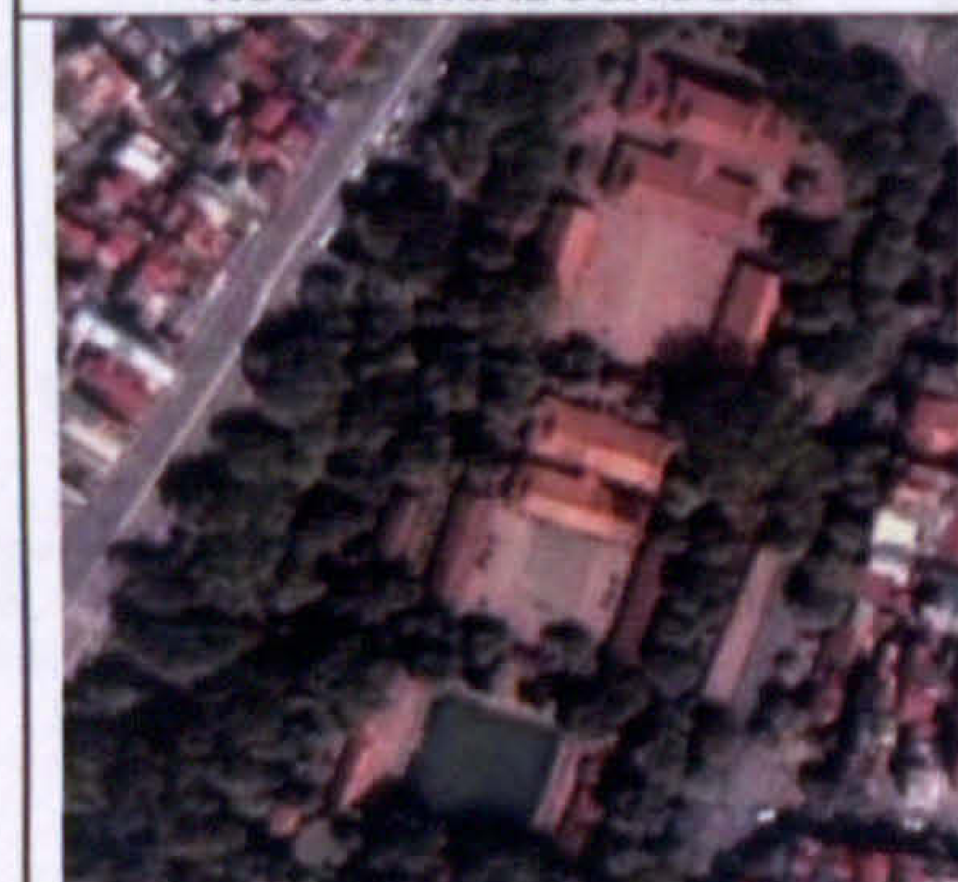
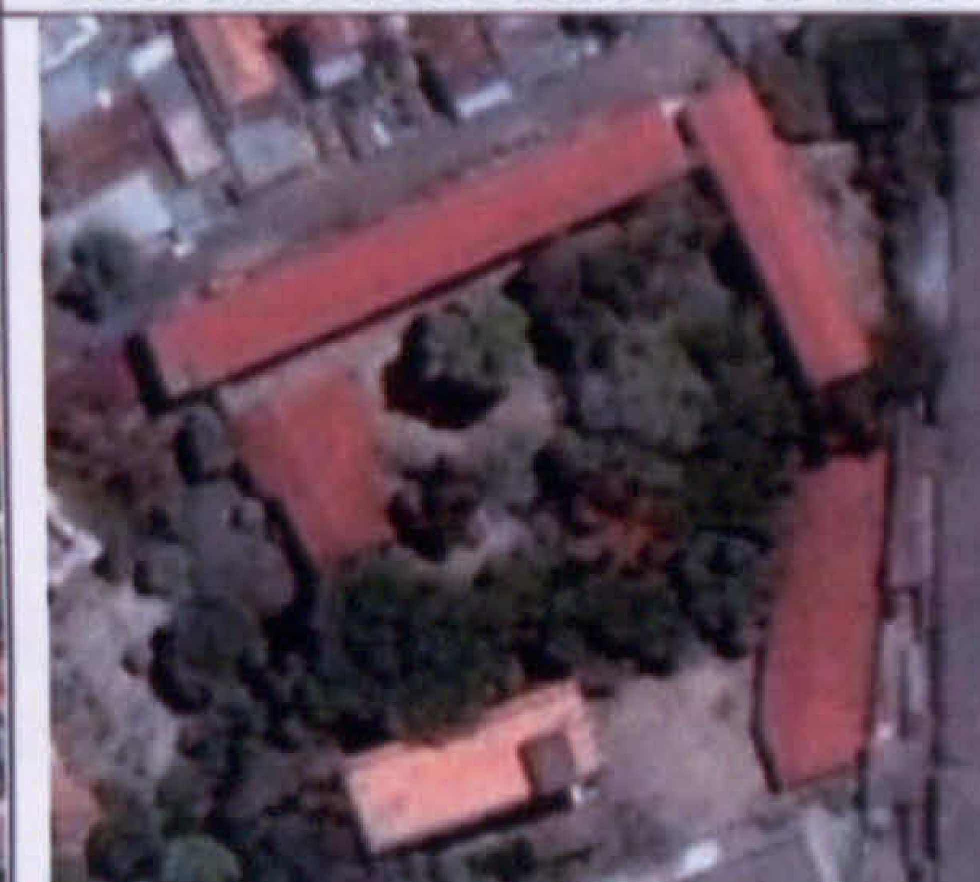
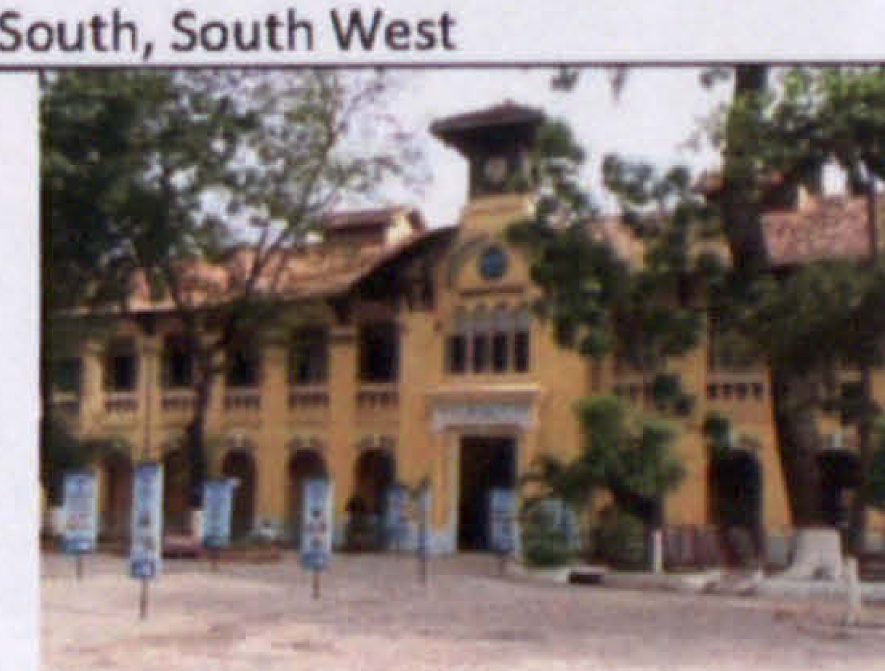
SITE LAYOUT			
TRADITIONAL SCHOOLS	**FRENCH COLONIAL SCHOOLS**	**SCHOOLS BUILT DURING 1945-1990**	**SCHOOLS BUILT AFTER 1990**
			
Imperial Academy, Hanoi, 11th	Nguyen Thi Minh Khai,HCMC, 19th	Hoang Hoa Tham,HCMC, 1970s	Nguyen Binh Khiem,HCMC, 1990s
Layout: Open plan, symmetrical, comprising several buildings surrounding courtyards, landscape featuring green spaces and water surfaces	*Layout:* Closed plan, symmetrical, comprising several buildings linked by side corridors, landscape features high trees providing shadings	*Layout:* Flexible and functional, , often compact, linear blocks, some green spaces, ground mostly concrete paved	*Layout:* Compact and functional, little green spaces, ground level being used as playground, mostly concrete paved
Main orientation: South, South East	*Main orientation:* South, South West	*Main orientation:* Flexible	*Main orientation:* Flexible
			
Building height: Low-rise, single storey	*Building height:* Low-rise, two to three storeys	*Building height:* Medium-rise, two to four storeys	*Building height:* Medium-to high rise, can be several storeys

Table 4.2

Comparison of classroom architecture

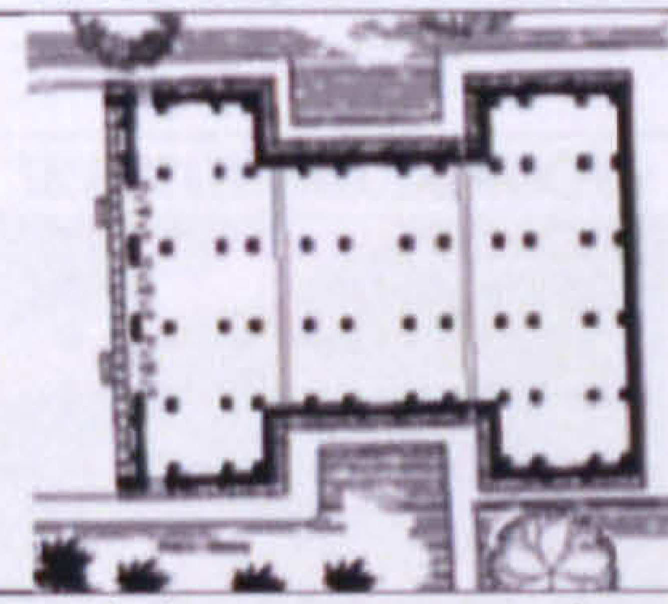
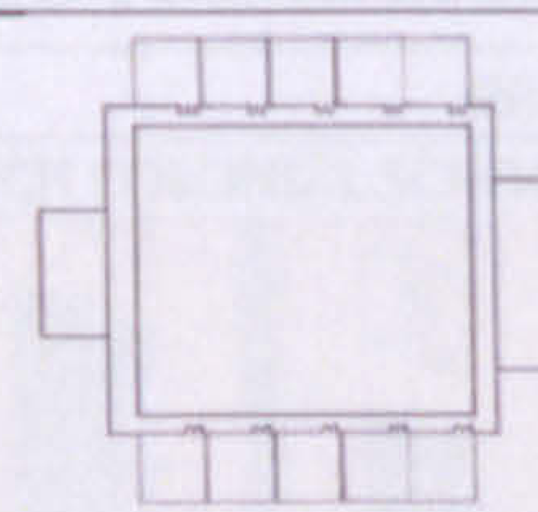
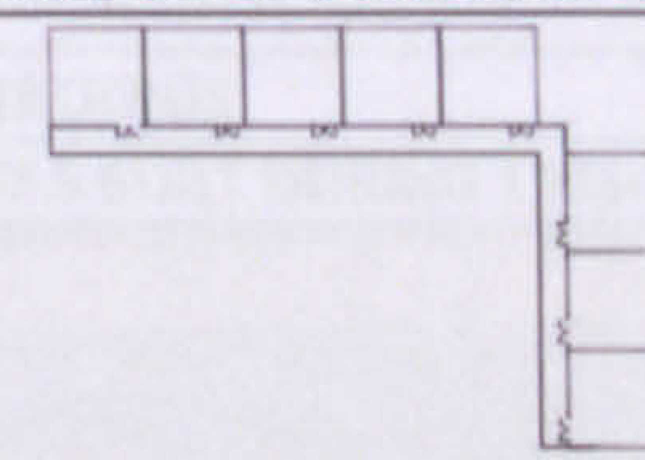
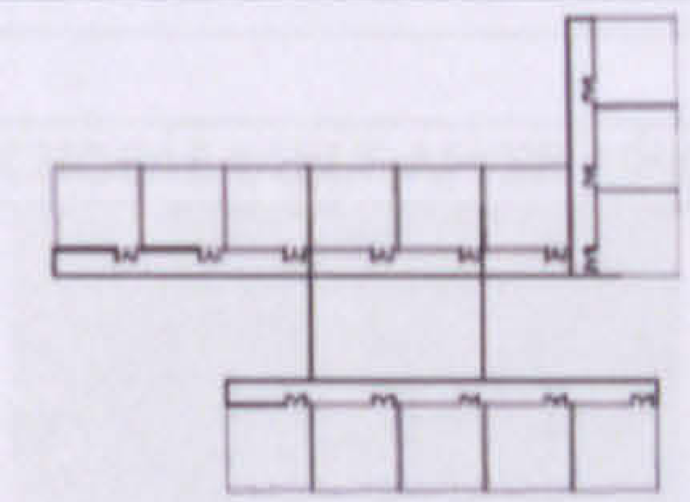
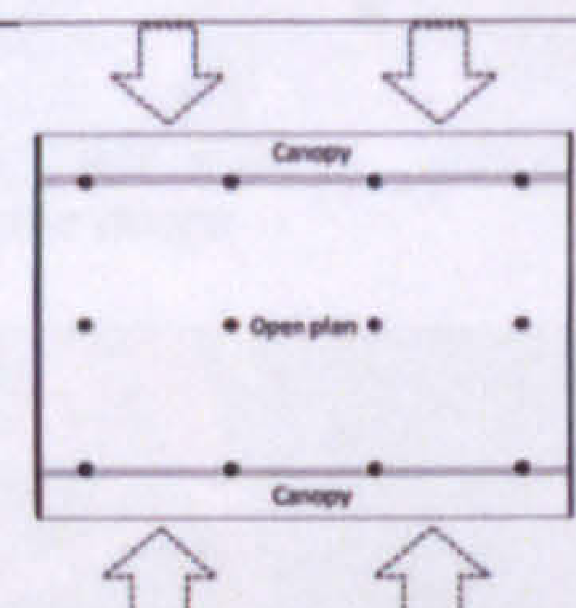
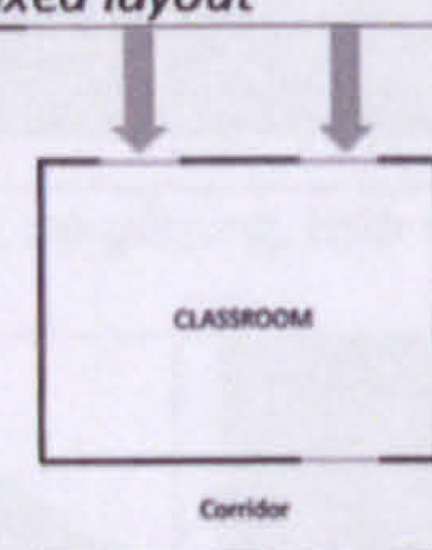
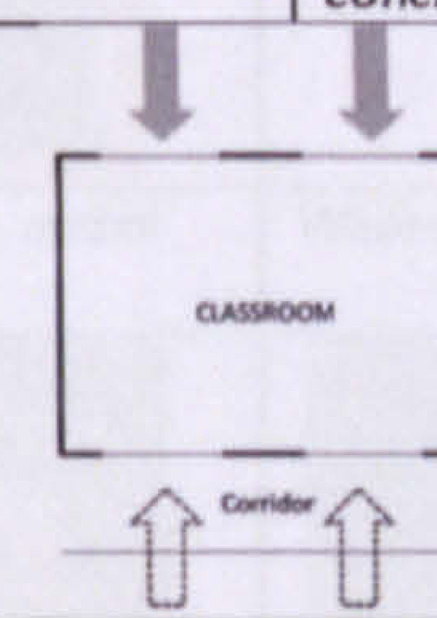
CLASSROOM ARCHITECTURE			
TRADITIONAL SCHOOLS	**FRENCH COLONIAL SCHOOLS**	**SCHOOLS BUILT DURING 1945-1990**	**SCHOOLS BUILT AFTER 1990**
			
No formal classroom, open plan	*Module 7x7m, high ceiling, brick masonry, fixed layout*	*Module 7.2x7.2m, , fixed layout, concrete structure*	*Module 7.2x7.2m, , fixed layout, concrete structure*
			
			
Daylight Strategies Buildings are well shaded, no direct sky access, opening facade with movable walls	*Daylight Strategies* Side lit, main windows located on external wall	*Daylight Strategies* Side lit, main windows located in both side walls	*Daylight Strategies* Side lit, main windows located on both side walls

Table 4.3

Comparison of windows and shadings

WINDOWS AND SHADINGS			
TRADITIONAL SCHOOLS	**FRENCH COLONIAL SCHOOLS**	**SCHOOLS BUILT DURING 1945-1990**	**SCHOOLS BUILT AFTER 1990**
			
Moveable doors	*Tall windows, no glazing, with wooden louvers*	*Wide windows, with single glazing, metal frame*	*Wide window, fully glazed*
	 	 	 
Shadings Large roof canopy	*Shadings* Overhangs and side corridors	*Shadings* Overhangs, concrete fins, side corridors	*Shadings* Overhangs, concrete or aluminium fins,

4.3. Initial evaluations of the current school and classroom

A simple survey on current operational conditions of schools and classrooms was conducted in 2007 and 2008 (see appendix A for further details of the survey). Questionnaires with multiple choices were distributed among 477 students of four secondary schools in Binh Thanh District in HCMC. This section presents an overview of the responses to the survey on the current conditions.

Votes for the architectural design are quite mixed. A high percentage (25%) of students gave neutral answers and approximately 28% of the students felt slightly unsatisfied or just satisfied with the current school design. Dissatisfied and satisfied votes were equivalent in percentage.

Building operation issues also received mixed results and was divided equally between *being dissatisfied* (41%) and *being satisfied* (43%). Again, the largest percentage of votes went for the neutral option. Similar results were found for building maintenance issues where only 10% of the populations felt the current building maintenance is good, while nearly double that (18%) voted that it is bad. The overall impression about the school architecture, operation and maintenance was quite neutral. School buildings are just simple and basic and some improvements should be made to provide more attractive designs and more efficient operation.

It is found that 45% of the responses were negative for lighting and ventilation issues and approximately 22% votes were neutral. It seems that the classroom environments are not so bad, but they do not meet comfort expectations. Further improvements are required to make the school buildings perform better.

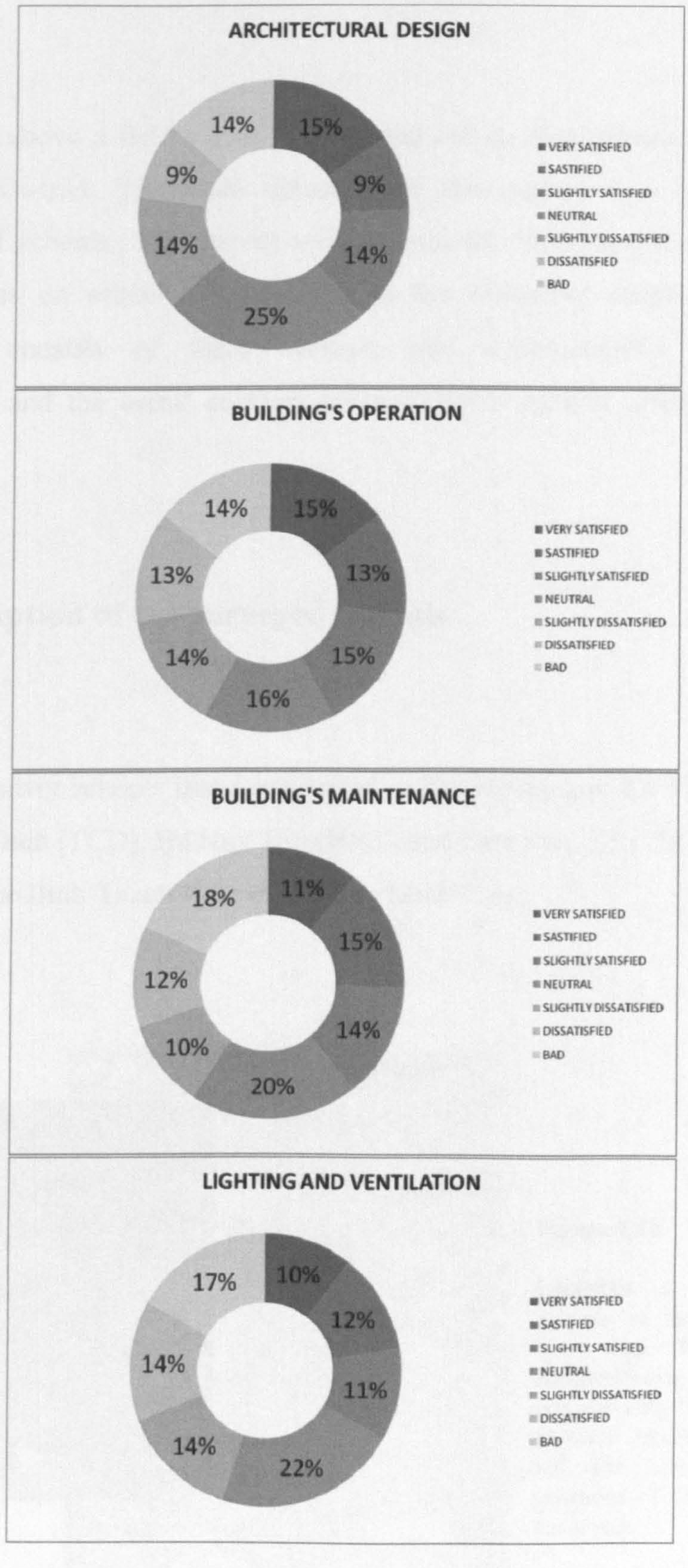


Figure 4.9 Results from a field survey on current conditions.

4.4. Examining the school architecture

As mentioned above a field survey was carried out on four selected schools in the Binh Thanh District. The main objective of this survey was to examine the architecture of schools. This survey will provide the fundamental information for further analysis on school performances in the following chapters. The field investigation consists of three surveys: site documentation, the physical measurements and the users' comfort survey. Details of this survey are given in appendix A.

4.4.1. Description of the surveyed schools

The four secondary schools that participated in the survey are: Le Van Tam(LVT), Truong Cong Dinh (TCD), Ha Huy Tap (HHT) and Lam Son (LS). These schools are all located in the Binh Thanh District, Ho Chi Minh City.

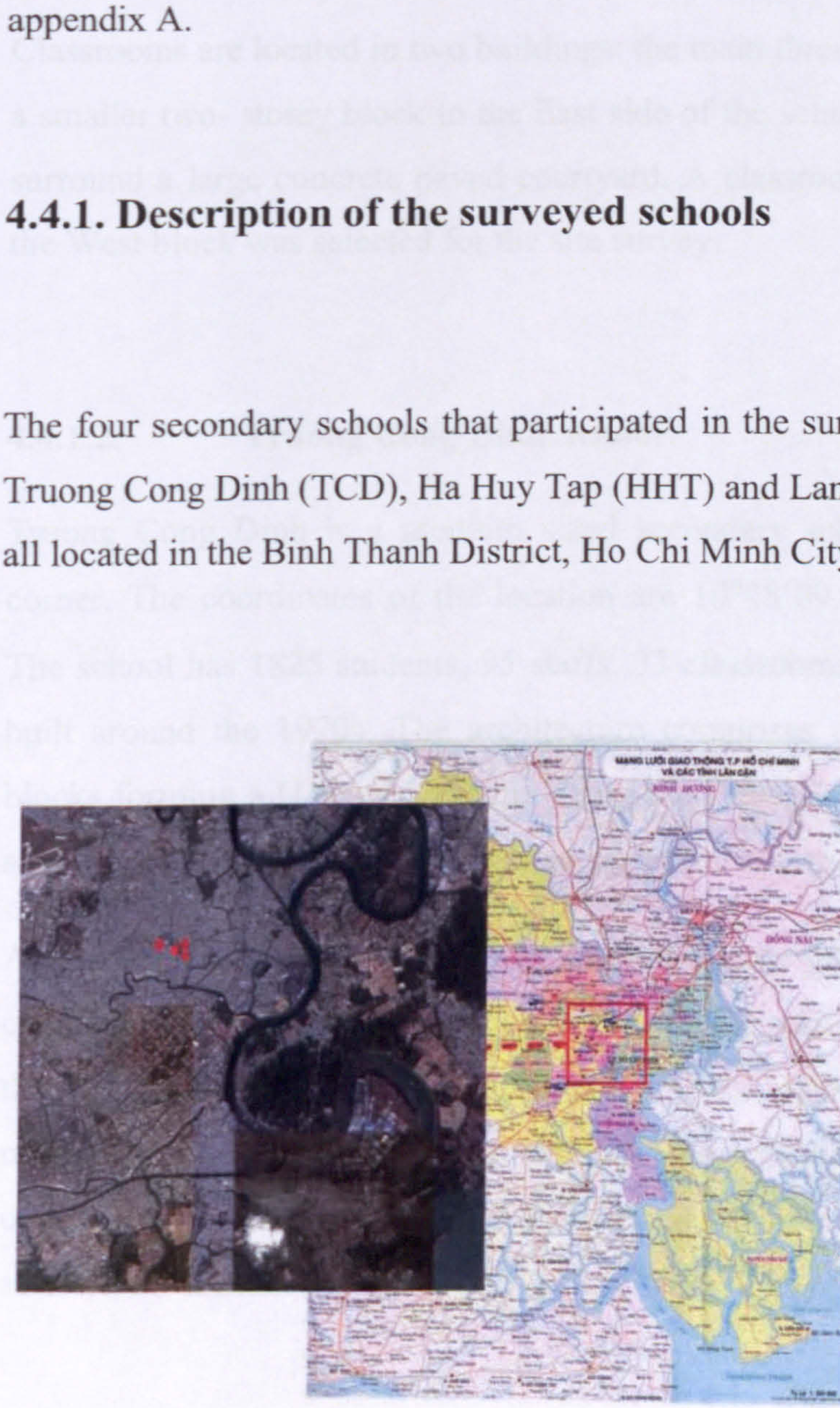


Figure 4.10

Locations of the four survey schools in the Ho Chi Minh City map. Right: the City administrative map with the red box showing the location of the zoomed satellite map on the left. The Left map shows the positions of those four schools surveyed.

4.4.1.1. Le Van Tam School

Le Van Tam is a medium sized secondary school located in a very busy corner of a high street junction. The coordinates of the location is 10°48'11.54" N and 106°41'51'' E. The school has 1580 students from grade 6^{th} to 9^{th}, 62 staffs, 23 classrooms and 9 labs. The school comprises of several linear buildings surrounding an inner court yard. These buildings have been built at different periods of time, dating back to the early 20^{th} century to recent years and the architectural style is a mix of French Indochina style of the early 20^{th} century and concrete architecture of the 1980s.

Classrooms are located in two buildings: the main three storey block in the West, and a smaller two- storey block in the East side of the school premises. All the buildings surround a large concrete paved courtyard. A classroom located on the top floor of the West block was selected for the site survey.

4.4.1.2. Truong Cong Dinh School

Truong Cong Dinh is a medium sized secondary school located at a busy street corner. The coordinates of the location are 10°48'09.07'' N and 106°41'47.33''E. The school has 1825 students, 95 staffs, 33 classrooms and 6 labs. The school was built around the 1970s. The architecture comprises of several three storey linear blocks forming a U shape, running along the West, South and East perimeter of the school premises, and wrapping a concrete paved courtyard.

Across the street on the East facade, there is a large green park with high trees. This can be an interesting view, but high trees from the park partly block daylight entering the classrooms. The intrusion of noise and air pollution from the street is also noticeable. The block on the East side has better access to the sky since its windows open directly to the street. A classroom on the top floor of the East block was selected for the site survey.

Figure 4.11 Site images of Le Van Tam Secondary School

Figure 4.12 Site images of Truong Cong Dinh Secondary School

4.4.1.3. Ha Huy Tap School

Ha Huy Tap is located at coordinates 10°48'07.41'' N and 106°41'39.42'' E. The school has 2300 students, 100 staffs, 34 classrooms and 6 labs. The school was built around the 1970s. The main building of the school comprises of two linear four-storey buildings forming an L shape running along the South and East perimeters. There is a large concrete paved courtyard. The longer block running along the East side faces directly into a small street. Thus it has a good offset from the neighbouring buildings. Both the East and the South blocks are totally blocked by neighbouring buildings on the ground level, so the ground floor is assigned for labs and other non-teaching rooms. One classroom on the first floor of the East block was selected for the site survey.

4.4.1.4. Lam Son School

Lam Son school comprises of an L shaped building located in a small but noisy street. The school has 1760 students, 93 staffs, 26 classrooms and 6 labs. The school is set back from the street by a small open courtyard linking two main blocks of classrooms. A classroom located on first floor of the longer wing was used for the survey.

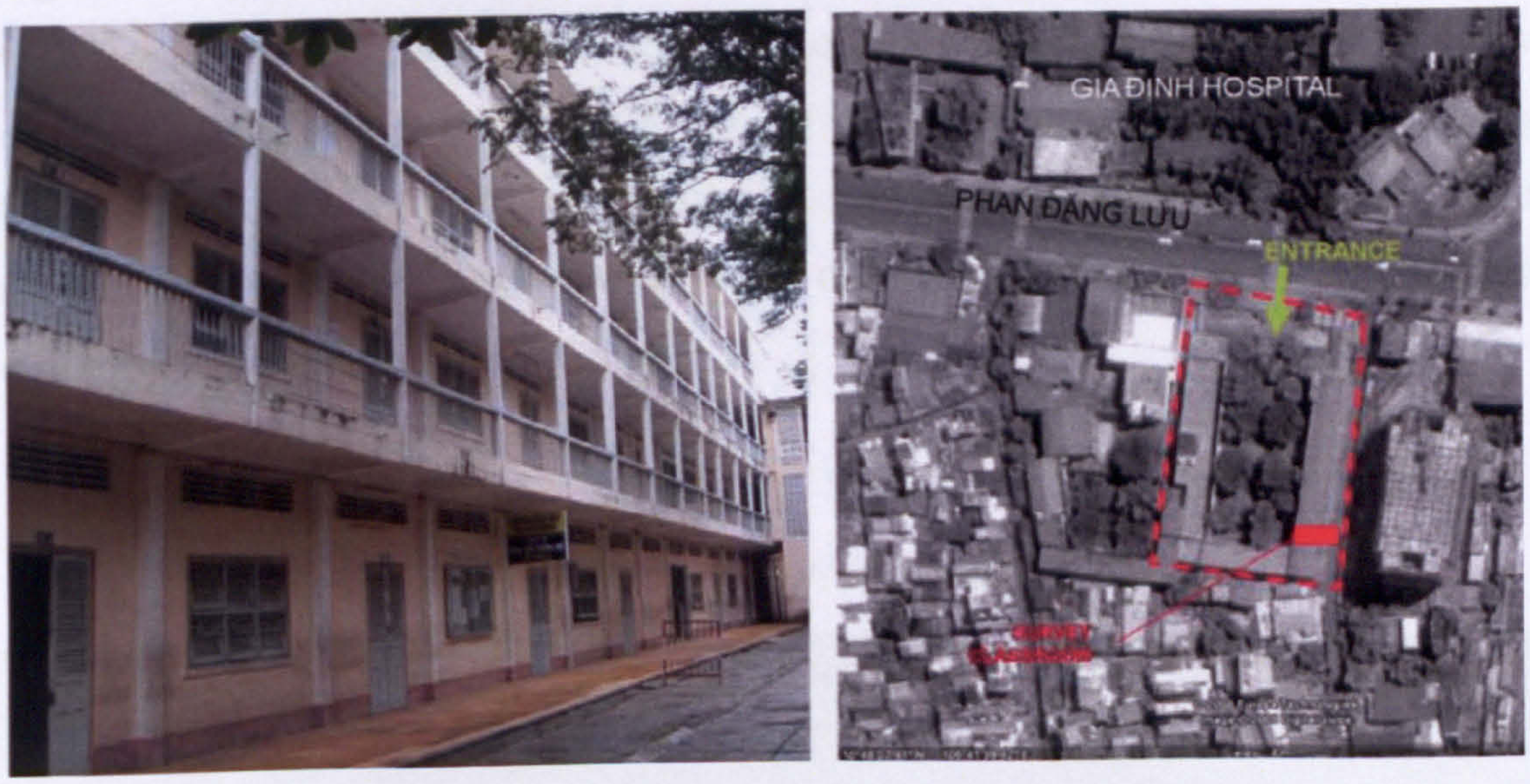


Figure 4.13 Site images of Ha Huy Tap Secondary School

Figure 4.14 Site images of Lam Son Secondary School

4.4.2. Site planning

The site drawings are given in appendix B. It is found that the school premises are often surrounded by dense low rise buildings. Most of the rooms in ground floor level have no access to the sky. Thus, it is often found that classrooms are located from level 1 and upwards and school offices and labs are located on ground floor.

4.4.2.1. Building density

In all the schools, the grounds are concrete paved and the building density is quite high. As shown in table 4.4, it is found that none of the schools surveyed comply with the code requirements (TCVN:3978). Le Van Tam school has the best site area ratio per classroom of only at 16 (79 % of the requirement), followed by Truong Cong Dinh School (10% of the requirement). The other two schools are at 12%. This shows that limited land allowance in dense metropolitan area is among the biggest challenge for schools in HCMC.

Table 4.4 Site area requirements as per TCVN: 3978 (1984)

School name	Number of classrooms	TCVN 3978(1984) recommendations [ha]	Actual site area [ha]	Percentage of code requirement [%]
Le Van Tam	23	2.8	0.47	**16.79**
Truong Cong Dinh	33	3.7	0.34	**9.19**
Ha Huy Tap	34	3.7	0.45	**12.16**
Lam Son	26	3.0	0.36	**12.0**

TCVN:3978 (1984) allows Building coverage ratio (BCR) of 25% maximum for schools built in dense and populous metropolitan area. The UK guidance BB98 (2004) recommends maximum BCR of 20%. As shown in table 4.5, all of the four surveyed schools have BCR higher than the code requirement. Lam Son school has the lowest BCR of 35.89 %, which is almost 1.5 times higher than the code. Truong Cong Dinh School has the highest BCR of 44.17%, which is almost 1.8 times higher than the code. This shows that the schools are densely built with very little of open space. The Floor per area ratio (FAR) is variable from 0.62 to 1.11. None of the surveyed school has more than 4 storeys. TCVN 3978(1984) allows up to 4 storeys, and international codes often recommend that schools be built in single or up to two storeys (BB:87, 2003), (BB95, 2002) and (ANSI/IESNA:RP3, 2000).

Table 4.5 Building Coverage Ratio (BCR), Open per area ratio and Floor per Area ratio (FAR) of the four surveyed schools.

SCHOOL	Gross area	BCR		Open Ratio		FAR	
	[m²]	[m²]	[%]	[m²]	[%]	[m²]	Floor/Gross Area ratio
Le Van Tam	4700	1871	**39.81%**	2829	**60.19%**	4171	0.89
Truong Cong Dinh	3362	1485	**44.17%**	1877	**55.83%**	3725	1.11
Ha HuyTap	4490	1629	**36.28%**	2861	**63.72%**	2792	0.62
Lam Son	3572	1282	**35.89%**	2290	**64.11%**	3982	1.11
Average	4031	1566.75	**39.04%**	2464.25	**60.96%**	3667.5	0.93

Table 4.6 Building Coverage Ratio (BCR) of the four surveyed schools and the codes recommendations.

SCHOOL	Gross area [m²]	Building Coverage Ratio (BCR)				Students	
		Code		Actual		Total	m² *per* student
		Vietnam	UK	[m²]	[%]		
Le Van Tam	4700	25%	18%	1871	39.81	1580	2.64
Truong Cong Dinh	3362			1485	44.17	1825	2.04
Ha HuyTap	4490			1629	36.28	2300	1.21
Lam Son	3572			1282	35.89	1760	2.26
Average (all schools)	4031			1567	39.03		2.04

High BCR means that classrooms may have less access to the sky. This results in less interesting views and less daylight access. It seems that there is little awareness on providing a good view. This can be seen in the school layout. It is very typical in HCMC that schools are designed in a layout of linear buildings wrapping a courtyard. Classrooms are often arranged along long corridors, with the main windows opening directly to the external and secondary windows. These open through the corridor indirectly accessing the internal courtyard. This means the main views are left to the external landscape which is not under the school's control. The advantage here is maximizing the use of land but the disadvantages are low access to sky and the uncontrollable intrusion of external environment such as noise and obstructions blocking daylight access.

4.4.2.2. Orientation

It is found that the main classroom buildings open to the East or West and only the main teaching block in Lam Son School opens to the South (see table 4.7). For HCMC climate, it is often recommended that South and South East are the best orientations for daylight access and natural ventilation (Pham, 2006). The East and West facades often receive excessive solar gain.

Table 4.7 Orientations.

School	LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON
Main teaching blocks	WEST	WEST	EAST	SOUTH
Secondary teaching blocks	EAST	SOUTH, EAST	SOUTH	EAST

4.4.2.3. View, Privacy, and Distraction

The only interesting external view found in classrooms is located in the East block of Truong Cong Dinh School, where windows open to a green park across the street. In other schools it has been found that they are surrounded by dense residential areas. Very little green or open space is found in the surrounding area. Furthermore, there is little privacy since the classrooms are within a few meters distance of the neighbouring buildings. Many of the classrooms have one side facing directly to the streets. Noise and air pollution are found in high levels in these classrooms and glazed tight windows are installed in some classrooms and they are closed all the time to reduce the noise and air pollution intrusion. This means there is no natural ventilation. It can be concluded that view and privacy have been compromised and there are distractions from different sources affecting the classroom environment.

4.4.3. Classroom architectural design

4.4.3.1. Overview

In all surveyed schools, classroom plan is often built in a rectangular shape of 6-8m on each side. Classrooms are arranged in a linear layout connected by side corridors. The main structures are reinforced concreted frames, concrete floors and ceiling. Both external and internal walls are constructed of cavity bricks and plastered on both sides. Walls are quite thin, approximately 200mm thick, and there is no insulation layer. In the classrooms on the top floor, because of overheating, there is a suspended plastered ceiling buffering the interior to the flat concrete roof.

The interior layout is quite similar in all schools. Typically, there are two areas: the students' desk and the teaching station. The student area consists of writing desks and sitting benches made of wood. The teaching area consists of a writing desk and a backboard mounted on one end wall. Furniture is not easily moveable, so it is likely that the layout is fixed. Windows are located on both side walls. The surface finishes are simple. Walls and ceiling are plastered in light colours and floors are covered by colour 200x200mm square cement tiles, which were very popular in Vietnam in the 1980s. Door and window frames are painted. Furniture is often finished in brown or light brown. Summary of the classroom architectural features are given in table 4.9.

Table 4.8 Classroom surfaces and furniture finishes.

School	*Le Van Tam*		*Truong Cong Dinh*		*Ha Huy Tap*		*Lam Son*	
Surface	*Type & Finish*	*Reflectance [%]*	*Type & Finish*	*Reflectance [%]*	*Type & Finish*	*Reflectance [%]*	*Type & Finish*	*Reflectance [%]*
Interior Walls	Brick wall, light yellow plastered	60	Brick wall, light blue plastered	55	Brick wall, light blue plastered	55	Brick wall, light blue plastered	60
Ceiling	Suspended plaster boards, white	65	Suspended wood panel, light cream painted	60	Concrete, white plastered,	60	Concrete, white plastered	65
Floor	Cement tile 200x200mm	50	Cement tile 200x200mm	50	Cement tile 200x200mm	50	Cement tile 200x200mm	50
Furniture Finish	Wood, brown	25	Wood, brown	20	Wood, brown	20	Wood, brown	25

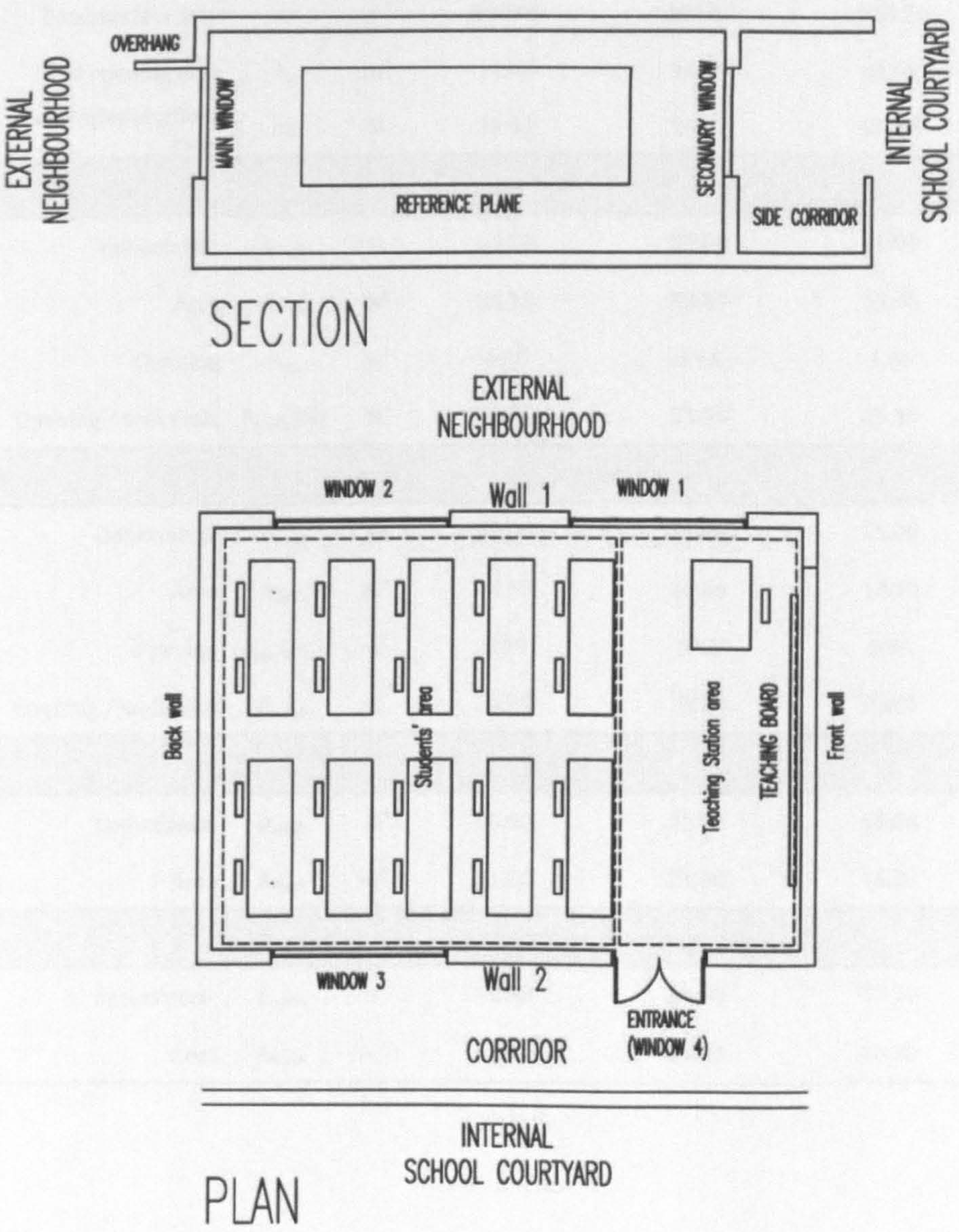


Figure 4.15 Typical cross section and plan of the surveyed classrooms.

Table 4.9 Architectural design parameters of the four surveyed classrooms.

School	Symbol	Unit	LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON
Classroom dimension	WxDxH	m	Width Length Height	Width Length Height	Width Length Height	Width Length Height
			7.00 7.80 3.10	6.00 8.00 3.50	6.00 7.00 2.70	8.00 8.00 3.60
Volume	V	m^3	169.26	168.00	113.40	230.40
Floor area	A_{floor}	m^2	54.60	48.00	42.00	64.00
Floor reflectance	ρ_{floor}	%	50.00	50.00	50.00	50.00
Ceiling area	$A_{ceiling}$	m^2	54.60	48.00	42.00	64.00
Ceiling reflectance	$\rho_{ceiling}$	%	65.00	60.00	60.00	60.00
Furniture reflectance	$\rho_{furniture}$	%	25.00	20.00	20.00	20.00
Area-weighted average reflectance	ρ	%	51.95	48.16	47.71	47.96
Total surface area	Ar	m^2	200.96	194.00	154.20	243.20
Total opening area	A_w	m^2	11.69	11.87	8.76	17.56
Total opening/floor ratio	Ro	%	21.41	24.73	20.86	27.44
Wall 1						
Reflectance	ρ_{wall1}	%	60.00	55.00	55.00	55.00
Area	A_{wall1}	m^2	24.18	28.00	18.90	28.80
Opening	A_{w1}	m^2	6.30	6.44	4.80	9.00
Opening / wall ratio	R_{wall1} (%)	%	26.05	23.00	25.40	31.25
Wall 2						
Reflectance	ρ_{wall2}	%	60.00	55.00	55.00	55.00
Area	A_{wall2}	m^2	24.18	28.00	18.90	28.80
Opening	A_{w2} (m^2)	m^2	5.39	5.43	3.96	8.56
Opening / wall ratio	R_{wall2}	%	22.29	19.39	20.95	29.72
Wall 3 (rear)						
Reflectance	ρ_{wall3}	%	60.00	55.00	55.00	55.00
Area	A_{wall3}	m^2	21.70	21.00	16.20	28.80
Wall 4 (front)						
Reflectance	ρ_{wall4}	%	40.00	37.50	37.50	40.00
Area	A_{wall4}	m^2	21.70	21.00	16.20	28.80

4.4.3.2. Daylight strategies

4.4.3.2.1. Window design

All of the surveyed classrooms are side lit from windows located on both walls. Main windows are located on the external wall. Windows are standardized in size, approximately 1.2m height x 2.4m width. There are also some small openings providing additional daylight and ventilation. Different types of windows can be seen in the schools. Le Van Tam classroom windows can be opened horizontally. In the Ha Huy Tap classroom, they can be opened vertically only. In Truong Cong Dinh and Lam Son classrooms, windows have sliding doors. There are also different types of window glazing (e.g. single glazing, wooden louvers, translucent). The window transmittance presented in table 4.9 is the average area-weight estimate of all window areas. In all classrooms, the daylight strategies are quite similar in principle but different in the details.

Vietnamese codes do not address any specific requirements for window design, with the only exception being in the *ĐRASTN* method where window properties are addressed. The size of the windows can be verified by the equation developed by Lynes (1979) (see chapter 3, section 3.3.1.4.2), given below:

$$\frac{B}{L} + \frac{B}{H} \leq \frac{2}{1 - Rb} \qquad (3.23)$$

Where:

B: Depth of the room from window to back wall [m]

L: Width of the room, measured parallel to the window [m]

H: Height of the window head above floor level [m]

R_b: Area-weighted average reflectance of the interior surfaces (walls, floor and ceiling) in the half of the room remotest from the window, expressed as a decimal.

Table 4.10 Evaluation of windows size using Lynes' formula.

School	*B*	*L*	*H*	*Rb*	$\frac{B}{L}+\frac{B}{H}$		$\frac{2}{1-Rb}$
Le Van Tam	7.0	7.8	2.4	0.62	3.81	≤	5.26
Truong Cong Dinh	6.0	8.0	2.5	0.55	3.15		4.44
Ha Huy Tap	6.0	7.0	2.1	0.59	3.15		4.88
Lam Son	8.0	8.0	2.5	0.6	4.2		5.0

Results presented in table 4.10 show that all of the schools have good window size. The classroom geometry is not so deep, so daylight seems to be able to enter most of the task area. Other window design criteria that are often addressed in the codes are window-to-floor-ratio and window-to-wall- ratio. The details of these ratios are given in table 4.9.

4.4.3.2.2. Daylight control system

In all the schools, main shadings are simple linear concrete overhangs running above windows. They are quite similar in construction, 800-1200mm width and 50mm thick, often plastered in light finishes. Same types of overhangs are installed in all facades regardless of orientation.

It should be noted that in both figure 4.16 and 4.17, windows of the classrooms on the lower floor are closed, due to noise and air pollution. In figure 4.16, the lower windows have been replaced by sliding doors and the upper floors have the original glazing.

Additional external rolling blinds are installed in Truong Cong Dinh and Lam Son School on the corridor side to provide more daylight control. In the interior, there are simple fabric curtains hanging above the windows, and they can be controlled manually by students., The shading systems are very basic and do not work effectively. All of these blinds and windows are manually controlled by either the school staff or the students. Summary of the shading devices are illustrated in table 4.11.

Figure 4.16
External overhangs of Truong Cong Dinh School.

Figure 4.17
External overhangs of Ha Huy Tap School

Table 4.11 Shading design

SHADING TYPE				
School	**Main windows, external facade**		**Side windows looking to the courtyard**	
Le Van Tam	Single concrete overhang above window, 0.8m		Open corridor, 1.8m	
Truong Cong Dinh	Continuous concrete overhang above window, 0.8m		Open corridor, 2.4m,with rolling blind	
Ha Huy Tap	Continuous concrete overhang above window, 0.8m		Open corridor, 1.4m	
Lam Son	Single concrete overhang above window, 1.0m		Open corridor, 1.8m, with rolling blind.	

Table 4.12 Window design

School	Primary windows	Secondary windows
LE VAN TAM		
	Glazing: Single glazing, clear tint brown glass, transmittance 65% *Opening:* four doors, horizontally *Frame:* Grey painted metal	*Glazing:* Single glazing, clear tint brown glass, transmittance 65% *Opening:* four doors, horizontally *Frame:* Grey painted metal
TRUONG CON DINH		
	Glazing: Single glazing, clear tint brown glass, transmittance 55% *Opening:* four doors, sliding *Frame:* Blue painted metal	*Glazing:* Single glazing, clear tint brown glass, transmittance 55% *Opening:* four doors, sliding *Frame:* Blue painted metal
HA HUY TAP		
	Glazing: None, wooden louvers *Opening:* flip doors, vertically *Frame:* Grey painted wood	*Glazing:* None, wooden louvers *Opening:* flip doors, vertically *Frame:* Grey painted wood
LAM SON		
	Glazing: Single glazing, translucent glass, transmittance 50% *Opening:* four doors, sliding *Frame:* Blue painted metal .	*Glazing:* Single glazing, clear glass, transmittance 65% *Opening:* four doors, sliding *Frame:* Blue painted metal

4.4.3.3. Artificial Lighting

Simple flourescent batterns are the main light fixtures used in all classrooms. They are very popular in Vietnam, due to their low-cost and efficiency advantages. In Le Van Tam School there is a simple painted metal reflector; in the other three schools the light fixtures are just bare 36W- T8 fluorescents. Therefore, glare is an obvious problem.

These lamps have a colour temperature of 4200°K and cool white light which is appropriate for this type of application, as per the codes. Although the classroom sizes and shapes are quite similar, the quantity and layout of the lighting fixtures vary. It is found that they are arranged in symmetrical grids rather than in relation to either architectural element or daylight availability. They are neither associated with furniture layout nor integrated into the constructional detail. Variations can also be seen in the mounting positions.

In Le Van Tam and Lam Son School, they are suspended from the ceiling by metal rods. In the other two schools they are mounted directly on the ceiling surface and some are even mounted vertically on the wall surfaces at the same height as the students' view.

The control strategies are basic: just on and off mode. Fixtures are grouped in two groups: one on-off switch for all the ceiling mounted fixtures and an on-off switch for the surface mounted fixtures above the teaching board. The switches are positioned next to the classroom's entrance and accessible by all students and school staff.

The lamp ballasts are the low-cost conventional magnetic types, they are very noisy, inefficient, flickering and non-dimmable. Although users have full access to the switches, there is nothing much that can be done to adjust these lamps to suit their needs. Site survey found that these lamps remain switched on at all times, even in the Dry season.

Table 4.13 Summary of the surveyed classroom artificial lighting system

School	Type	Quantity	Mounting position	Lamp	Colour Temperature	Optical control	Ballast	Control
STUDENT DESK AREA								
Le Van Tam	Ceiling suspended fixture	8	Ceiling	36W - T8 fluoresce nt tube	4200⁰K	White painted aluminium reflector	Conventional Magnetic ballast	On-off
Truong Cong Dinh	Surface mounted fixture	6	4 on 2 side walls, and 2 on back wall	36W - T8 fluoresce nt tube	4200⁰K	None	Conventional Magnetic ballast	On-off
Ha Huy Tap	Surface mounted fixture	8	Ceiling	36W - T8 fluoresce nt tube	4200⁰K	None	Conventional Magnetic ballast	On-off
Lam Son	Ceiling suspended fixture	6	Ceiling	36W - T8 fluoresce nt tube	4200⁰K	None	Conventional Magnetic ballast	On-off
TEACHING BOARD								
Le Van Tam	Surface mounted fixture	2	Above teaching board, washing down	36W - T8 fluorescent tube	4200⁰ K	White painted aluminium reflector	Conventional Magnetic ballast	On-off
Truong Cong Dinh	Surface mounted fixture	2	Above teaching board, washing down	36W - T8 fluorescent tube	4200⁰ K	White painted aluminium reflector	Conventional Magnetic ballast	On-off
Ha Huy Tap	Surface mounted fixture	2	Above teaching board, washing down	36W - T8 fluorescent tube	4200⁰ K	White painted aluminium reflector	Conventional Magnetic ballast	On-off
Lam Son	Surface mounted fixture	2	Above teaching board, washing down	36W - T8 fluorescent tube	4200⁰ K	White painted aluminium reflector	Conventional Magnetic ballast	On-off

These problems may be the result of the lack of proper design guidline. In the current Vietnamese codes very little detail has been given for articial light system requirements. The most critical issue is the luminaire layout which is not well addressed. These codes are also outdated for most of the terms regarding light sources, fixture design and controlling strategies.

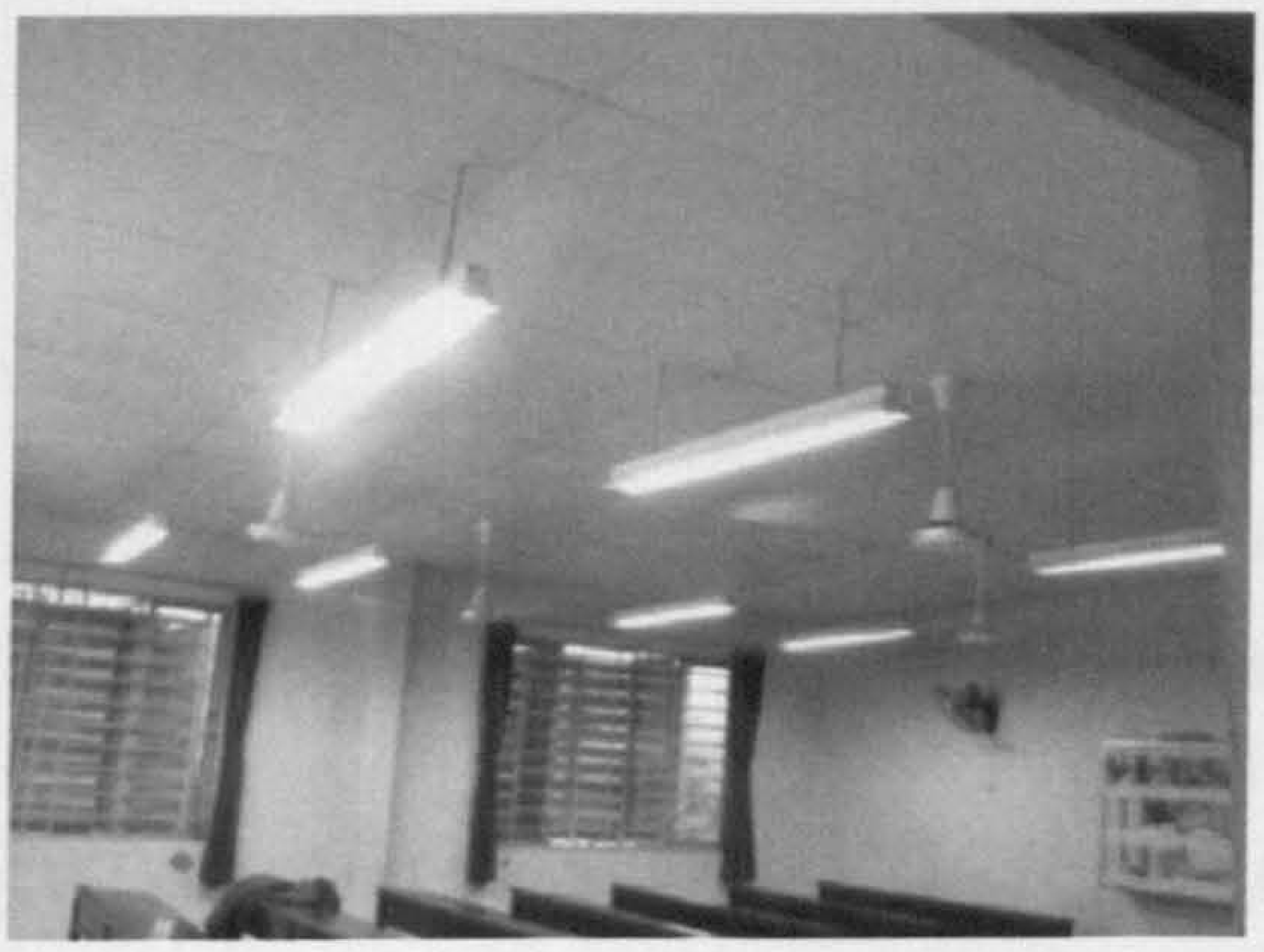


Figure 4.18
Le Van Tam classroom's artificial lighting system.

Figure 4.19
Truong Cong Dinh classroom's artificial lighting system.

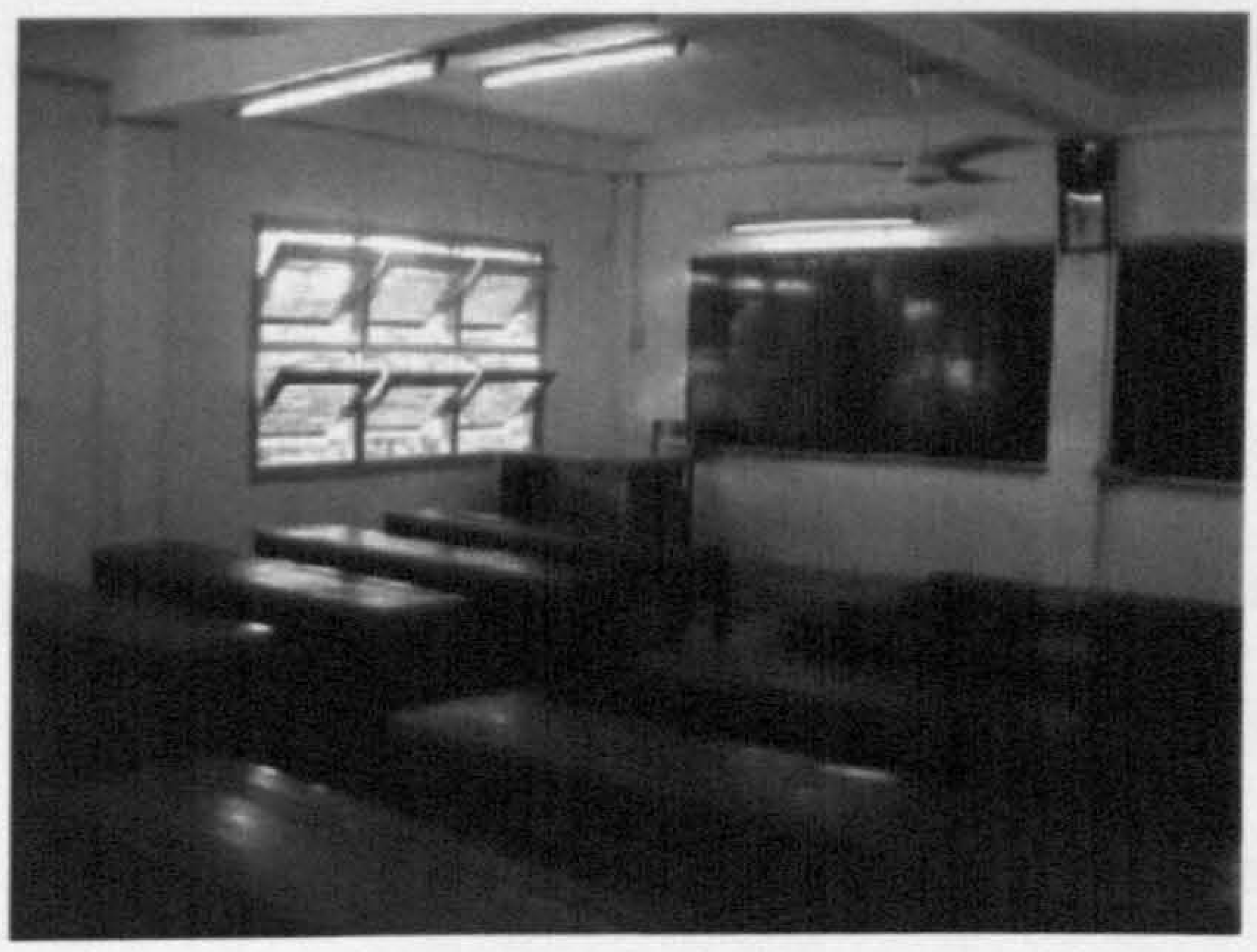


Figure 4.20
Ha Huy Tap classroom's artificial lighting system.

Figure 4.21
Lam Son classroom's artificial lighting system.

4.5. Conclusions

Although education has been established in the 10th century in Vietnam, no formal traditional school or classroom design was developed. It is found that traditional architecture is well designed to take advantage of climate and site context. Although some traditional design strategies and architectural elements can be applied for future school design, they are generally no longer appropriate for modern teaching-learning activities.

There are several school types existing in HCMC. It has been found that there has not been a lot of evolution in the school and classroom design since the early 20th century. The development of school design has been held back for many years due to wars, lack of budget and awareness. Some improvements have been seen in new school design built after the 1990s, but the lack of appropriate design guideline has lead to inappropriate variations.

Results obtained from the users' comfort survey suggest that the school design is not identical and inspiring. Problems are also seen in the operation and maintenance leading to poor environmental performance.

Further review revealed some critical problems found in HCMC schools, e.g. the lack of land leading to high building density, high density neighbourhood compromising access to daylight, view, and privacy. Initial evaluation of current classroom lighting design presents that they are not working efficiently. Problems are found on the window designs, i.e. the choice of glazing, size and position. Shading devices are basic and are not well coordinated with daylight availability of the site. The daylight control system is very basic and the artificial lighting system is also ineffective. The luminaire layout is not well coordinated with the architecture. Luminaries do not have proper optical control and they are mounted in wrong positions. This review also presents that many critical issues are either missing or not addressed in the Vietnamese classroom lighting codes. These gaps in the design guidance have lead to inappropriate design interpretation in practice.

Chapter 5

Daylight and classroom illumination

5.1. Introduction

This chapter describes the investigation of current classroom lighting conditions focusing particularly on the relationship between daylight and task illuminance. It is structured into three parts:

1. Reviewing and understanding the daylight context
2. Indentifying the problems
3. Proposals to improve the current conditions

The first part focuses on understanding the site's daylight context from site documentations. The aims are to find out what the daylight context is in reality, and to define the key factors that may have significant impact on the interior illumination. It is furthered by examining the context using current methods introduced by the codes and then comparing the results to the real data measured on site to identify potential conflicts and problems that may arise.

The second part provides further analyses, using established daylight theories to explain the situations, verifying the codes and then identifying the sources of these conflicts and problems.

The third part attempts to establish a simple daylight design indicator, the window-to-floor ratio, which is appropriate for HCMC classrooms.

This process is illustrated in figure 5.1.

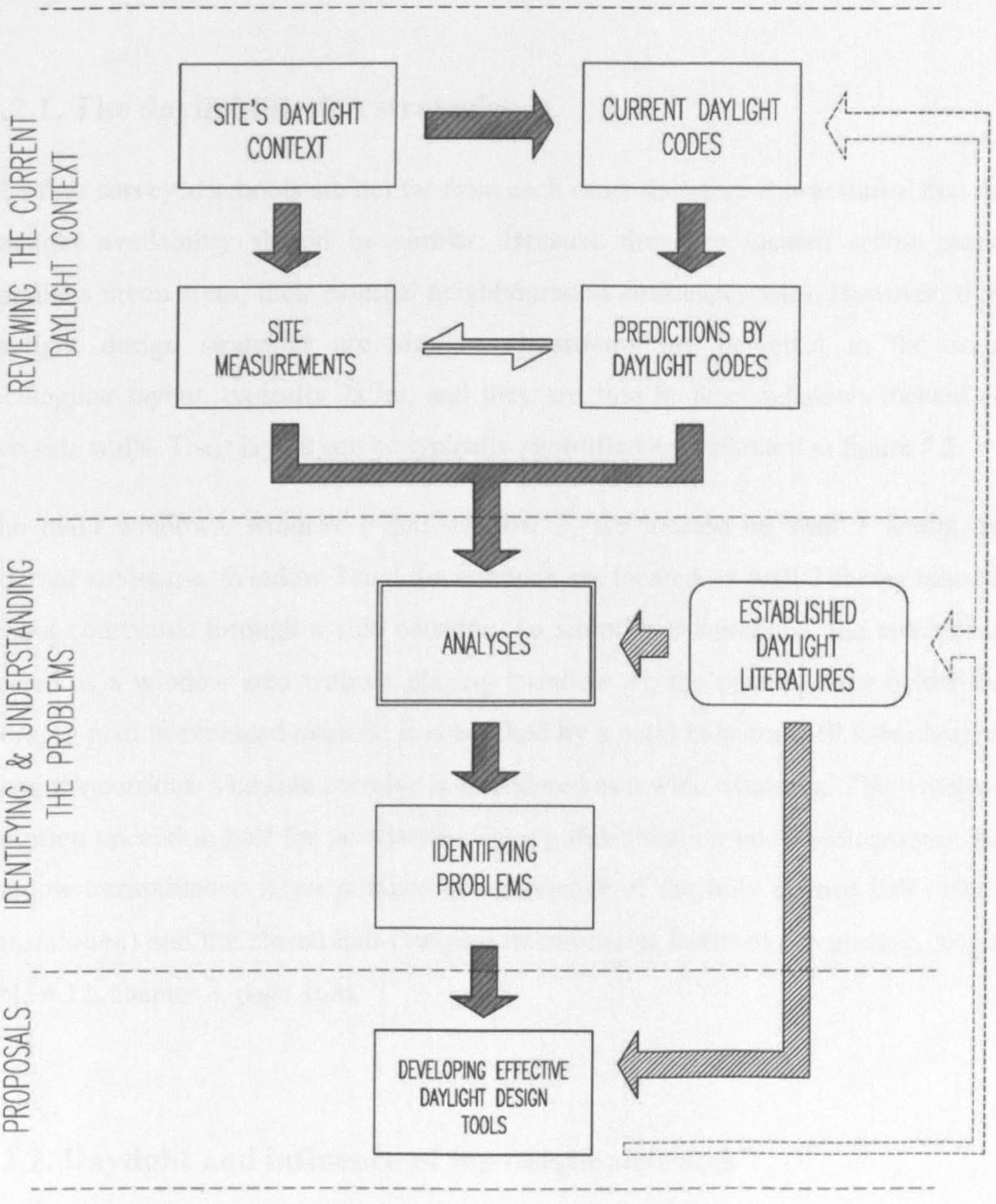


Figure 5.1 Analytical structure of the daylight investigation.

5.2. Review of the daylight context

This part provides the extensive review of the daylight context of the four surveyed classrooms. The first discussion focuses on reviewing the daylight strategies, and the second discussion analyses the influences of the neighbourhood and highlights the key factors that may have significant impact on the interior illumination.

5.2.1. The daylight design strategies

The four surveyed schools are not far from each other therefore it is assumed that the daylight availability should be similar. Because they are located within dense populous urban areas, their external neighbourhood landscapes vary. However, their daylight design strategies are similar: classrooms are designed in the same rectangular layout, typically 7x7m, and they are side lit from windows located on two side walls. Their layout can be typically simplified as illustrated in figure 5.2.

The main windows, window 1 and window 2, are located on wall 1 facing the external landscape. Window 3 and the entrance are located on wall 2 facing internal school courtyards through a side corridor. To simplify calculations, the entrance is treated as a window area without glazing (window 4); the opening area below the working plan is excluded because it is blocked by a solid balustrade (0.9-1m height) along the corridor. The side corridor is considered as a wide overhang. The windows are often opened in half for ventilation. Taking this situation into consideration, the window transmittance factor is taken as an average of the fully opened half (100% transmission) and the closed half (varying transmission factor of the glazing, as per table 4.12, chapter 4, page 168).

5.2.2. Daylight and influence of the neighbourhood

The influence of the neighbourhood on the daylight context of these schools is quite complex and challenging. There are dense external buildings of various shapes and height, streets of varying sizes and low and high trees with different foliage.

Assessing daylight availability for these classrooms can prove to be a representative example for most of the schools in the city.

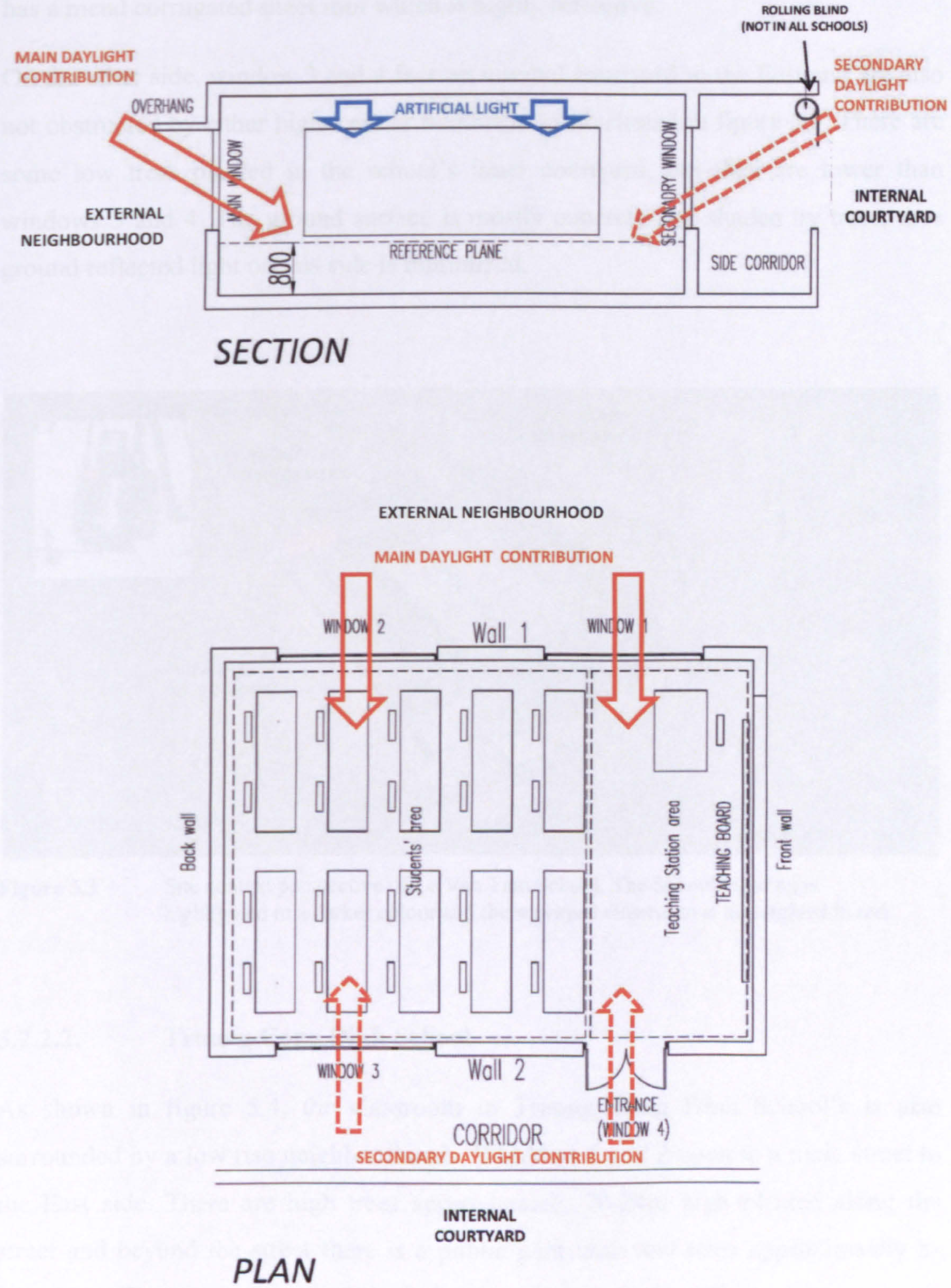


Figure 5.2 The plan, section and lighting scheme of the surveyed classrooms

5.2.2.1. Le Van Tam School

The main external window 1 and 2 of Le Van Tam School (LVT) classroom faces a low rise neighbourhood to the West which does not form any obstruction to the amount of daylight entering the room. However the building closest to the window has a metal corrugated sheet roof which is highly reflective.

On the other side, window 3 and 4 face an internal courtyard to the East and are also not obstructed by either high trees or buildings, as illustrated in figure 5.3. There are some low trees planted in the school's inner courtyard, but they are lower than windows 3 and 4. The ground surface is mostly concrete and shaded by trees, thus ground reflected light on this side is minimized.

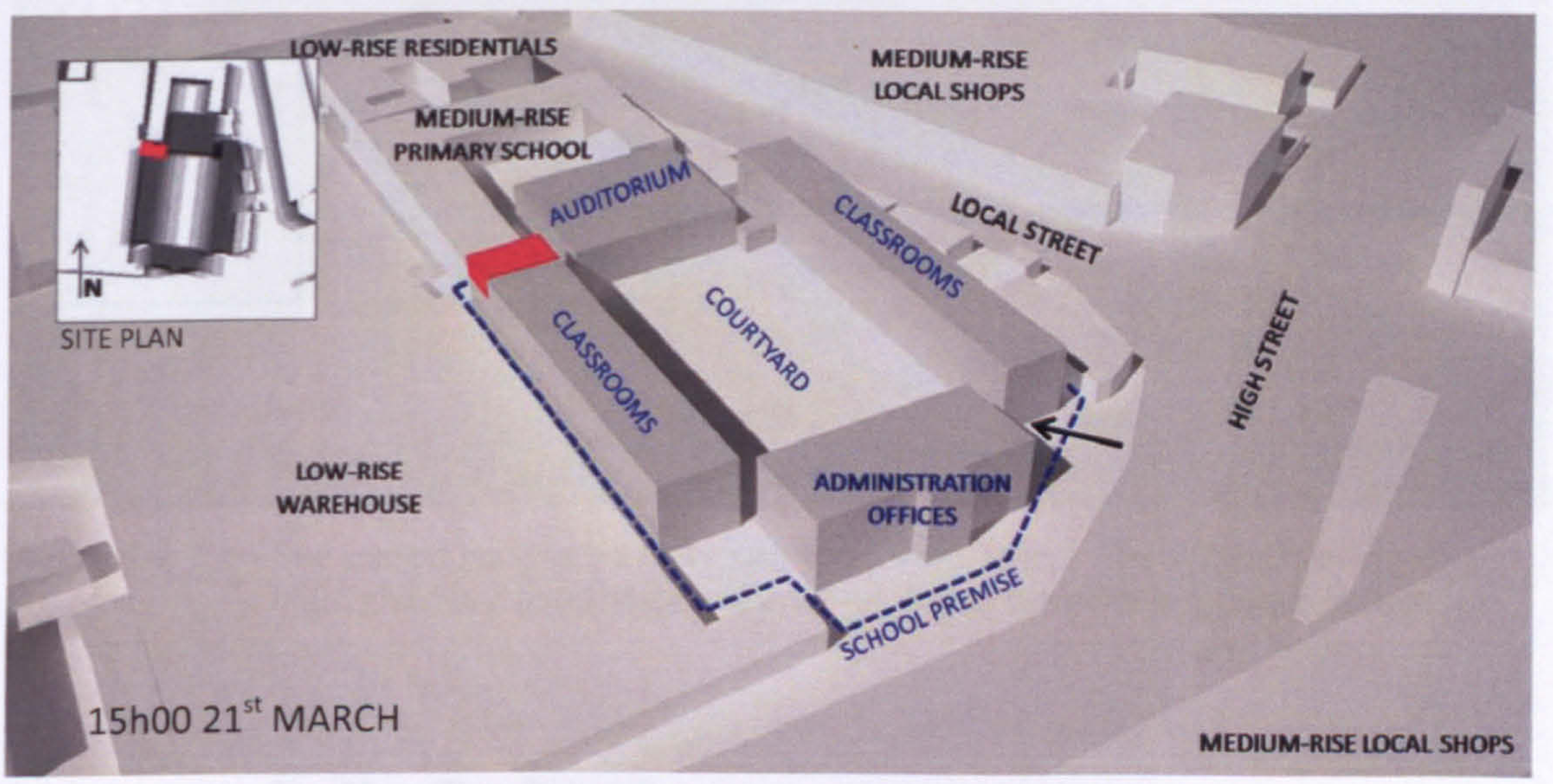


Figure 5.3 Site context perspective of Le Van Tam School. The School building is highlighted in a darker colour and the surveyed classroom is highlighted in red.

5.2.2.2. Truong Cong Dinh School

As shown in figure 5.4, the classroom in Truong Cong Dinh School's is also surrounded by a low rise neighbourhood. Windows 1 and 2 open to a main street to the East side. There are high trees approximately 20-24m high planted along the street and beyond the street there is a public park with low trees approximately 8-12m high. These trees have a foliage density of approximate 80% and are green all year round. Hence the ground reflected component is not significant because the ground is paved and well shaded.

The secondary windows to the West side open through a side corridor into a small courtyard, with low level trees which partly obstruct view. The corridor has rolling blinds which are permanently fixed one third ways down. These blinds being translucent, allow approximately 30% light. The surrounding buildings are low rise and do not obstruct the view.

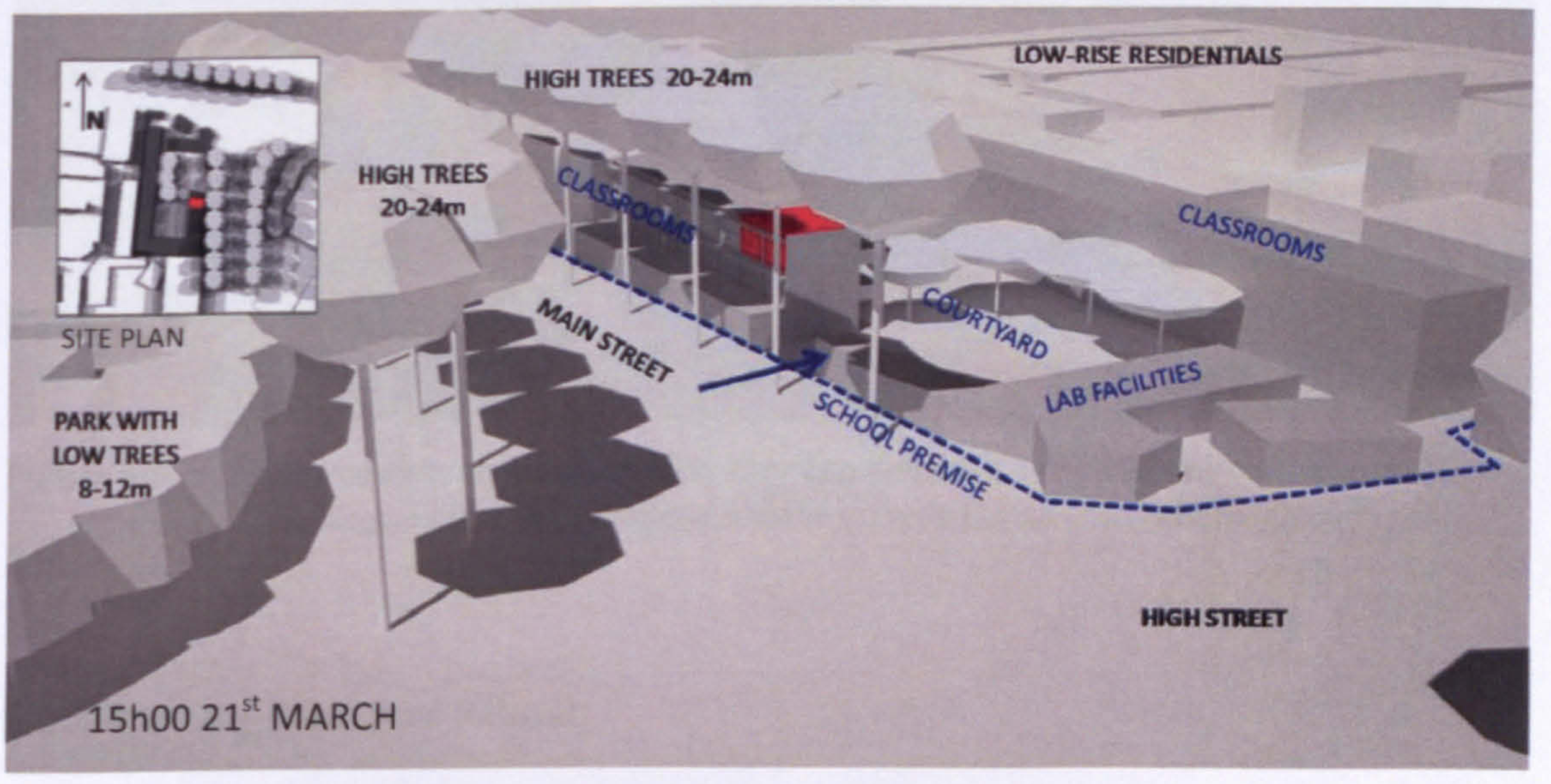


Figure 5.4 Site context perspective of Truong Cong Dinh School. The School building is highlighted in a darker colour and the surveyed classroom is highlighted in red.

5.2.2.3. Ha Huy Tap School

Ha Huy Tap School is located within a dense residential area with buildings mostly two to three floors in height (6m to 9m). The main windows on the East facade open to a narrow street between the school premises and the residential buildings. There are no trees on this side, so the main obstructions are the buildings. For this type of urban area it is estimated that the reflectance factor of these obstructing buildings is as low as 20%, as their facades are largely glazed and shaded, and pollution and dirt also reduces a lot of reflecting light. The ground landscape is all hard.

The secondary windows on the West side open through a side corridor into a courtyard with no trees. There is however a stair located next to the corridor, which blocks a large part of the direct sky access.

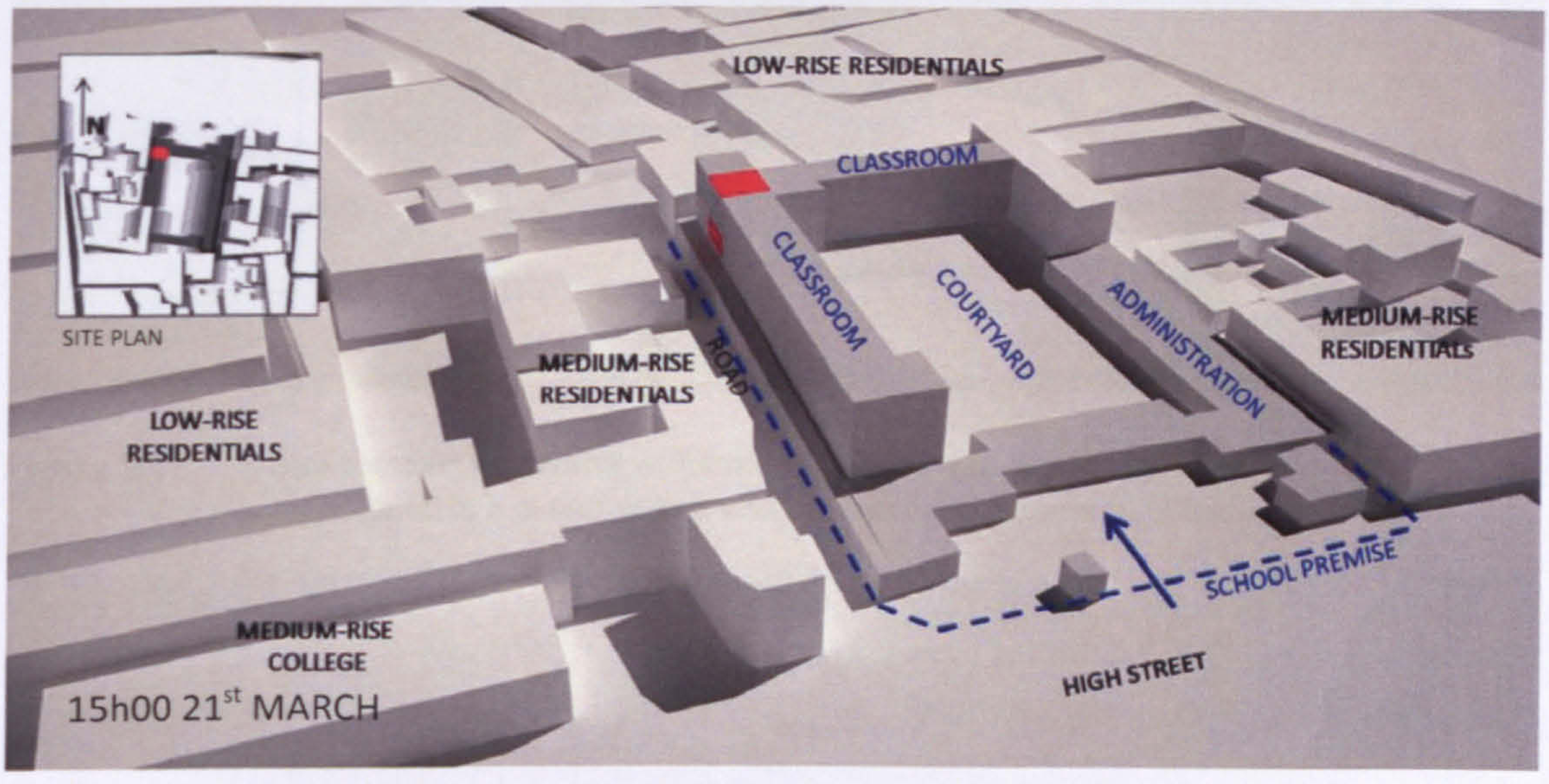


Figure 5.5 Site context perspective of Ha Huy Tap School. The School building is highlighted in a darker colour and the surveyed classroom is highlighted in red.

5.2.2.4. Lam Son School

Lam Son School is located in a dense residential area with the main windows of the surveyed classroom located on the South facade. The windows open directly to a medium height neighbourhood; mostly two to three floor buildings (6m to 9m) with no trees on this side.

The secondary windows open into the school courtyard through a small side corridor partly covered by external rolling blinds downed half way; these translucent blinds allow daylight through (30% transmission). There are some buildings on this side that partly obstruct sky access.

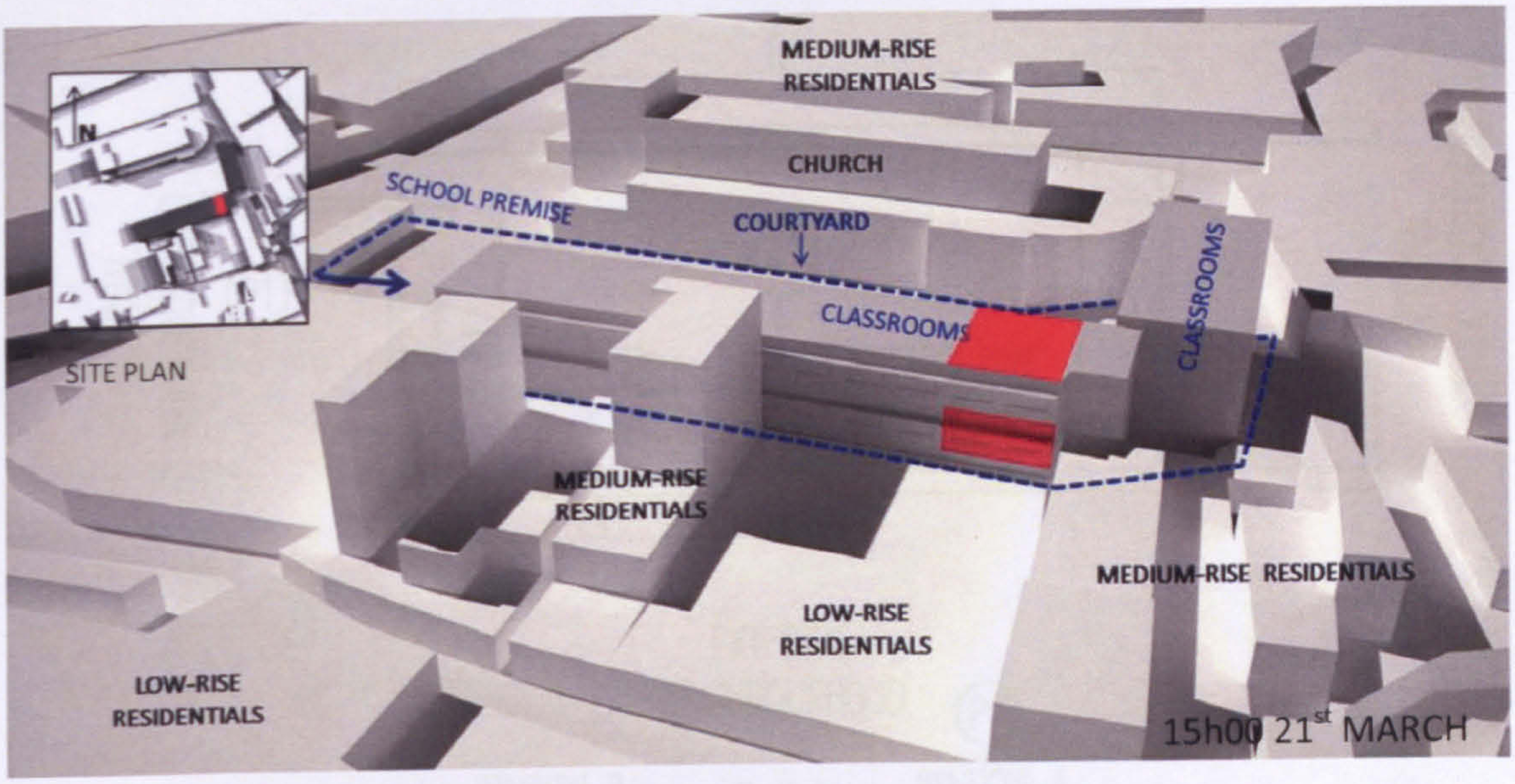


Figure 5.6 Site context perspective of Lam Son School. The School building is highlighted in a darker colour and the surveyed classroom is highlighted in red.

5.3. Examining the daylight context by the current codes

This section examines the daylight context to provide initial predictions on how daylight contributes to the interior illumination, by using theoretical calculations. The examination employs the daylight calculation methods introduced in the Vietnamese codes (i.e. *ĐRASTN* and *Danhiluc chart*) and the popular Waldram diagram.

Three reference points have been identified for the study: the vertical illumination point P1 located externally at the centre of the window, the vertical illumination point P2 located internally at 2m height on the wall facing into the classroom and the horizontal illumination point P3 in the centre of the classroom at a student desk (0.8m height) facing upward. The design parameters and the positions of the reference points are illustrated in figure 5.7.

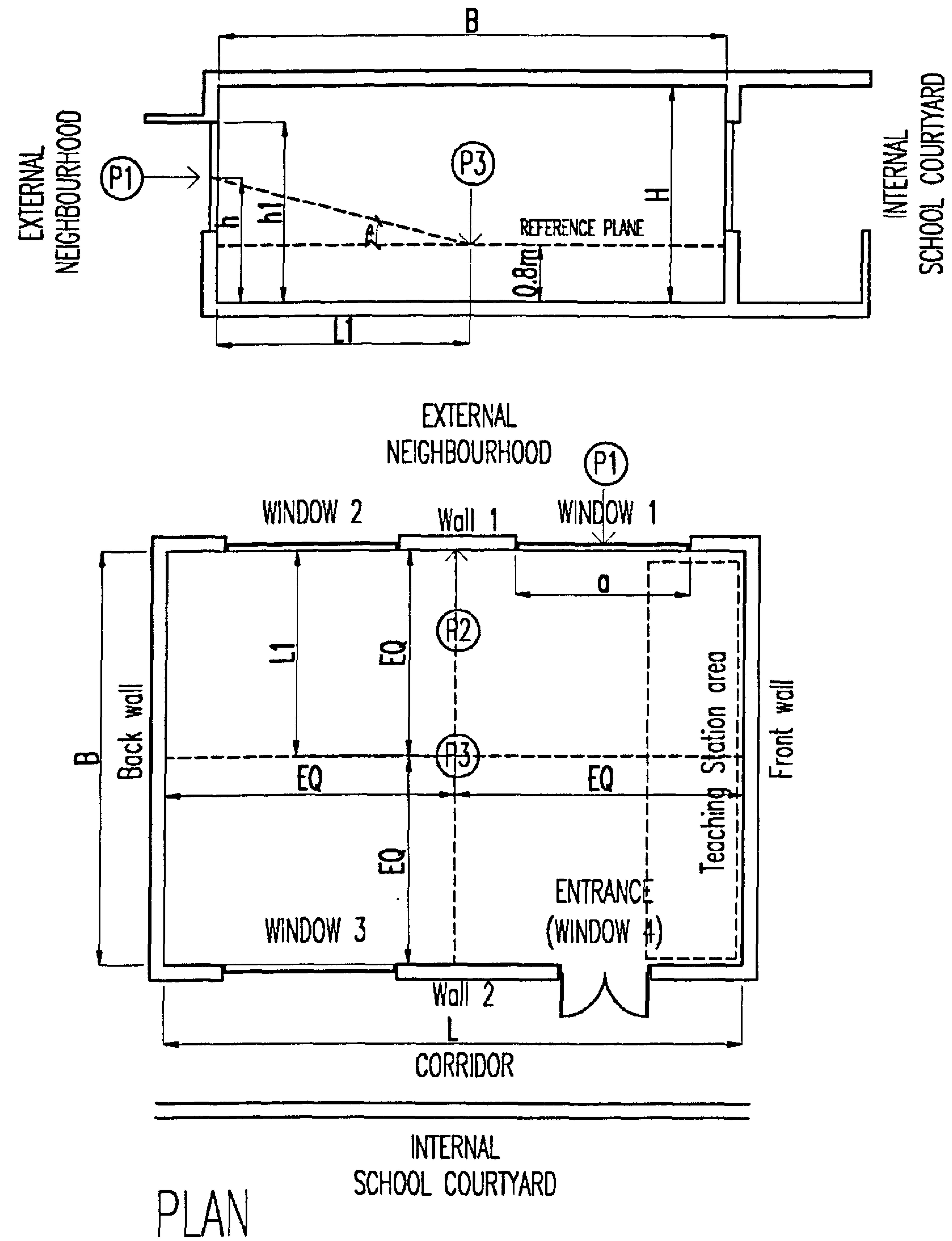


Figure 5.7 Definitions of room geometry and positions of the reference points

5.3.1. The Vietnamese codes

The daylight calculation process in Vietnamese codes requires two steps:

1. Step1: using the *ĐRASTN* formula
2. Step 2: using the Danhiluc charts

Further details are described in chapter 3.

STEP 1

Theoretically, the *ĐRASTN* value is obtained by:

$$ĐRASTN = \frac{S_{cs}.\tau_{cs}.r_1}{S_s.K.\eta_{cs}}.100 \qquad (5.1)$$

Where:	S_{cs}:	Total window area [m^2]
	S_s:	Total floor area [m^2]
	K:	Maintenance factor (by dirt, cleaning frequency), expressed as a decimal, often taking K=1.2
	η_{cs}:	Window-Room index, expressed as a decimal, obtained from table J.1 of appendix J
	τ_{cs}:	Window transmittance index: $\tau_{cs} = \tau_1.\ \tau_2.\ \tau_3.\ \tau_4.\ \tau_5$, these values can be obtained from appendix J.
	r_1:	Reflectance correction factor by internal reflected light and external reflected light from ground, expressed as a decimal, obtained from table J.6 of appendix J.

For classroom daylight, TCXD: 29 (1991) recommends that minimal *ĐRASTN* measured at student desk should not be lower than 2%.

Using the equation (5.1), the *ĐRASTN*$_i$ contribution of each window *(i)* is calculated separately. The total *ĐRASTN* at P3 is the sum contribution of all four windows:

$$ĐRASTN = ĐRASTN_1 + ĐRASTN_2 + ĐRASTN_3 + ĐRASTN_4$$

The *ĐRASTN* at P3 contributed by all windows are estimated and presented in table 5.1. The details of the calculation process, which is very time-consuming and complicated and the estimated contribution of each window are given in table D.1 and D.2 of appendix D (page 421-422).

In this calculation, there are two special notes about the *shading device index* (τ_4) :

- The code considers the overhang as part of the window glazing, which is defined by shading device index (τ_4). To estimate this τ_4, the overhang protection angle *VSA* must be calculated from the overhang geometry and then the shading device index τ_4 is obtained from a referencing table of values which is dependent on the *VSA*.
- Because the wooden louvered window, as can be seen in the Ha Huy Tap School, is quite popular in Vietnam buildings, this type of window is addressed in the code; it is defined as a special type of "glazing" reducing daylight contribution, and thus the impact of these wooden louvers also included in the index τ_4. (see table J.5 of appendix J, page 446).

The results presented in table 5.1 indicate that none of the classrooms meet the minimal 2% *ĐRASTN* requirements of the code. Le Van Tam and Lam Son School have the highest *ĐRASTN*, while the other two schools are lower than 1%.

As estimated in table D.1 and D.2 of appendix D, windows located on both sides have equal contribution. During the calculation, it is found that the main factors that significantly alter the results are the window to floor area ratio $\frac{Scs}{Ss}$, the transmittance factor τ_{cs} and the reflectance correction factor r_1. Typically, an overhang (0.8 m width and 30^0 *VSA*) reduces 20% of the overall *ĐRASTN* and all other glazing properties result in further reductions, leaving the sum *ĐRASTN* value very low.

Table 5.1
Estimate of total *ĐRASTN* at P3, which is the sum of contribution from each window.

	Symbol	Descriptions	*School* Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
ROOM GEOMETRY	S_{ct}	Total window area (m^2)	11.69	11.87	8.76	17.56
	S_s	Floor area (m^2)	54.60	48.00	42.00	64.00
	$R_w = \frac{S_{ct}}{S_s} 100\%$	Window-to-floor area ratio (%)	21.41	24.73	20.86	27.44
	B	Room width (m)	7.00	6.00	6.00	8.00
	L	Room length (m)	7.80	8.00	7.00	8.00
	L_1	Offset distance from wall to reference point (m)	3.50	3.00	3.00	4.00
	ρ_{tb}	Area-weighted average reflectance	0.62	0.55	0.59	0.57
TOTAL	*ĐRASTN(%)*	$ĐRASTN = ĐRASTN_1 + ĐRASTN_2 + ĐRASTN_3 + ĐRASTN_4$	**1.41**	**0.87**	**0.66**	**1.64**
	Comparing to the code's minimum requirement (2%)		70.34%	43.69%	32.86%	81.94%

The *ĐRASTN* values of Le Van Tam and Lam Son School are different due to the larger window areas of the latter. In the case of Truong Cong Dinh School, it is the reflectance correction factor r_1 that greatly reduces the values; the r_1 is the function of average-weight reflectance ρ_{tb} and various room geometry indices such as the $\frac{B}{h1}$ ratio (room width to window height above the working plane). In this case, the disproportional $\frac{B}{h1}$ ratio leads to the small r_1. This indicates that Truong Cong Dinh School classroom does not have a good proportion of room and window geometry. In the case of Ha Huy Tap School, it is the louvered windows that result in the low τ_4 (as seen in table D.1 of appendix D, in the estimates of contribution of the entrance area when there is no glazing or louver, the $ĐRASTN_4$ value is double).

These results suggest that the survey classrooms do not have good design geometry (i.e. room geometry, window geometry and positions). If it is assumed that the room properties remain the same, perhaps minor improvements on the window design (i.e. window size, position and shape), as in the case of Lam Son School, can help improve the overall results and meet the codes requirements.

STEP 2

The second step, employing Danhiluc chart (i.e. two parts), is essential to examine the external obstructions. Similar to step 1, the contribution $ĐRASTN_{Di}$ in the Danhiluc chart of each window area *(i)* is estimated by:

$$ĐRASTN_{Di} = (\frac{n_{1i}.n_{2i}}{100} q_i + \frac{n_{1i}'.n_{2i}'}{100} Ri).r_{1i}.\frac{\tau_{csi}}{K_i} \quad (5.2)$$

Where:

$n_1.n_2$: Area of visible sky defined by plan and section grid line

q: Sky luminance coefficient by CIE overcast sky model

$n_1'.n_2'$: Area of obstructed sky defined by plan and section grid line

R: External obstruction index, given in table J.9 of appendix J

r_1, τ_{cs}, and K as defined in equation (5.1)

The $ĐRASTN_D$ at P3 is the sum of all windows $ĐRASTN_{Di}$:

$$ĐRASTN_D = ĐRASTN_{D1} + ĐRASTN_{D2} + ĐRASTN_{D3} + ĐRASTN_{D4}$$

The calculation process and specific contribution of each window are presented in table D.3-D.6 of appendix D (page 423-426). The final results are presented in table 5.2.

As seen in these tables, the first issue to be spotted here is that the Danhiluc chart method is not user-friendly. The calculation is a time-consuming process which requires determining of many coefficient factors. The process of estimating the external obstruction employs many coefficient factors which are complicated to define.

Originally, the estimates of $ĐRASTN_D$ shown in table 5.2 are calculated under CIE overcast sky (as defined by the code). The luminance distribution of the sky dome in the Danhiluc chart method is defined by the sky luminance coefficient q. When the sky luminance coefficient q is reset to 1, it represents a simpler uniform sky model. For assessment purposes, the result in table 5.2 is then recalculated to table 5.3 with coefficient q reset to 1. Therefore, the $ĐRASTN_{Du}$ values in this case are calculated under uniform sky.

Table 5.2

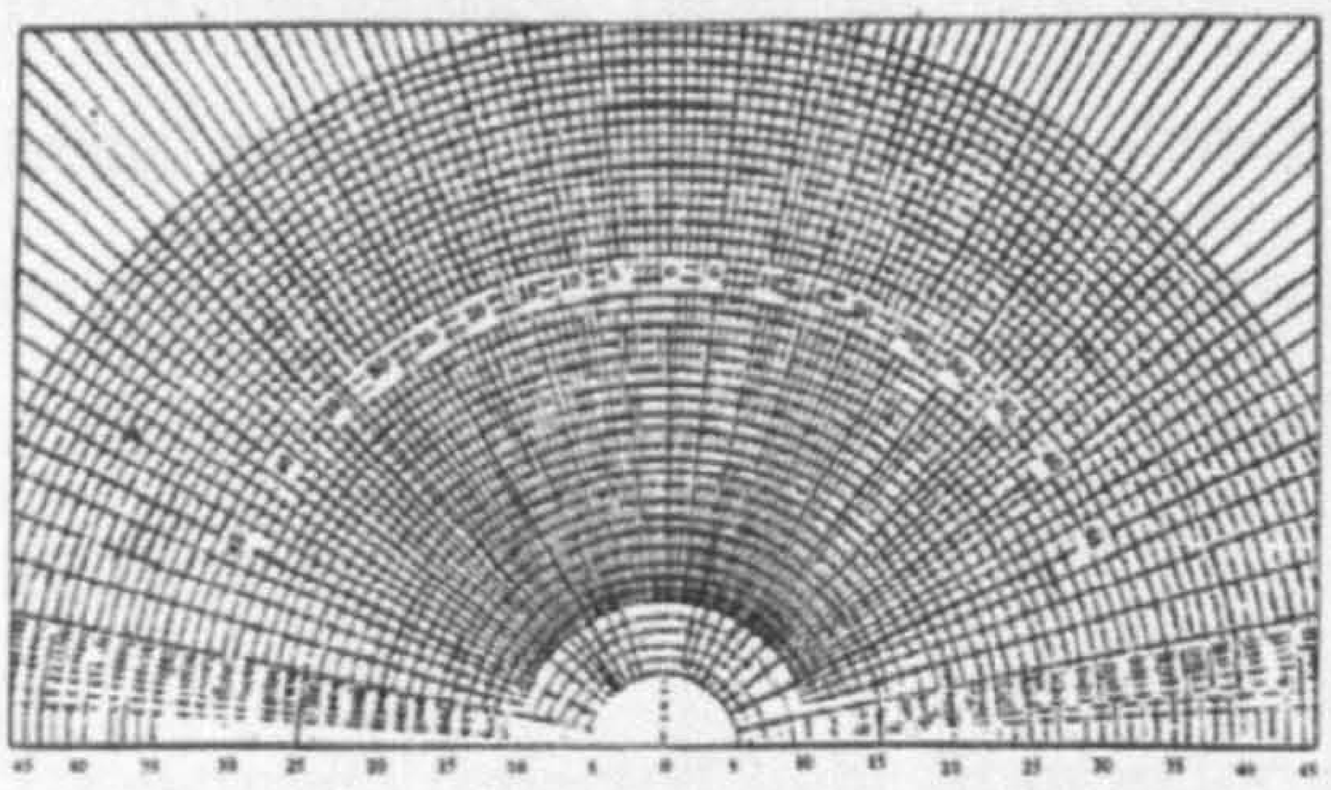
Estimates of total $ĐRASTN_D$ contributed by all windows, using Danhiluc chart in CIE overcast sky

Descriptions		School			
		Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
$ĐRASTN_{D1}$	[%]	0.45	0.30	0.13	0.55
$ĐRASTN_{D2}$		0.45	0.30	0.17	0.31
$ĐRASTN_{D3}$		0.26	0.10	0.21	0.11
$ĐRASTN_{D4}$		0.19	0.06	0.00	0.44
$ĐRASTN_D$		**1.35**	**0.76**	**0.51**	**1.41**

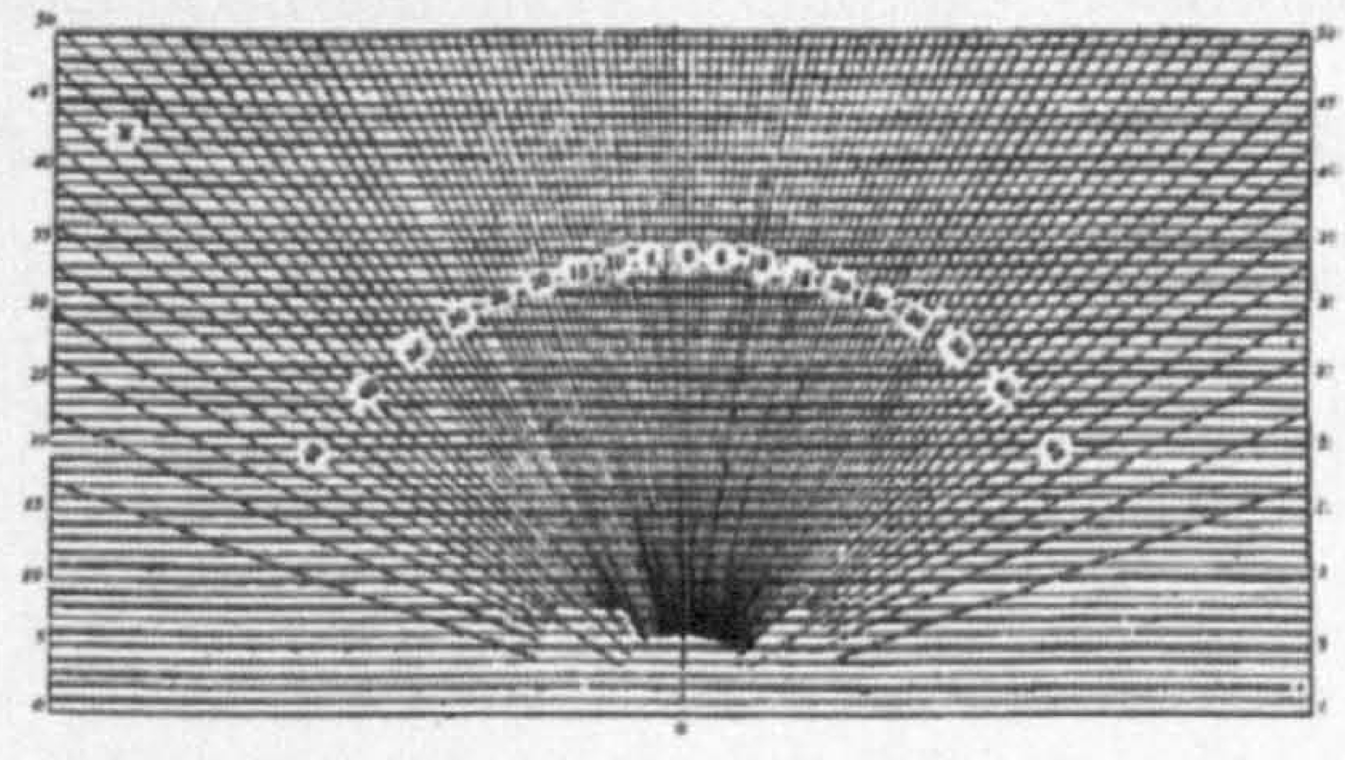
Table 5.3

Estimate of total $ĐRASTN_{Du}$ contributed by all windows, using the Danhiluc chart in uniform sky.

Descriptions		School			
		Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
$ĐRASTN_{D1u}$	[%]	0.70	0.41	0.13	0.85
$ĐRASTN_{D2u}$		0.70	0.41	0.27	0.31
$ĐRASTN_{D3u}$		0.41	0.13	0.33	0.13
$ĐRASTN_{D4u}$		0.30	0.08	0.00	0.63
$ĐRASTN_{Du}$		**2.11**	**1.03**	**0.73**	**1.92**



Danhiluc chart for section



Danhiluc chart for plan

Figure 5.8 Danhiluc charts (TCXD:29, 1991).

Due to the complexity of the external obstructions, the results found in step 1 and step 2 are different. It is unclear in the codes what should be done in this case. In Step 1 the *ĐRASTN* is calculated from an equation and in Step 2 it is estimated by graphical estimation from the diagrams. Therefore, these two steps are independent of each other. The difference in results obtained from each step is quite clear when the external obstructions are taken into consideration. As seen in the in table 5.1 and table 5.2, the difference is approximately 10-20%.

In summary the calculation method introduced by the Vietnamese code seems to be quite complicated and not capable of providing a straight forward and accurate estimate in a context of complex external obstructions.

5.3.2. The Waldram diagram

In this section, the daylight contribution in these classrooms is verified again by another popular method, the Waldram diagrams, which is quite similar to the Danhiluc charts (see discussion in section 3.3.1.3.3 of chapter 3).

The Waldram diagram method is a simple yet powerful tool for estimating the daylight factor, especially in a complex site context, because it is possible to plot all external obstructions with different shapes and heights into a simple 2D graph. (Wilkinson, 2008). The theories behind this method are described in chapter 3 and the diagrams used in this plotting are given in appendix F.

In this estimation, reflected light from external obstructions (i.e. shadings, buildings, trees, blinds) is taken into consideration. Empirically, reflected sky light from the overhang is ignored, because it is reflected twice before reaching the task plane and therefore the contribution is too small to have a significant impact (Tregenza & Wilson, 2011).

To estimate reflected light from external buildings, the luminance of the facades of the external building is often empirically estimated as a fraction of the luminance of the obstructed sky (Hopkinson et al,1966; Brotas, 2004). Because uniform sky is employed in this estimation, the external reflected component (ERC) is simply calculated as (Wilkinson, 2008):

ERC=Area of buildings through window x Reflectance of buildings x 100%

Empirically, the reflectance of the building's facade is often taken as 0.2 which represents the realistic conditions of a dense urban space (Synthlight, 2001).

It is a more complex process to estimate the impact of the trees, because trees both reflect light as well as allow direct daylight to travel through the space between the leaves defined by the trees' foliage. In this case, it is estimated that the trees' foliage is approximately 80%. This means trees allow 20% of direct light reaching the trees to travel through. Added to this, trees also reflect light. It is assumed that the reflectance factor of the tree crowns is at 20%. Total area obstructed by trees is about 40% that of the same size clear sky plotted in the diagram. The point to note is that in HCMC, trees are green all year round; hence it is assumed that these values remain stable. Uniform sky model is used in this calculation and sunlight is excluded as per the definition in the literature.

There are two sets of Waldram diagram plotting:

- The first set is the vertical plotting from P1 (from centre of wall 1, at mid height of the window's, using vertical Waldram diagram for uniform sky, and with no glazing). The first sets of vertical plotting are illustrated in figure 5.9 and the values are presented in table 5.4.
- The second set is the horizontal plotting from P3 (from middle of the classroom at desk top level, and look to windows on both wall 1 and 2 , using horizontal Waldram diagram for uniform sky, and with no glazing). The results of the second Waldram diagram plotting are summarized in table 5.5.

The details are presented in appendix E and F.

As seen in table 5.4, in the first set of plotting, the results vary in each case. In Le Van Tam School and Lam Son School, direct light from the sky is the main contributor. In Truong Cong Dinh and Ha Huy Tap School both of which are more obstructed, direct and reflected light from sky are main contributors. It is noted that the 0.8m width overhangs (as seen in three schools: Le Van Tam, Truong Cong Dinh and Ha Huy Tap) obscure approximately 20-30% of the window's area. Because they obscure the upper part of the window, the reduction of direct sky component by this overhang is 50%. It has been noted that the Ha Huy Tap classroom has special windows with wooden louvers. However, the reductions caused by these louvers are excluded, because the vertical plotting is from point P1which is on the outer surface of the window.

By definition, Sky Factor, *SF* [%] , represents the direct sky components of uniform sky, in this estimation (as in table 5.4) the contributions of external reflected light are also included and converted in to equivalent sky factor. The total sky factor expresses the equivalent sum contributions of both direct and reflected components.

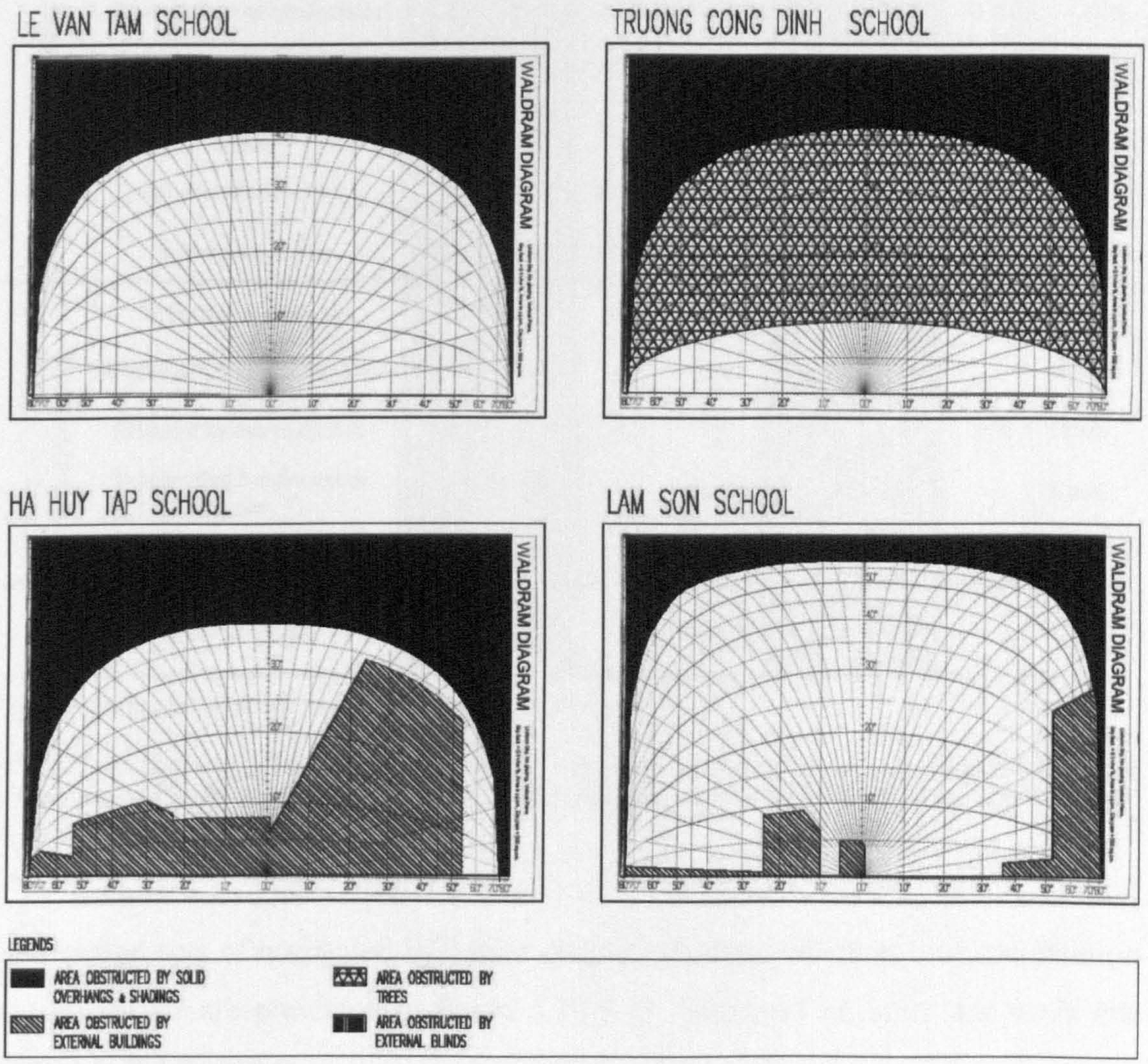


Figure 5.9 Plotting of shadings and obstructions on *Waldram* diagram vertically from reference point P1.

Table 5.4 Estimates of equivalent vertical sky factor *SF* [%], as seen vertically from point P1 of window 1 plotted in Waldram diagrams.

	DESCRIPTIONS	School							
		LE VAN TAM		TRUONG CONG DINH		HA HUY TAP		LAM SON	
		% of window area (*)	SF (**)	% of window area (*)	SF (**)	% of window area (*)	SF (**)	% of window area (*)	SF (**)
DIRECT COMPONENTS	Area obstructed by shadings	31.75%	15.88%	31.75%	15.88%	38.02%	19.01%	15.35%	7.68%
	Area obstructed by external buildings	0%	0%	0%	0%	26.86%	13.43%	8.67%	4.33%
	Area obstructed by external blinds	0%	0%	0%	0%	0%	0%	0%	0%
	Area obstructed by trees	0%	0%	51.23%	25.61%	0%	0%	0%	0%
	Unobstructed area	68.25%	34.12%	17.02%	8.51%	35.12%	17.56%	75.98%	37.99%
EXTERNAL REFLECTED COMPONENTS	Reflected by shadings	N/A	0%	N/A	0%	N/A	0%	N/A	0.00%
	Reflected by external buildings		0%		0%		13.43%		4.33%
	Reflected by external blinds		0%		0%		0%		0.00%
	Transmitted & reflected by trees		0%		10.25%		0%		0.00%
	Total		0%		10.25%		13.43%		4.33%
TOTAL	(Direct + External Reflected)		34.12%		18.75%		30.99%		42.32%

(*) as percentage of obstructed area to the total window area

(**) SF: vertical sky factor, as fraction of the whole sky. The total area of a Waldram diagram represents half a sky dome. The SF estimates for reflected light is calculated as the equivalent SF value of direct light.

The second sets of horizontal Waldram diagram plotting, which is from the interior at position P3 are presented in figure 5.10-5.13. Windows on both side walls are plotted in the diagrams.

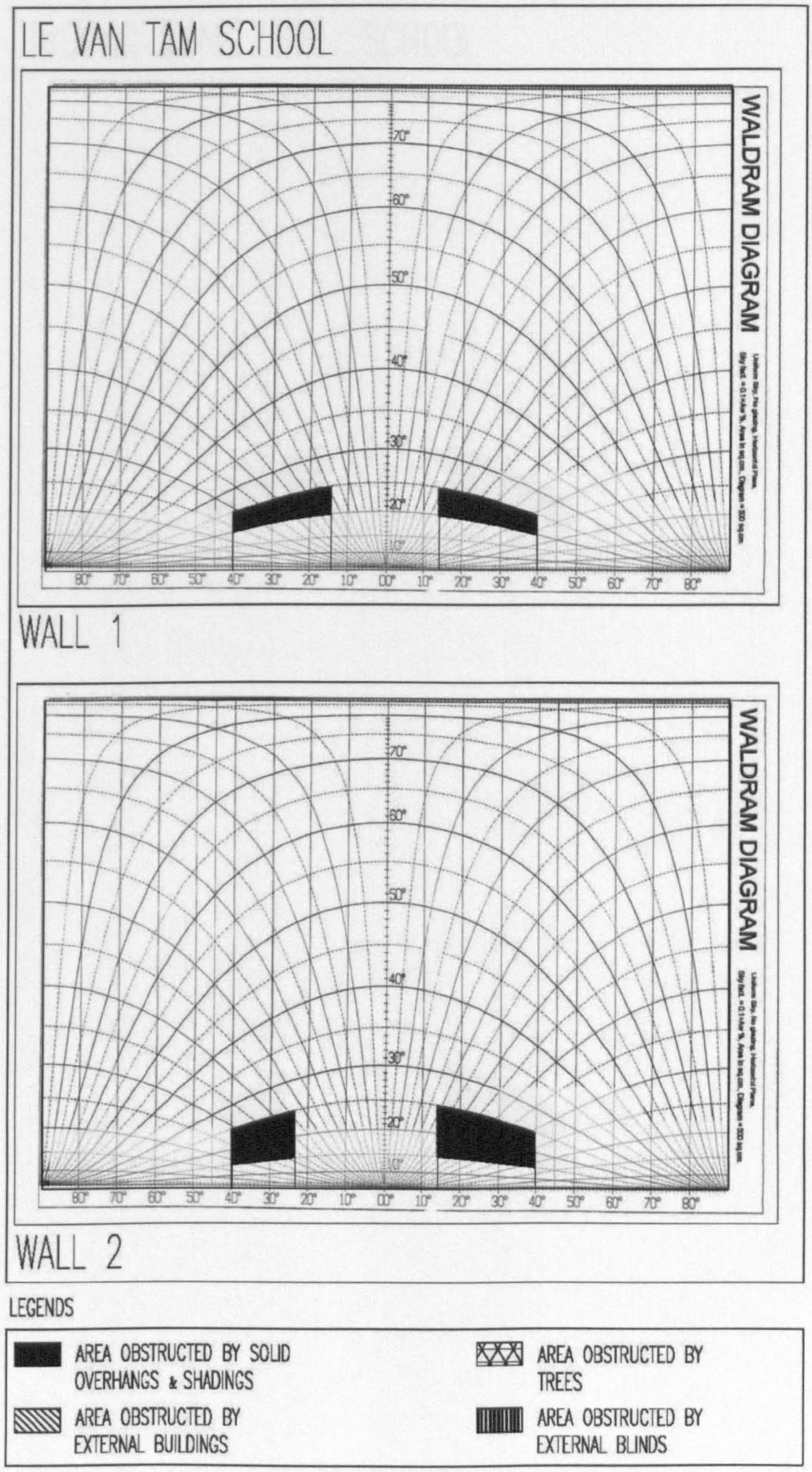


Figure 5.10 Plotting of window areas and obstructions of Le Van Tam School on Waldram diagram from reference point P3.

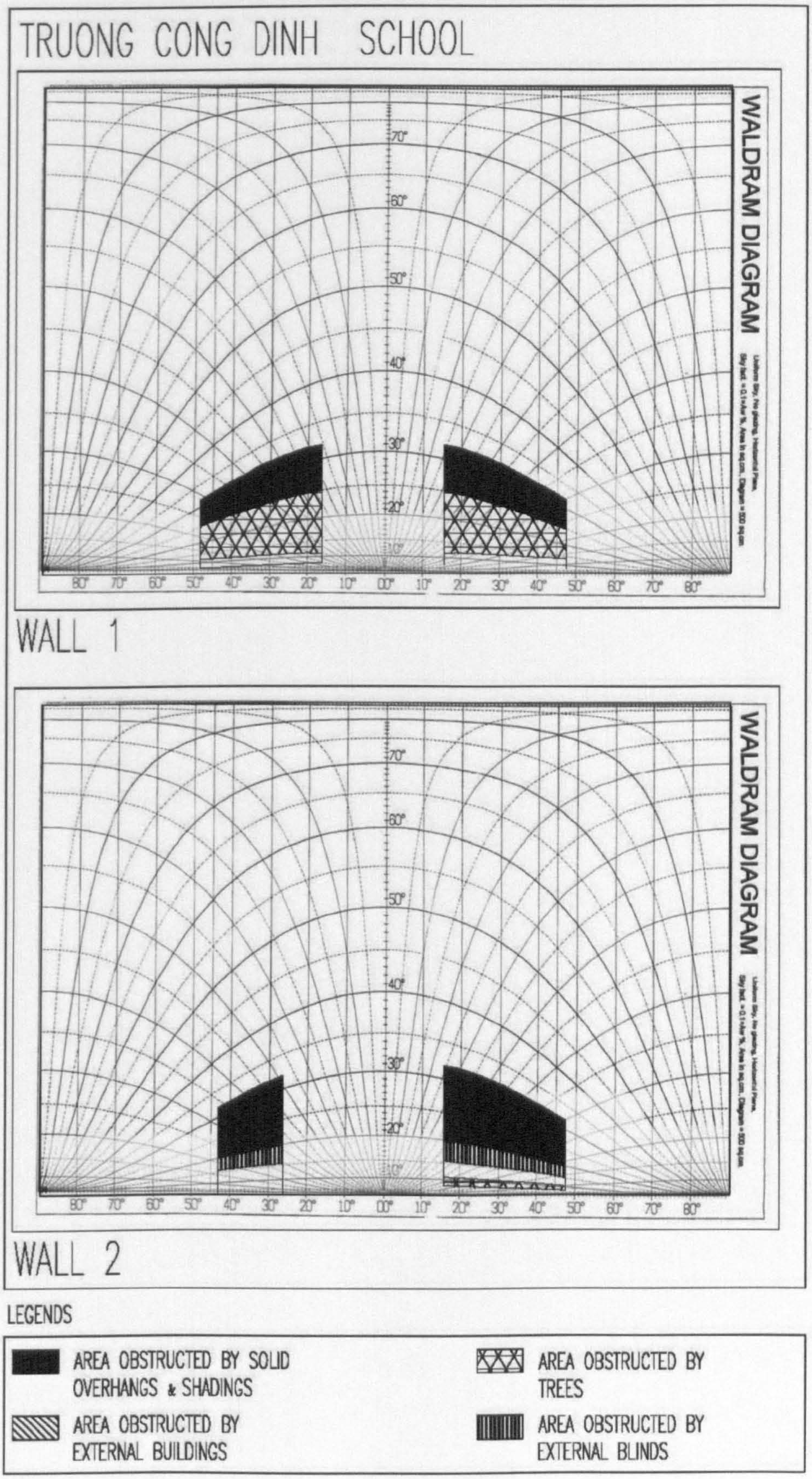


Figure 5.11 Plotting of window areas and obstructions of Truong Cong Dinh School on Waldram diagram from reference point P3.

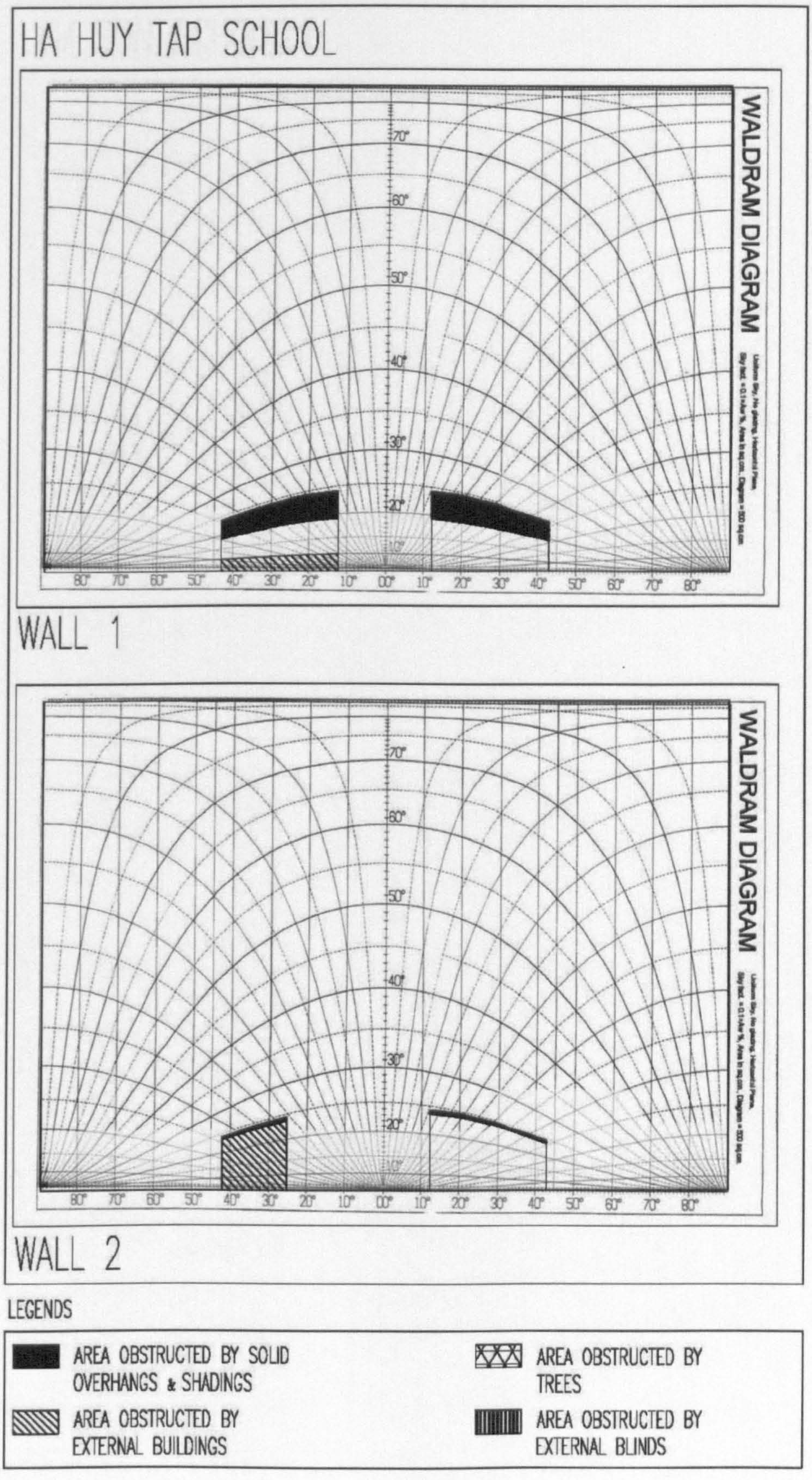


Figure 5.12 Plotting of window areas and obstructions of Ha Huy Tap School on Waldram diagram from reference point P3.

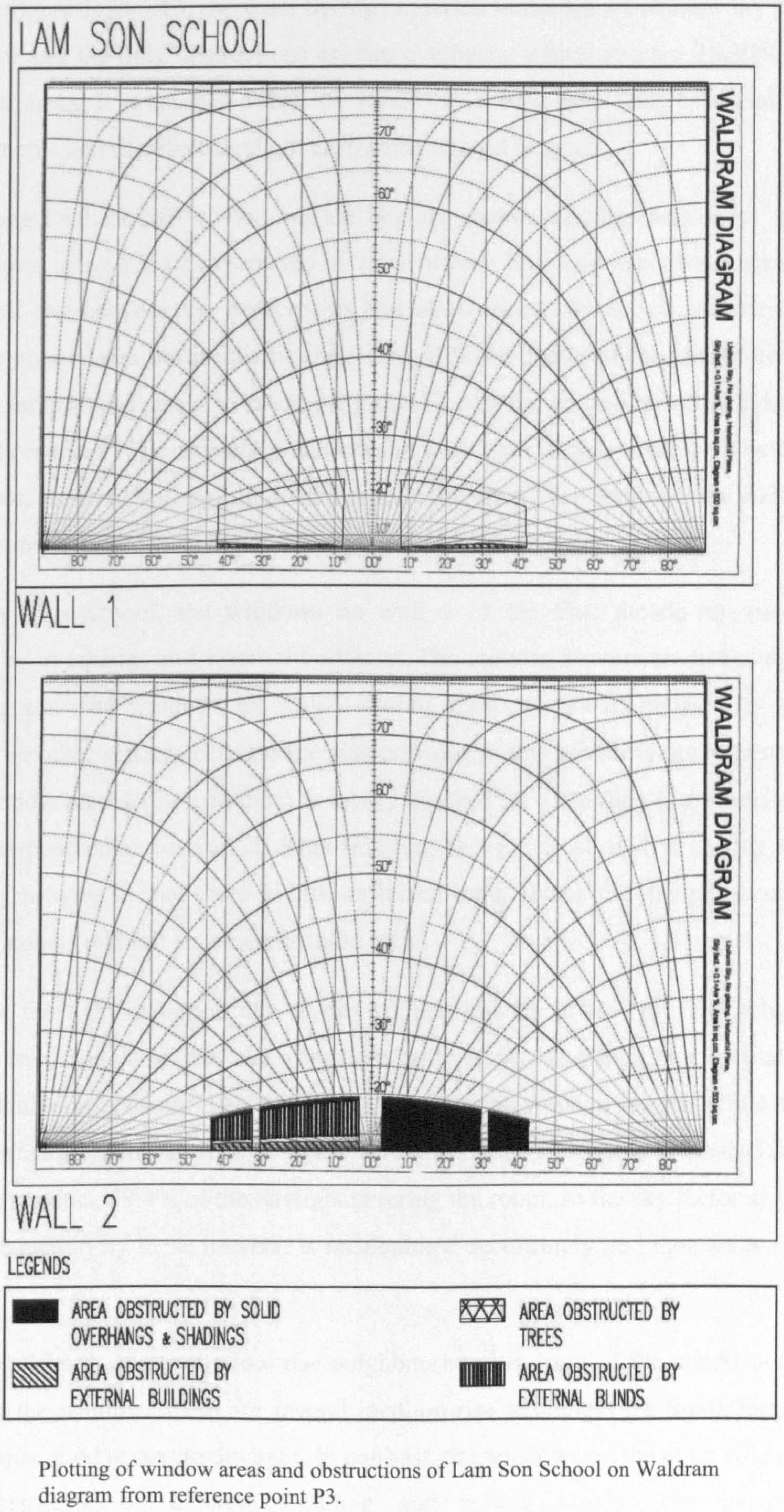


Figure 5.13 Plotting of window areas and obstructions of Lam Son School on Waldram diagram from reference point P3.

As seen in figure 5.10-5.13, there are no high external buildings around the Le Van Tam School and the only obstructions are the overhangs which obscure 20-30% of the window areas. It is estimated that the windows on both side walls have similar sky components and therefore daylight uniformity should be good.

Truong Cong Dinh School's windows are heavily obstructed from both sides: the main windows in wall 1 are obstructed by trees at both high and low level; there is only a small gap between the tree crowns that allow direct sky access. As per the assumption above, area obstructed by trees is at 40% sky factor of the unobstructed area of the same size. Trees also shade the ground hence the ground reflected light is significantly reduced. The secondary windows in wall 2 are heavily obstructed by the side corridor, external rolling blinds and trees. Therefore, the windows on wall 1 provide the main access to daylight, although most of it is reflected light.

In Ha Huy Tap School, the windows on wall 1 of the East facade are partly obstructed by overhangs and external buildings. The wooden louvers are not plotted in this diagram. The windows on wall 2 facing West are not as blocked by the corridor as in other schools because the side corridor in this school is quite narrow. But the window area 4 (the entrance) is totally blocked by a building (i.e. staircase) which is perpendicular to wall 2. This building is very close and it shades the surrounding heavily so that there is little reflected light. Hence the daylight access from the windows on both sides seems to be equal.

To estimate the light reduction due to the wooden louvers in Ha Huy Tap school classroom, two models of this classroom are built in *Dialux* which is a specialist lighting calculation software. One model is built with the wooden louvers while the other one excludes them (as seen in figure 5.14 and figure 5.15). It is estimated that these louvers reduce 59.4% of the daylight entering the room, so the sky factor at P3, including reduction by these louvers, is recalculated accordingly and then shown in table 5.5.

In Lam Son School, due to the low rise neighbourhood in front of the windows (to the sides of the windows there are several medium rise buildings) the South facade seems to enjoy good access to daylight. In contrast, the windows on the other side are heavily obstructed by external building and rolling blinds. The external neighbourhood is all hard landscape (i.e. buildings, concrete paved ground), thus ground reflected component is considerable.

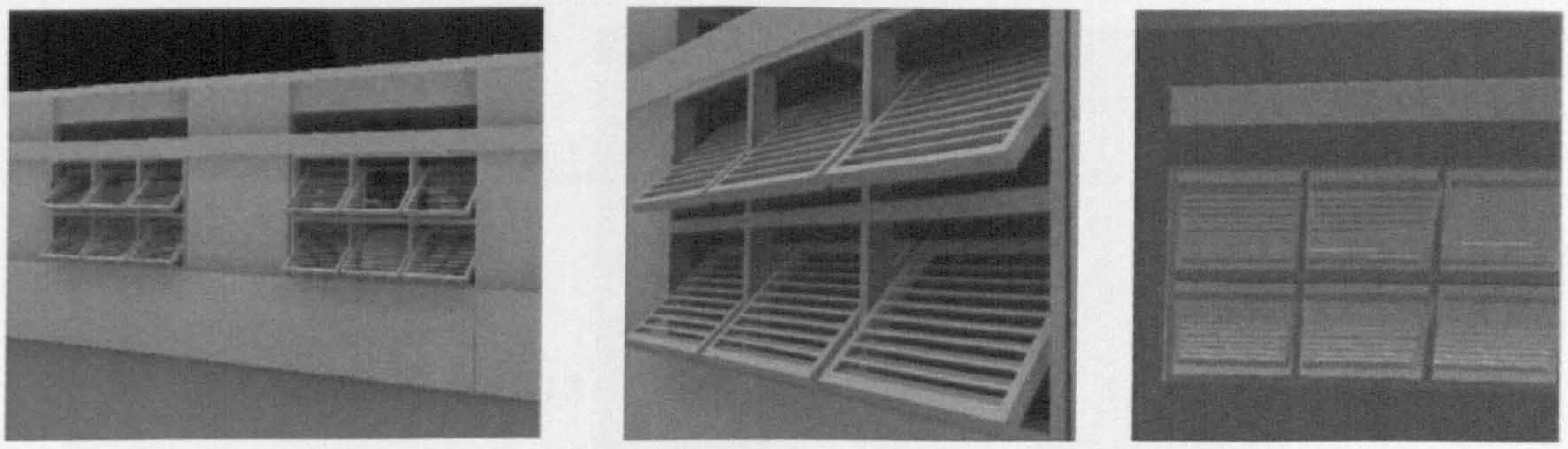
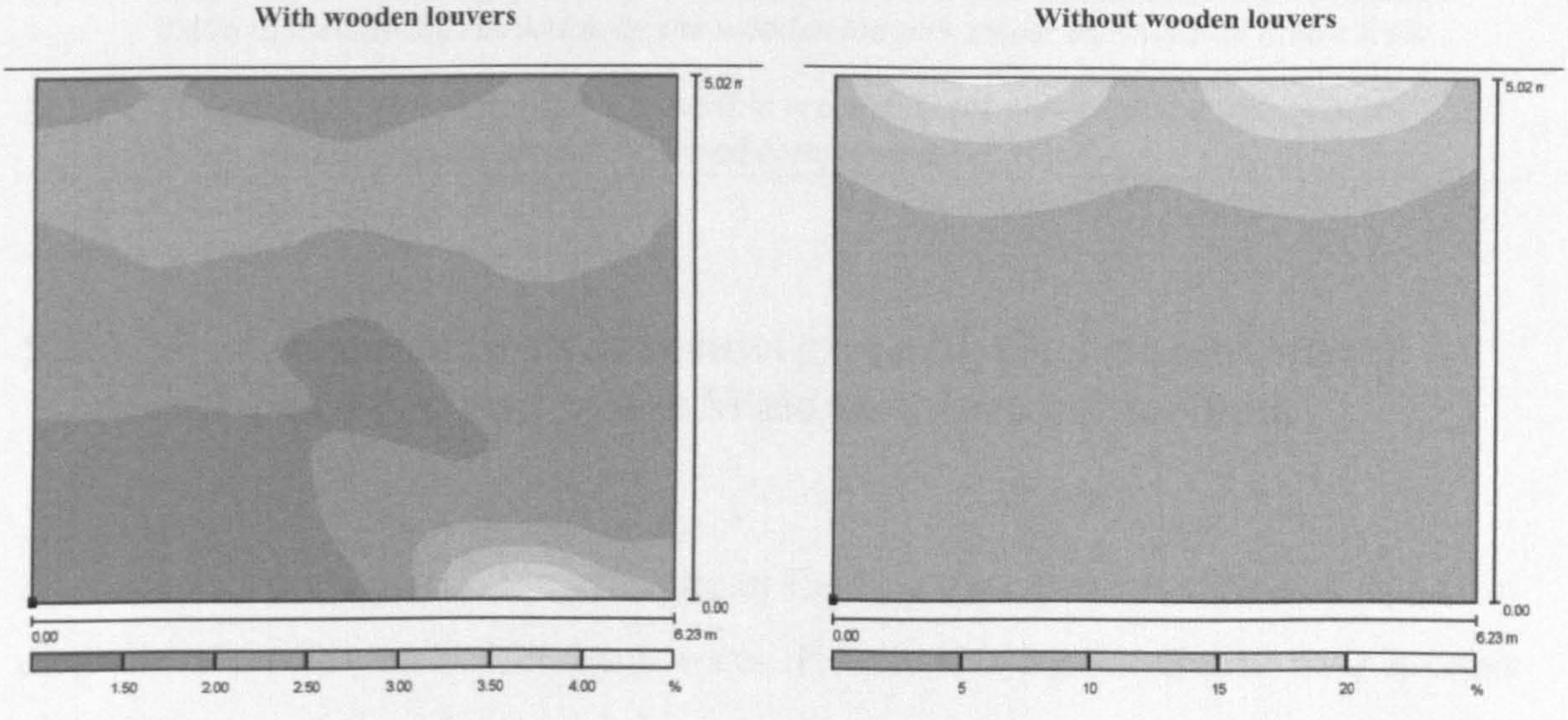


Figure 5.14 Computerized *Dialux* model of Ha Huy Tap Classroom



$\overline{D}_{av}$ [%]	$\overline{D}_{min}$[%]	$\overline{D}_{max}$[%]	$\overline{D}_{av}$[%]	$\overline{D}_{min}$[%]	$\overline{D}_{max}$[%]
1.82	1.24	4.16	4.48	2.23	21

Figure 5.15 Estimating the daylight reduction by the wooden louver windows in Ha Huy Tap classroom by *Dialux* simulation. The picture on the left is the daylight factor greyscale plotting with the wooden louvers installed. The picture on the right is plotted without the wooden louvers.

Table 5.5 Estimates of sky factors, as seen horizontally from point P3 at student's desk top, plotted in Waldram diagram.

Descriptions	Position	School			
		LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON
DIRECT AND EXTERNAL REFLECTED COMPONENTS	WINDOW 1	0.70%	0.55%	0.76%	1.12%
	WINDOW 2	0.70%	0.55%	0.56%	1.13%
	Windows on wall 1	***1.40%***	***1.11%***	***1.32%***	***2.25%***
	WINDOW 3	0.39%	0.36%	1.13%	0.34%
	WINDOW 4	0.25%	0.31%	0.11%	0.33%
	Windows on wall 2	***0.64%***	***0.67%***	***1.24%***	***0.67%***
	TOTAL	**2.04%**	**1.78%**	**1.04%** (*)	**2.92%**

(*): *Originally the total Sky factor of Ha Huy tap School is 2.57%, and then it is multiplied 0.406 to include the reduction by the wooden louvers, as per estimates in figure 5.15.*

Note: *The sky factor [%] presented in this table represents the sum contributions of both direct and equivalent external reflected components.*

5.3.3. Comparisons of results given by the Danhiluc chart method and by the Waldram diagram method.

As discussed in chapter 3, the principle of the Danhiluc chart method and Waldram diagram method is similar in many ways. Hence, it is meaningful to have a cross review between the results given by each method.

In the case of Le Van Tam School, because there is no external obstruction, the results provided by the Waldram diagram method (see table 5.5) seem to be concurrent with the estimate from the Danhiluc chart method (see table 5.3). Both are calculated under uniform sky model. In other cases, where there are considerable external obstructions, the estimates given by the Waldram diagram method are significantly lower than what is estimated by the Danhiluc chart method.

Particularly, in the case of Truong Cong Dinh School, the impact of trees is plotted in the Waldram diagram, but they are excluded in the Danhiluc chart. As in table 5.5, the equivalent sky factor of Truong Cong Dinh school classroom is 1.78%, if the trees are excluded from the Waldram diagram plotting and the area obscured by trees (i.e. approximately 1.9% sky factor, see table E.5 of appendix E) are considered as an unobstructed sky area which provides full direct sky access, the contributions of transmitted and reflected light are taken out (i.e. 0.76% equivalent sky factor, see table E.7 of appendix E) ; the total equivalent sky factor *SF* from P3 is recalculated as:

$$SF_{TRUONG\ CONG\ DINH} = 1.78\% + 1.9\% - 0.76\% = 2.92\%$$

In contrast to the results given by the Danhiluc chart method, the results given by the Waldram diagram method indicate that three of the surveyed classrooms meet the minimum 2% daylight factor recommendation.

The Waldram diagram method seems to be more accurate, since it is able to plot obstructions and estimate their impact directly from the graph. In the Danhiluc chart on the other hand the impact of obstructions is indirectly estimated. First, the obstructing indices Z_1 and Z_2, which are dependent on external buildings geometry, need to be calculated. Following this, these indices have to be used to find the obstruction index *R,* which is obtained from reference table J.8 of appendix J. Each value of these indices represents a range of conditions rather than an exact condition. Therefore, the error in calculation is probably high.

5.4. The site measurements

This part presents data of the real conditions recorded by three photocells installed in the classrooms. These measurements were conducted during two site visits. The first site visit was in February-March 2007 (the Dry season) and the second visit was in September-October 2008 (the Wet season). Because of the solar geometry (Equinox), the sun path diagram during both visits is quite similar (as shown in figure 5.16). Therefore, daylight availability differences are due to sky conditions, particularly the cloud conditions.

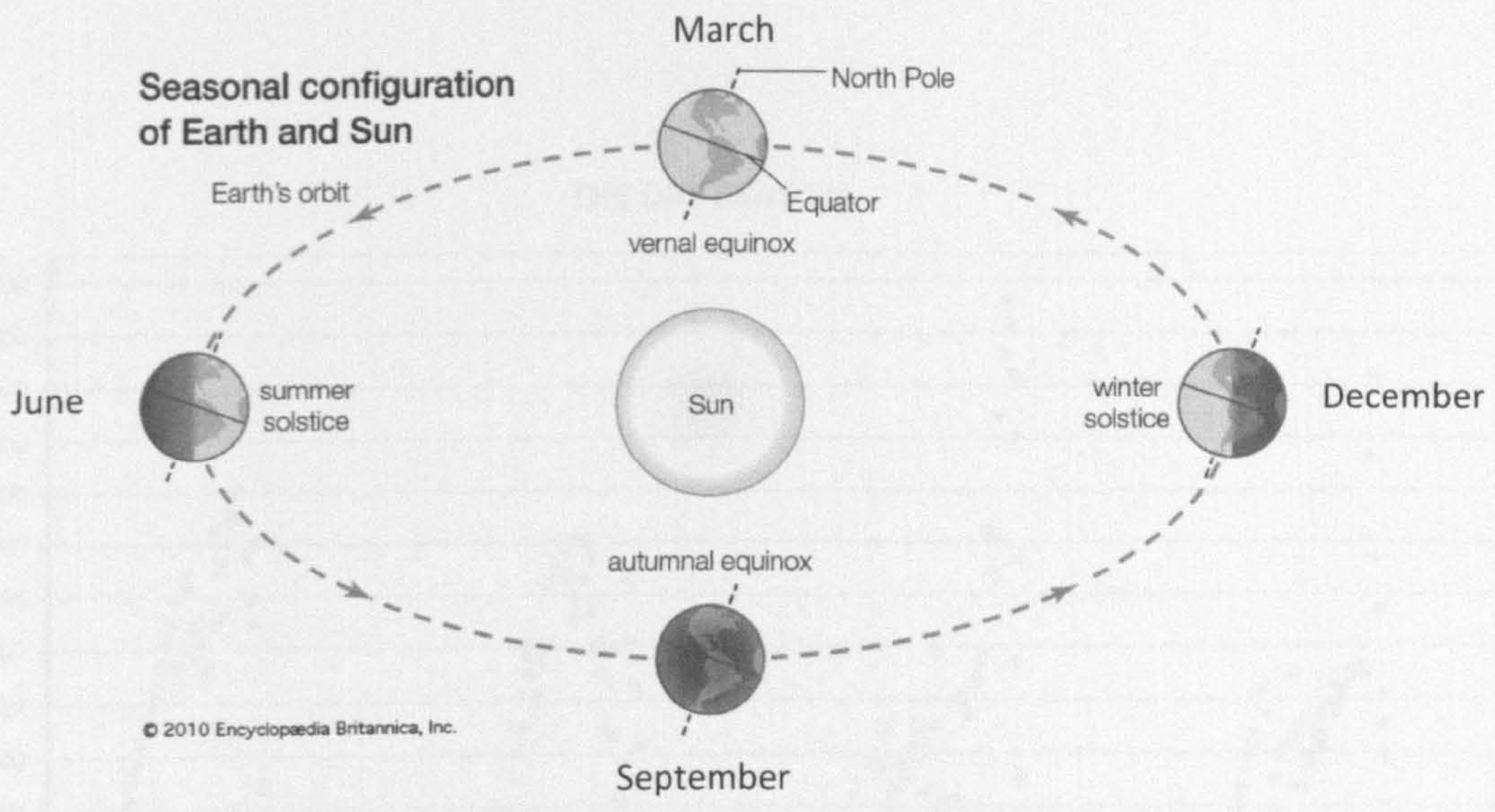


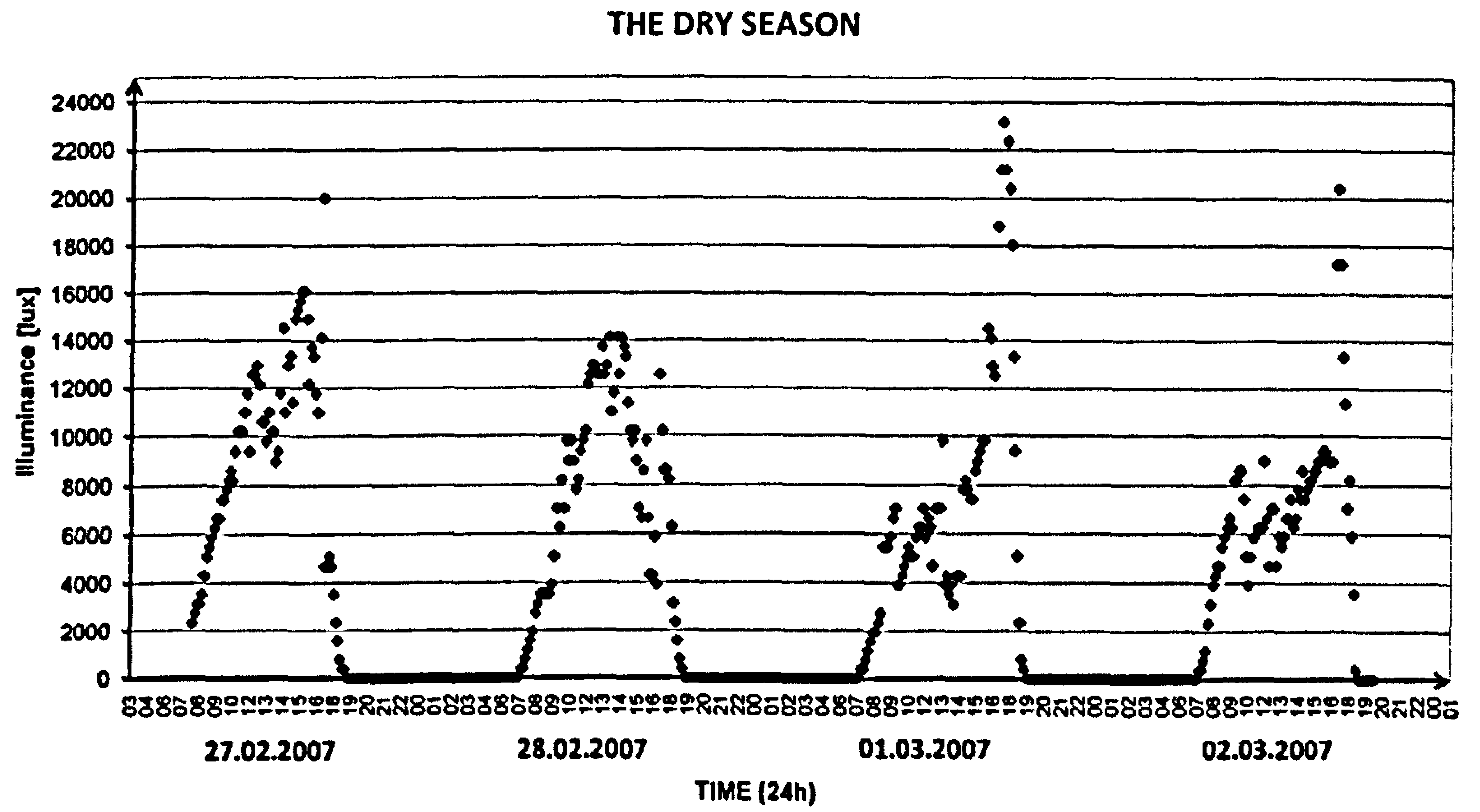
Figure 5.16 Seasonal configuration of Earth and the Sun. (Encyclopædia Britannica Online, 2010)

Three photocells which were used to monitor the lighting conditions were mounted at position P1, P2, and P3, in the same positions as illustrated in figure 5.7.

- The photocells mounted at position P3 collected data on the interior horizontal illuminance *Eih*, recorded during the Dry season (*Eih-D*) and the Wet season (*Eih-W*).
- The photocell mounted at position P2 recorded the interior vertical illuminance *Eiv* measured in the Dry season (*Eiv)* and in the Wet season (*Eiv-W)*.
- The last photocell mounted vertically at position P1 looking outward, it recorded the exterior vertical illuminance *Eev* measured at the centre of the windows during both seasons (i.e. *Eev-D* in the Dry season and *Eev-W* in the Wet season). Only the readings recorded during class hours (from 7.00 am to 5.30 pm) are plotted out.

5.4.1. The Exterior Vertical Illuminance *Eev*

The site recorded data of the *External vertical illuminance* (*Eev,* in lux) of each individual school is plotted in figure 5.17-5.20. The results suggest that the availability of *Eev* is subject to the time of the day, orientation and external obstructions.



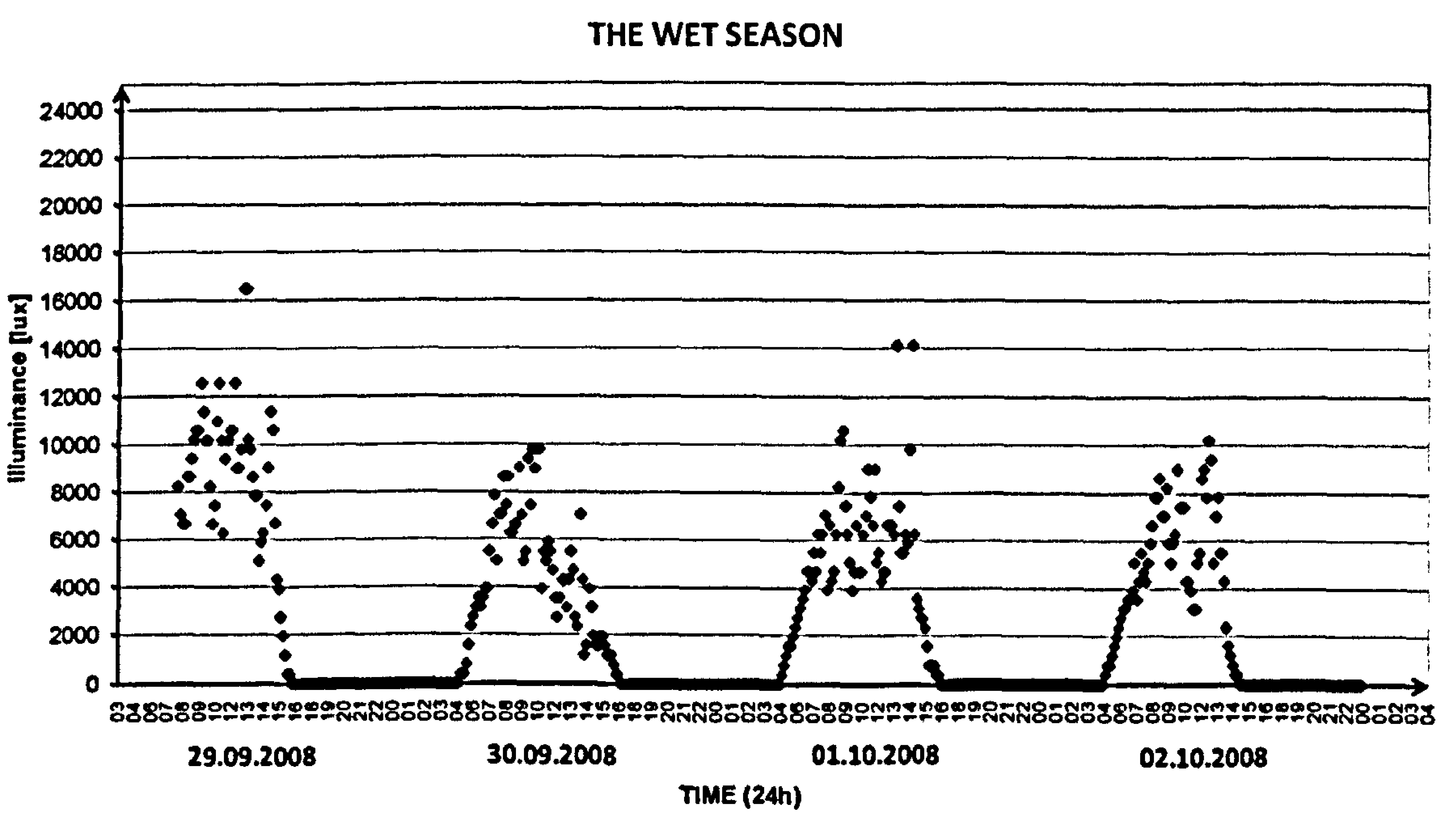
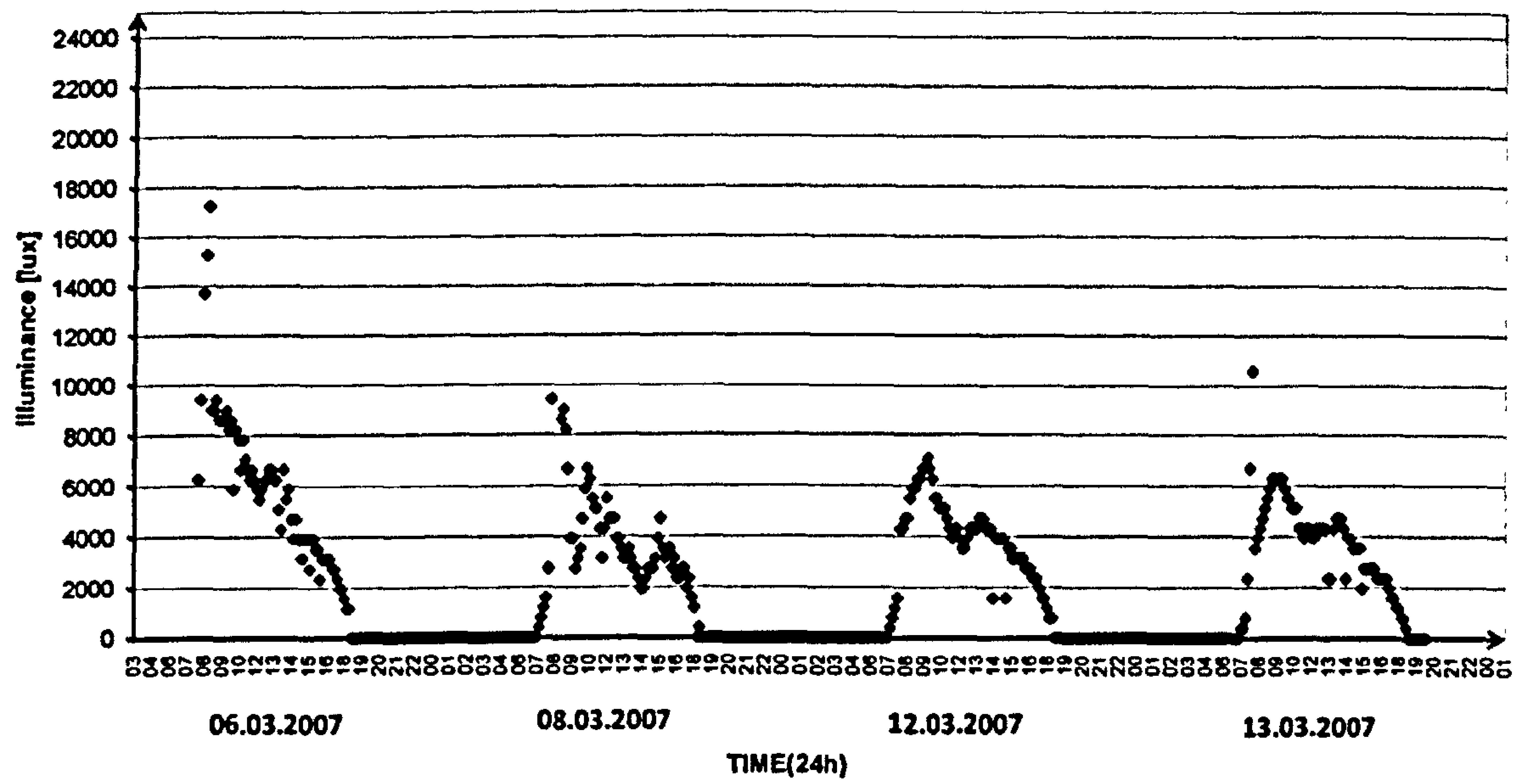


Figure 5.17 Le Van Tam School's Exterior vertical illuminance (*Eev*) measured onsite.

THE DRY SEASON



THE WET SEASON

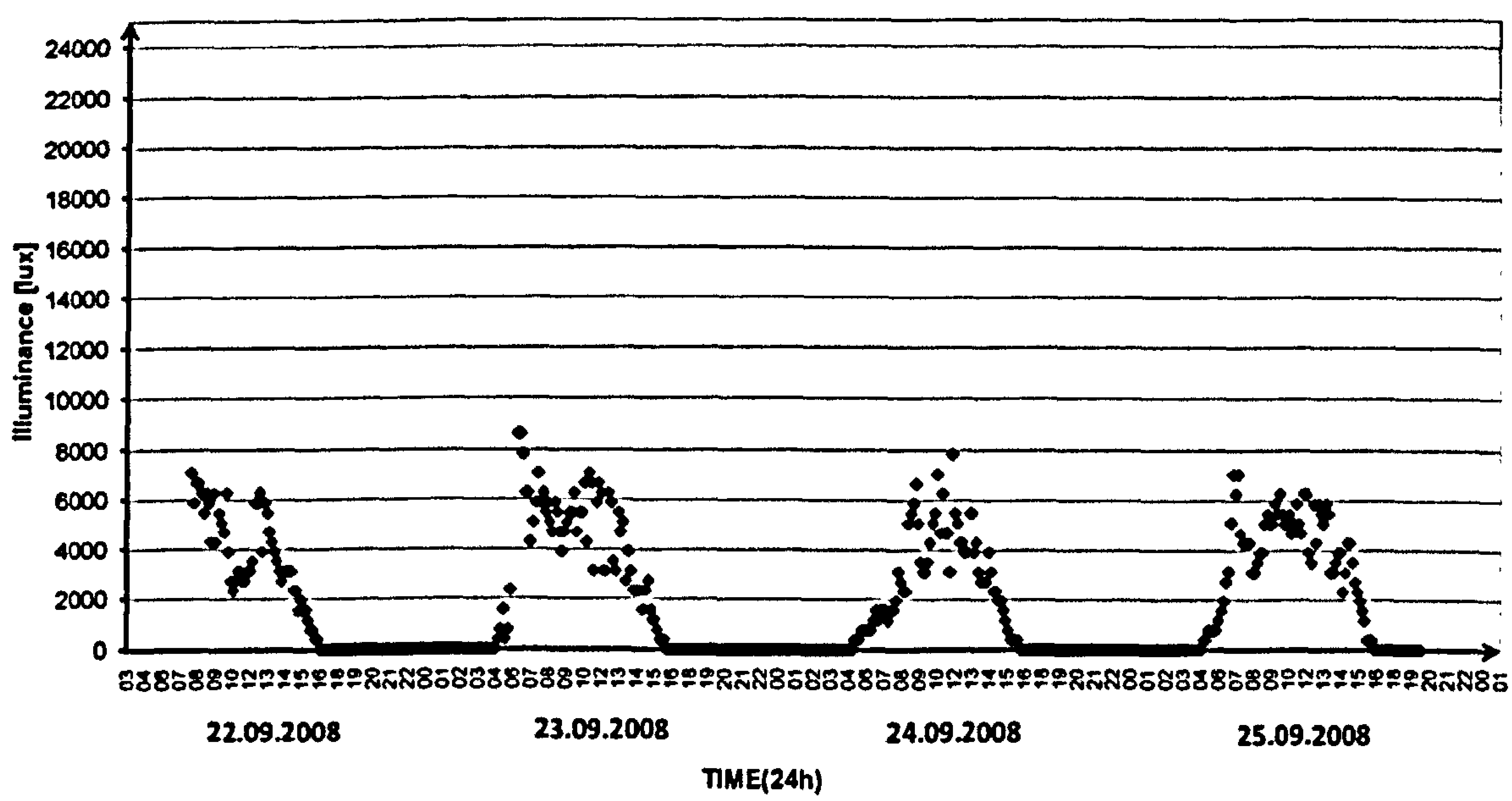


Figure 5.18 Truong Cong Dinh School's Exterior vertical illuminance (*Eev*) measured onsite.

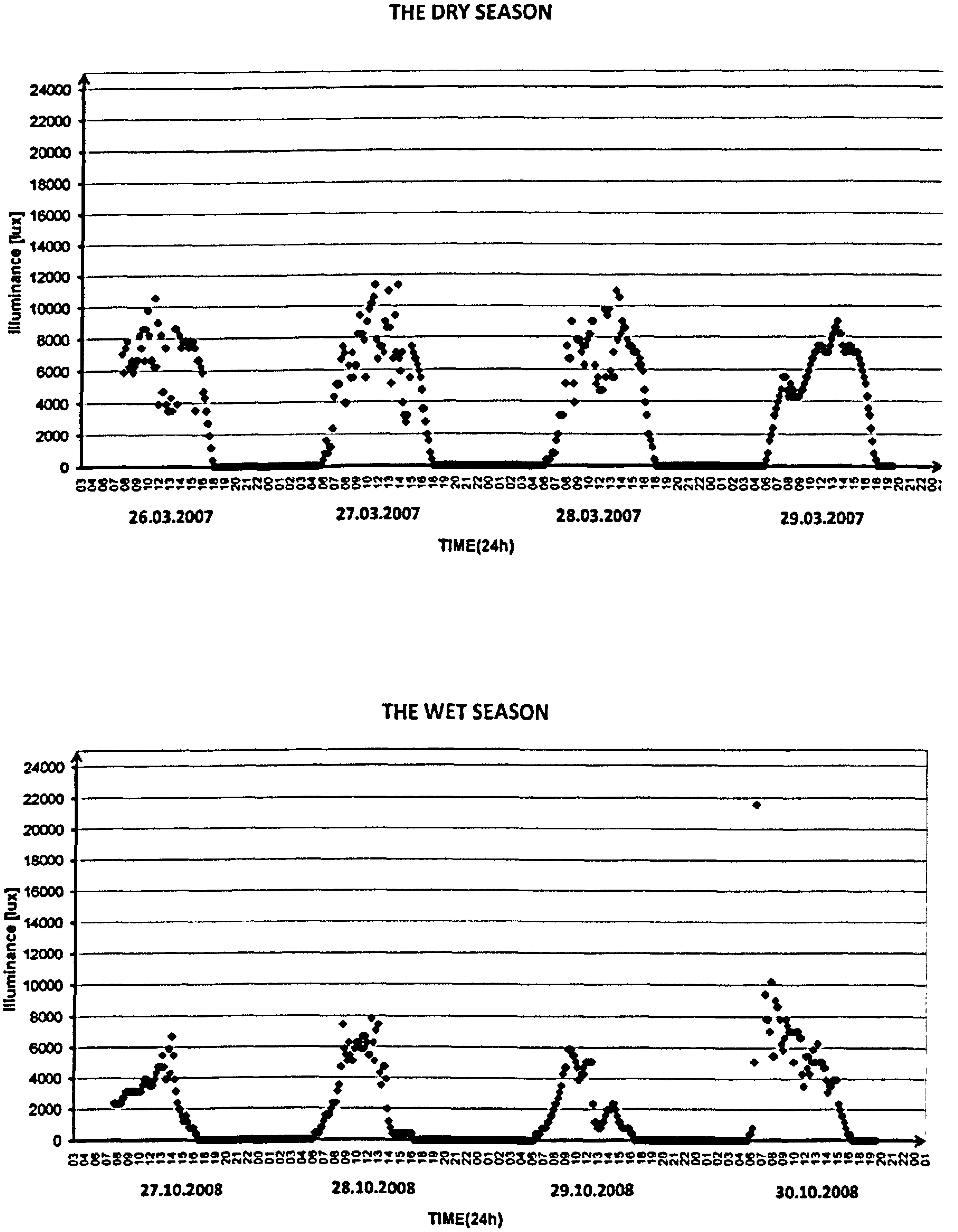
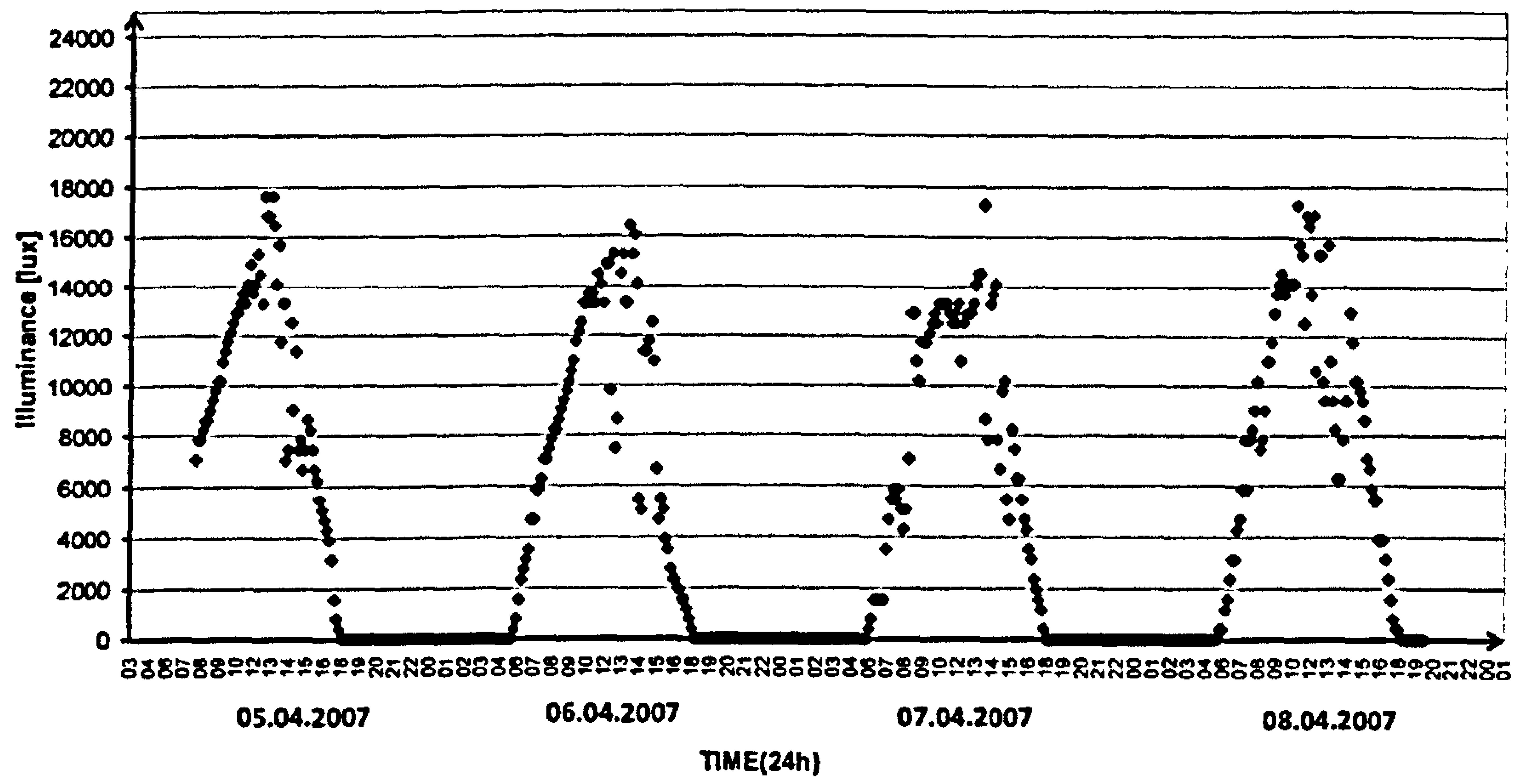


Figure 5.19 Ha Huy Tap School's Exterior vertical illuminance (*Eev*) measured onsite.

THE DRY SEASON



THE WET SEASON

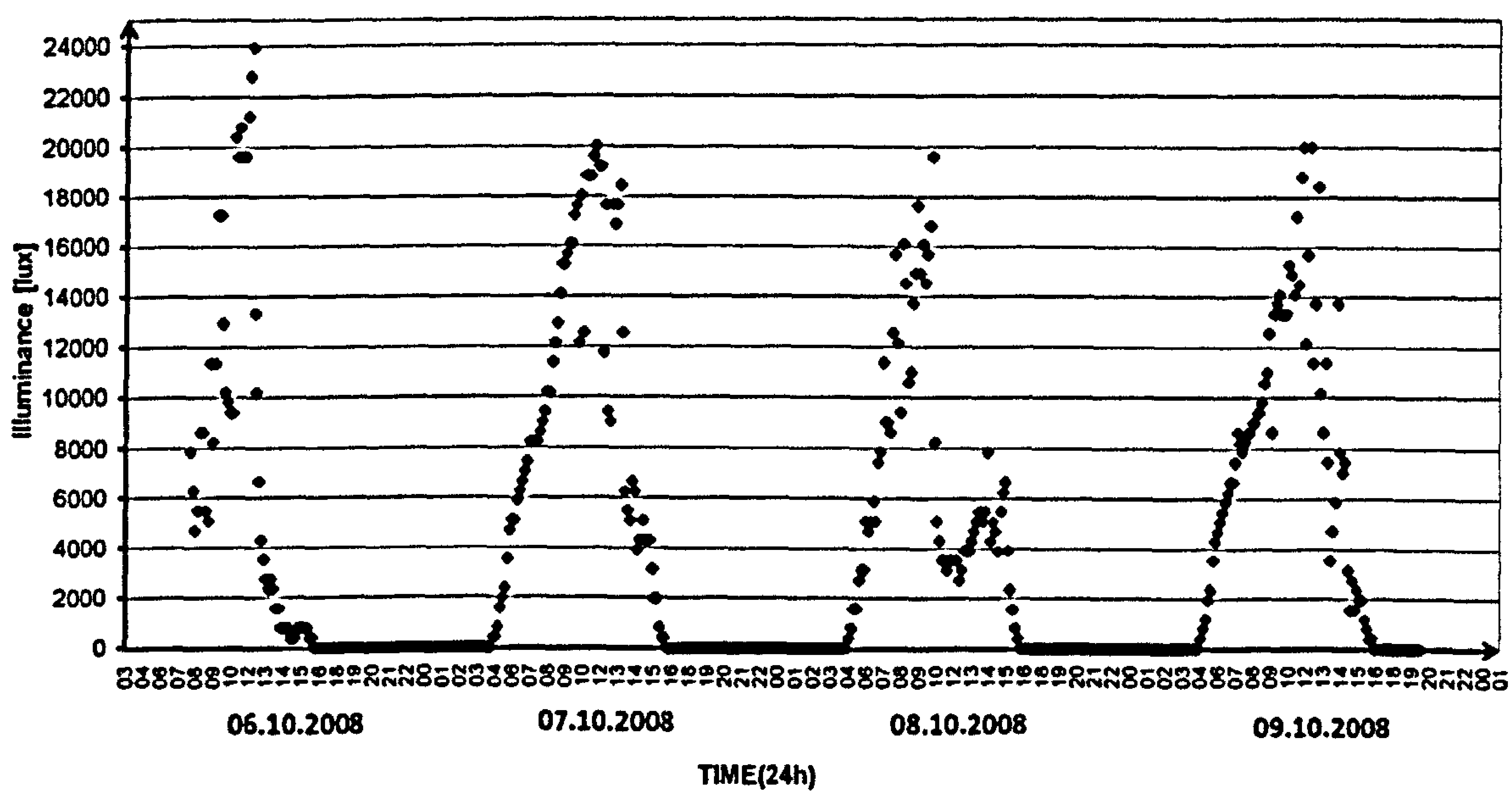


Figure 5.20 Lam Son School's Exterior vertical illuminance (*Eev*) measured onsite.

Figure 5.21 - 5.28 show the typical distributions of *Eev* in a season. In these graphs, the readings of four days, recorded at a 10 minute interval continuously from 8h00 to 17h30, are plotted overlapping in the same graph. (the readings from 7h00 to 8h00 are taken out due to a lot of noises). The noises shown on the readings are caused due to many reasons, for instance due to the students' activities or due to the equipments' low resolution (Brotas, 2004) (see appendix A for further information of the equipment's resolution).

As discussed in chapter 2, HCMC has annually 39% days which have six to nine hours of sunlight. Thus sunlight has a significant impact on the classroom's daylight contribution, especially in the Dry season. Site measurements show that during the class hours, *Eev-D* varies in a very wide range, from 2000 lux to 18 000 lux at peak. In the Wet season, daylight is more diffused. The *Eev-W* is quite stable around 5000 lux and it is distributed more evenly during the day. Although all four surveyed schools are located not too far from each other geographically, it is found that the daily distribution of *Eev-D* and *Eev-W* of each school is different. Perhaps this is the result of sunlight and external obstructions, because the difference is more obvious in the Dry season.

In the Dry season, as seen in the case of Le Van Tam School where the main facade faces West, the distribution graph forms an asymmetric parabolic curve with its peak at 16 000 lux, between 14h00 – 15h00 (see figure 5.21 and figure 5.22).

For East facing facades (i.e. Truong Cong Dinh and Ha Huy Tap), the distribution graphs of *Eev-D* also forms a parabolic curve reaching its peak at 16 000 lux around 8h00 – 9h00 after which the *Eev-D* declines slowly (see figure 5.23-5.26). In the case of Ha Huy Tap school, the distribution seems more even, due to the impact of dense neighbouring buildings partly blocking the direct sunlight (see figure 5.25 and figure 5.26).

For the South facing facade of Lam Son School, the distribution graph forms a symmetrical parabolic curve with its peak at noon. The daylight availability on this facade is quite high (16 000 lux at peak) and it is distributed more fairly during the day. In the Wet season, the distribution graph on all facades is quite similar. The *Eev-W* varies in a smaller range, maintained around 5000 lux during the day (see figure 5.27 and figure 5.28).

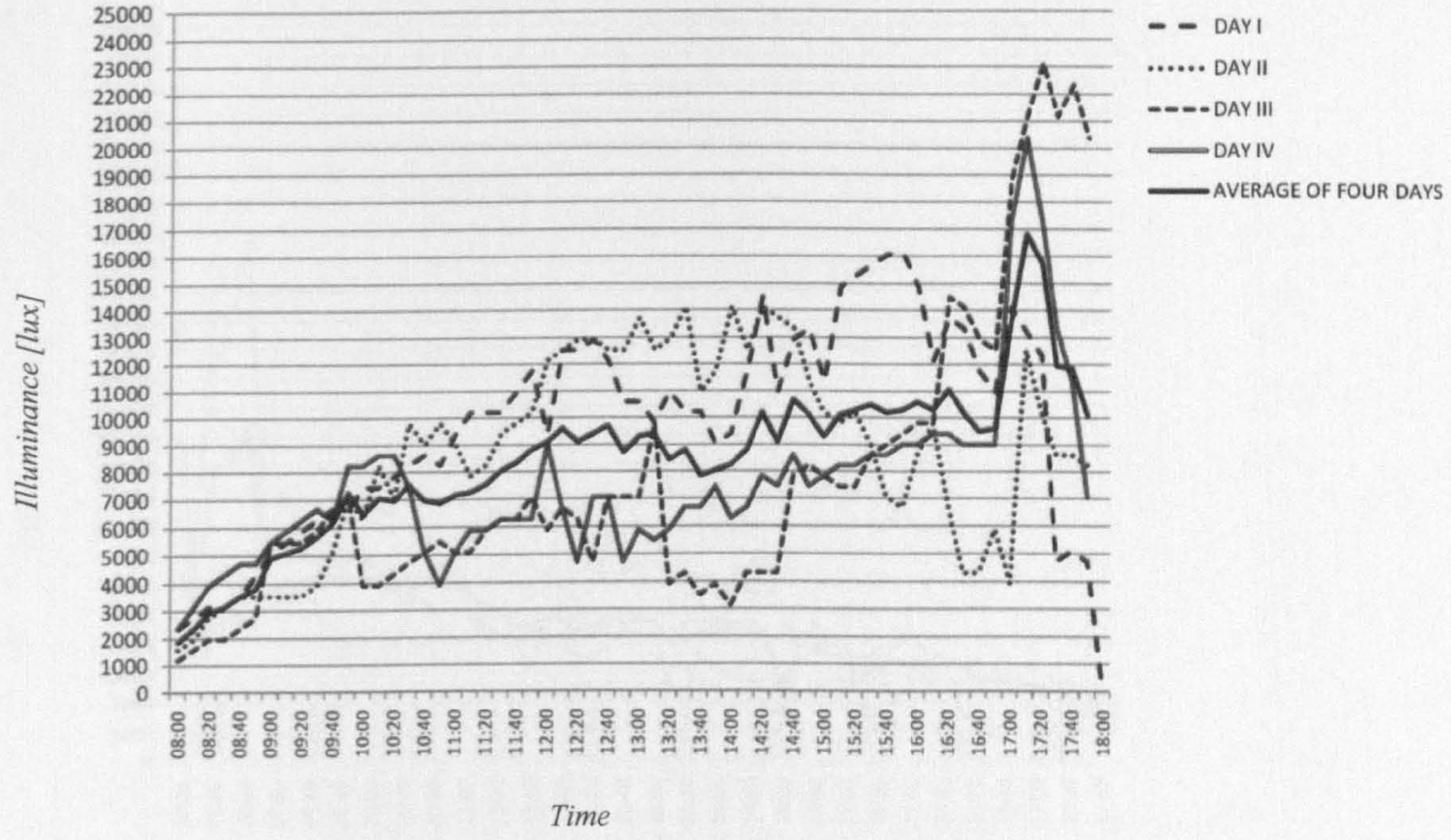


Figure 5.21 Daily distribution of *Eev-D* of Le Van Tam School, readings of four days recorded in February 2007 are plotted in the graph.

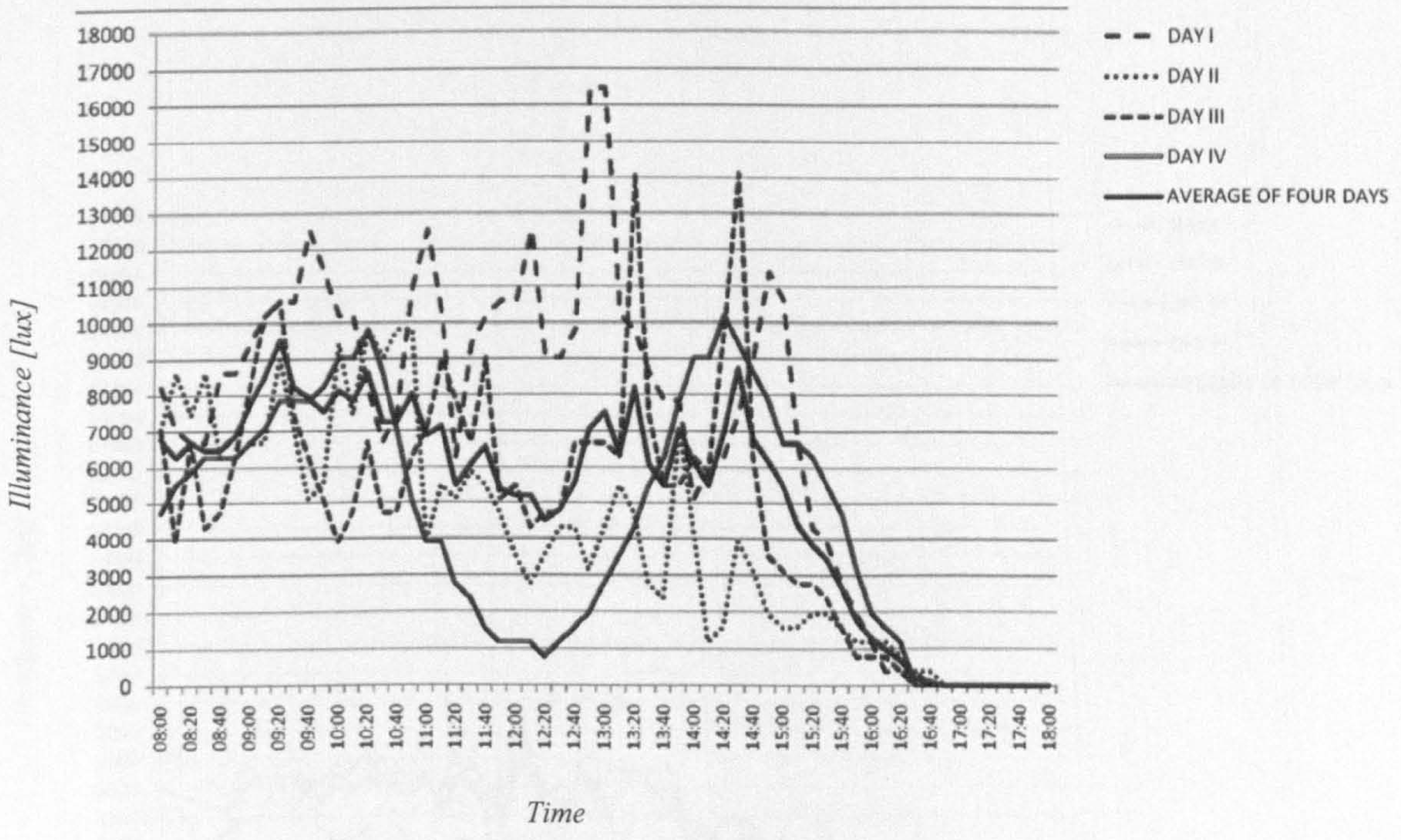


Figure 5.22 Daily distribution of *Eev-W* of Le Van Tam School, readings of four days recorded in October 2008 are plotted in the graph.

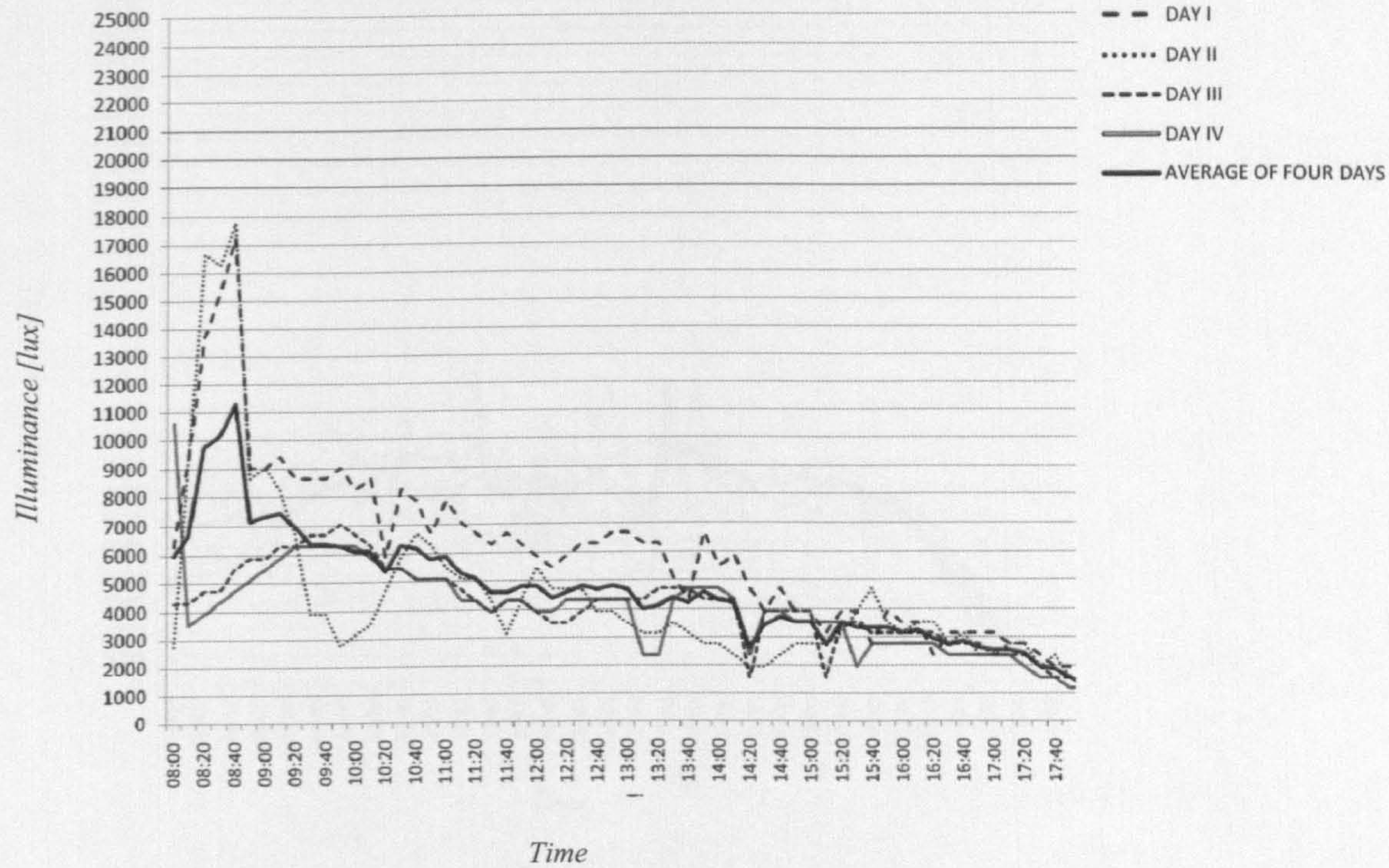


Figure 5.23 Daily distribution of *Eev-D* of Truong Cong Dinh School, readings of four days recorded in March 2007 are plotted in the graph.

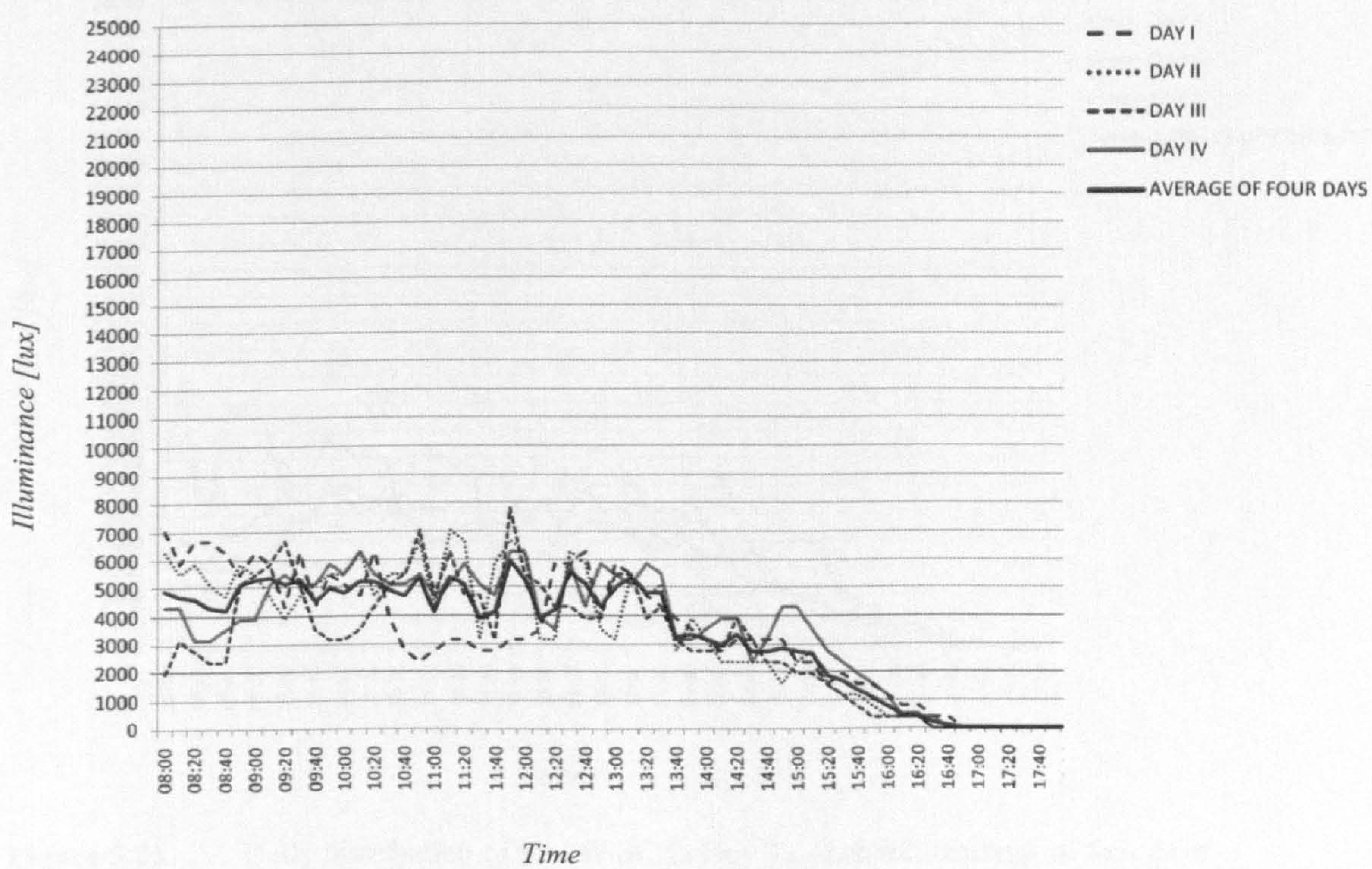


Figure 5.24 Daily distribution of *Eev-W* of Truong Cong Dinh School, readings of four days recorded in September 2008 are plotted in the graph.

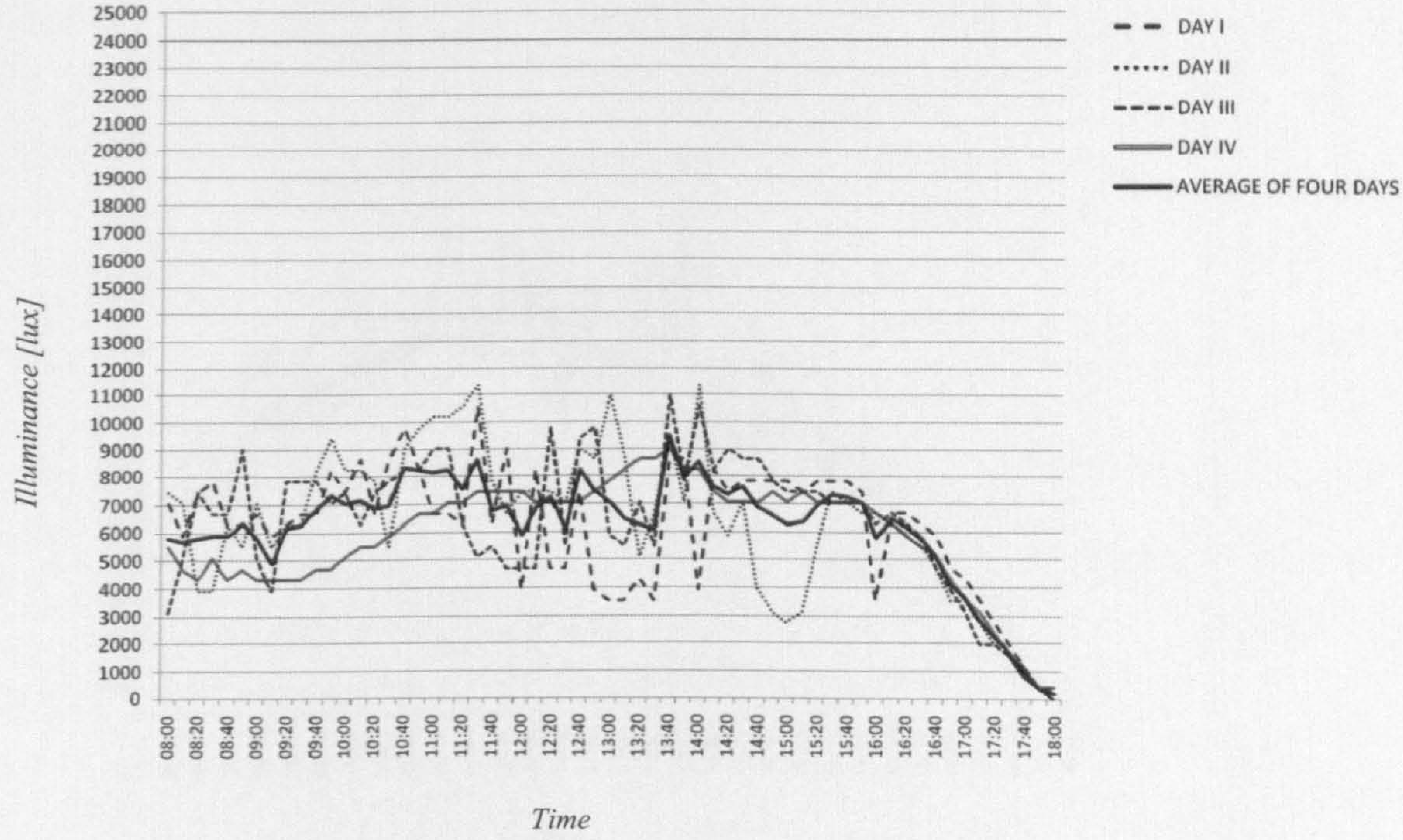


Figure 5.25 Daily distribution of *Eev*-D of Ha Huy Tap School, readings of four days recorded in March 2007 are plotted in the graph

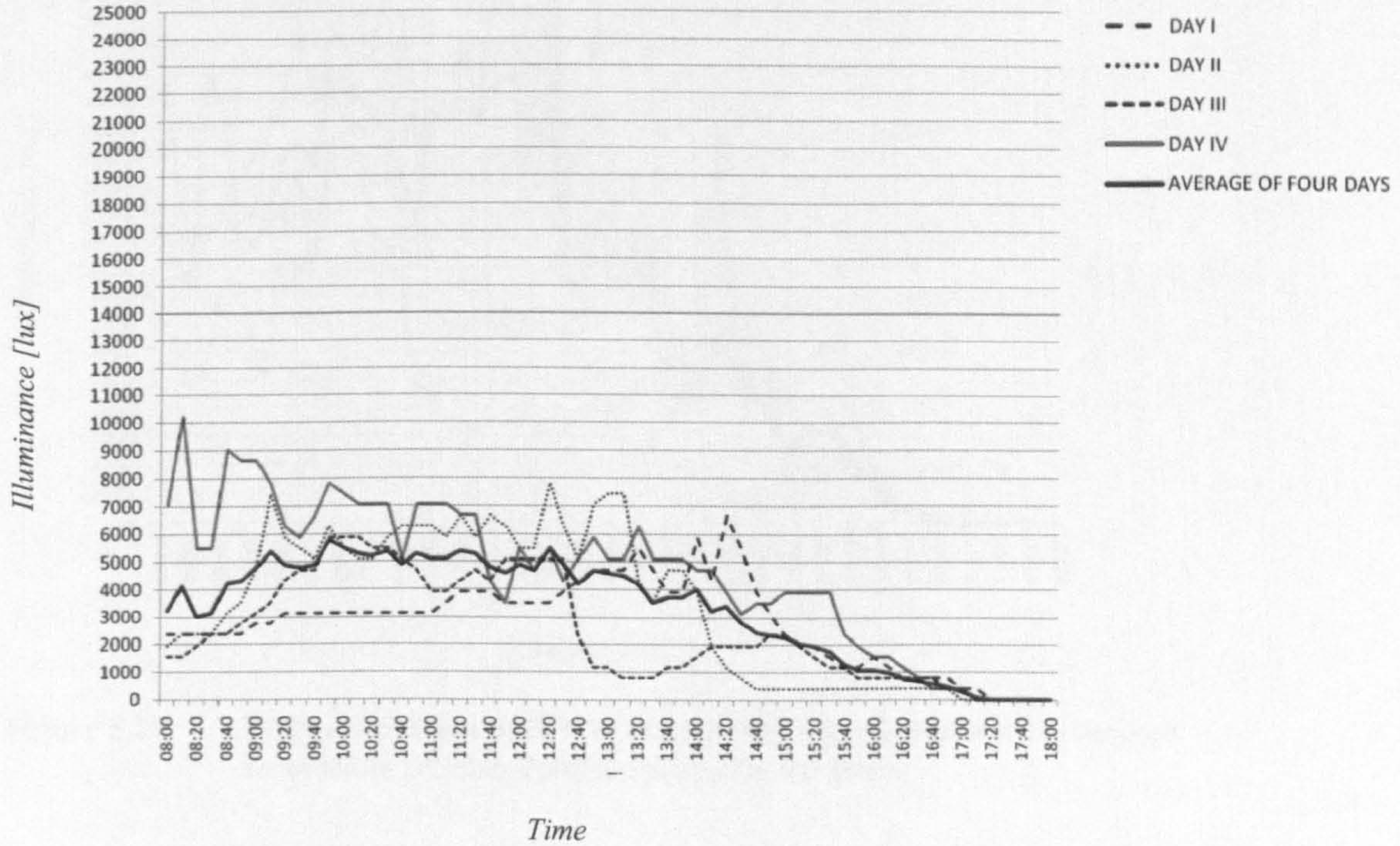


Figure 5.26 Daily distribution of *Eev*-W of Ha Huy Tap School, readings of four days recorded in October 2008 are plotted in the graph

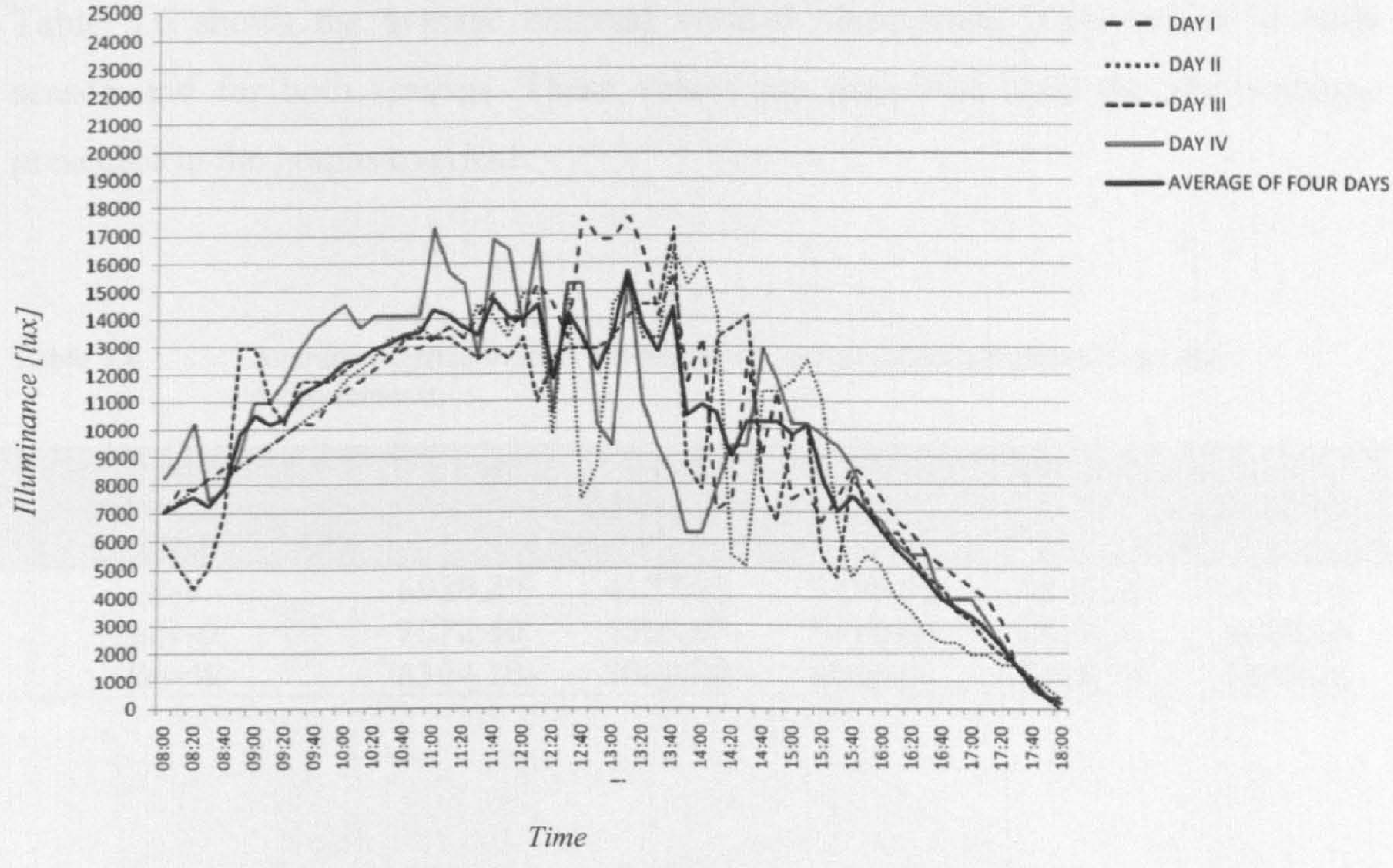


Figure 5.27 Daily distribution of *Eev*-D of Lam Son School, readings of four days recorded in March 2007 are plotted in the graph.

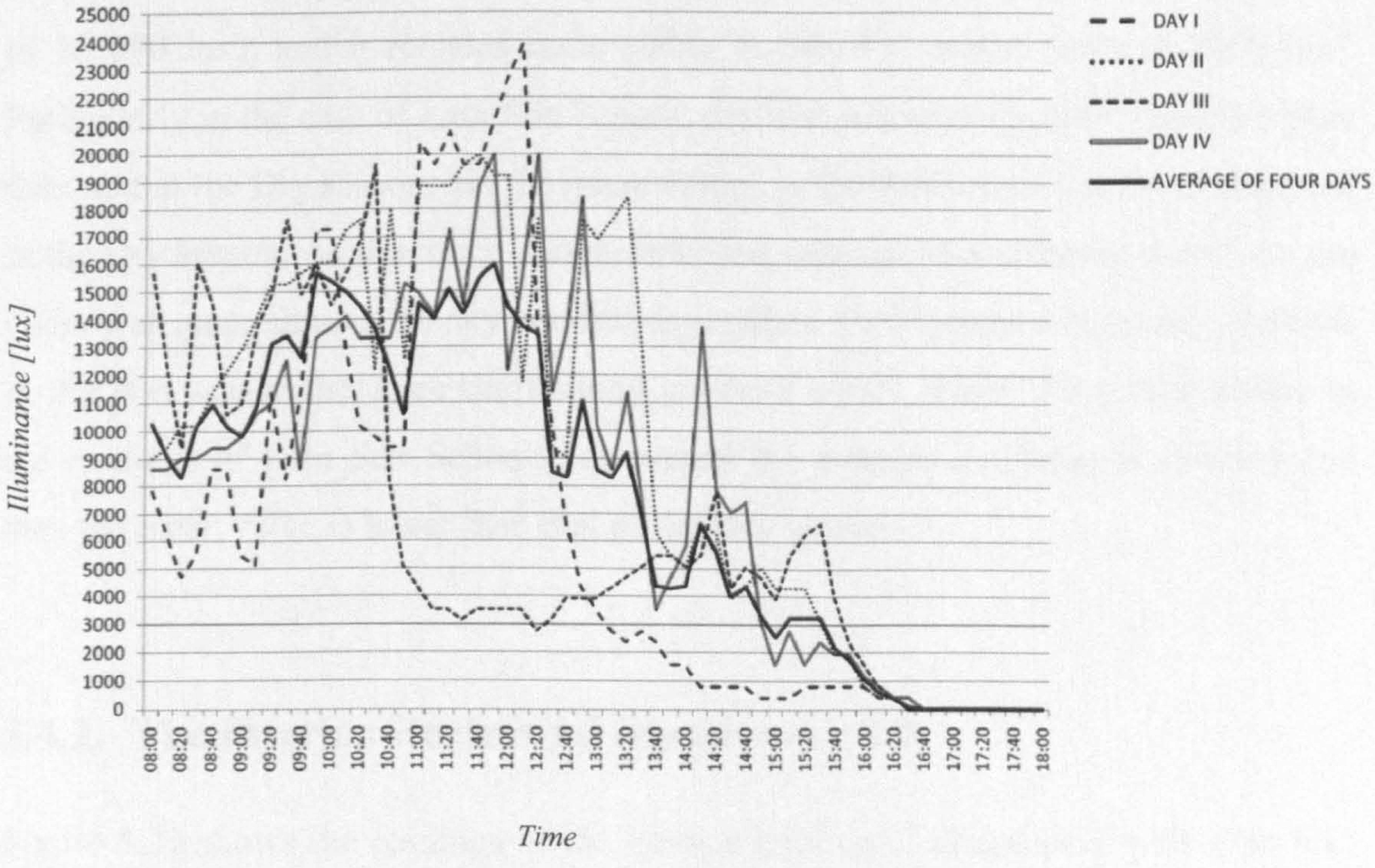


Figure 5.28 Daily distribution of *Eev*-W of Lam Son School, readings of four days recorded in October 2008 are plotted in the graph.

Table 5.6 shows the average external vertical illuminance (*Eev)* values of each season and for both seasons. These values are generated from the site readings presented in the graphs overleaf.

Table 5.6 Average external vertical illuminance *Eev* [lx] values generated from site measurements.

External vertical illuminance [lux]	LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON	ALL SCHOOLS
Eev	6938.29	4137.03	5196.99	9095.50	6341.95
Eev-D	7572.40	4385.87	5810.04	9534.31	6825.66
Eev-W	6304.18	3888.20	4583.94	8656.70	5858.25

Although the average *Eev* values are not very different between both seasons, the daily distribution varies in a very wide range during the Dry season (from 2000 lux to 16 000 lux), and it remains quite stable in the Wet season (around 5000 lux). Particularly in the case of Lam Son School, the Wet season daily peak value is higher than that in the Dry season, but the mean values in the Wet season are lower than that in the Dry season. As described above, since the solar geometry during these two site visits was quite similar the sky conditions regulate the daylight availability. Perhaps in the Wet season there are short sunny intervals which results these high values in the readings of Lam Son School; but overall the average condition is cloudier and thus the mean value is lower than that of the Dry season.

5.4.2. The Interior Horizontal Illuminance *Eih*

Figure 5.29 shows the readings of the Interior horizontal illuminance (*Eih-D,*in lux) recorded in the Dry season and figure 5.30 shows the readings of *Eih-W* recorded in the Wet season. It is noted that the Truong Cong Dinh and the Ha Huy Tap classrooms are only used in the morning shift, so the afternoon readings (after 11h30) are taken out.

Because during the field survey the students are asked to switch the artificial light on at all time, the *Eih* (which is the task illuminance) is taken as the sum of daylight contribution (*EihD*) and artificial light contribution (*EihA*). The *EihA* is measured separately by handheld lux-meter during night visits. By taking out the artificial light contribution the *EihD* contributions can be estimated (shown as red line in the graphs).

The recommendations for task illuminance by the codes are also plotted in a dashed-line. From these graphs, it is possible to estimate the total time when daylight is adequate and *EihD* can be fully used and hence energy can be saved by switching off the artificial light *(EihA)*. The estimated values are shown in table 5.9.

It should be noted that the Vietnamese codes provide different task illuminance values (100 lux, 200 lux, and 300 lux). These codes have been published for different purposes (i.e. lighting design code, school hygienic requirements and energy saving code) at different times (i.e. 1984, 1986 and 2005) and no effort has been made to coordinate all these codes together. This could be attributed to the fact that these codes are prepared by different institutions. Perhaps it would be appropriate to use the latest recommendation (300 lux) from the code TCVN: 09 (2005).

Table 5.8 presents the estimate of contribution [%] from daylight (*EihD*) and from artificial light (*EihA*), to total task illuminance (*Eih*) in each season. The percentage of daylight contribution in Le Van Tam and Lam Son School is higher in the Dry season than in the Wet season. In contrast, daylight contribution in those heavily obstructed schools (i.e. Truong Cong Dinh and Ha Huy Tap School) is higher in the Wet season. Perhaps this difference is due to the orientation and external obstructions.

Table 5.7 Average internal horizontal illuminance *Eih* [lx] values generated from site measurements.

Descriptions	Symbols	Illuminance [lx]				
		Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son	All Schools *(average)*
Internal horizontal illuminance	*Eih*	377.16	130.66	166.57	409.27	270.92
Internal horizontal illuminance in the Dry season	*Eih-D*	393.23	115.12	150.42	451.78	277.64
Internal horizontal illuminance in the Wet season	*Eih-W*	361.10	146.20	182.73	366.77	264.20
Contributions of daylight on Internal horizontal illuminance	*EihD*	129.16	39.50	17.73	236.98	105.85
Contributions of daylight on Internal horizontal illuminance in the Dry season	*EihD-D*	145.23	23.96	1.58	279.49	112.57
Contributions of daylight on Internal horizontal illuminance in the Wet season	*EihD-W*	113.10	55.04	33.89	194.48	99.13
Contributions of artificial light on Internal horizontal illuminance	*EihA*	248.00	91.00	149.00	172.00	165.00

Table 5.8 Estimate of daylight and artificial light contribution [%] to task illuminance.

Descriptions	*Equations*	*LE VAN TAM*	*TRUONG CONG DINH*	*HA HUY TAP*	*LAM SON*	*ALL SCHOOLS*
Average Daylight contribution in both seasons	$\frac{EihD}{Eih} x100\%$	34.25%	30.23%	10.65%	57.90%	39.07%
Average Daylight contribution in the Dry season	$\frac{EihD-D}{Eih-D} x100\%$	36.93%	20.81%	1.05%	61.86%	40.54%
Average Daylight contribution in the Wet season	$\frac{EihD-W}{Eih-W} x100\%$	31.32%	37.65%	18.55%	53.02%	37.52%
Average Artificial light contribution in both seasons	$\frac{EihA}{Eih} x100\%$	65.75%	69.77%	89.35%	42.10%	60.93%

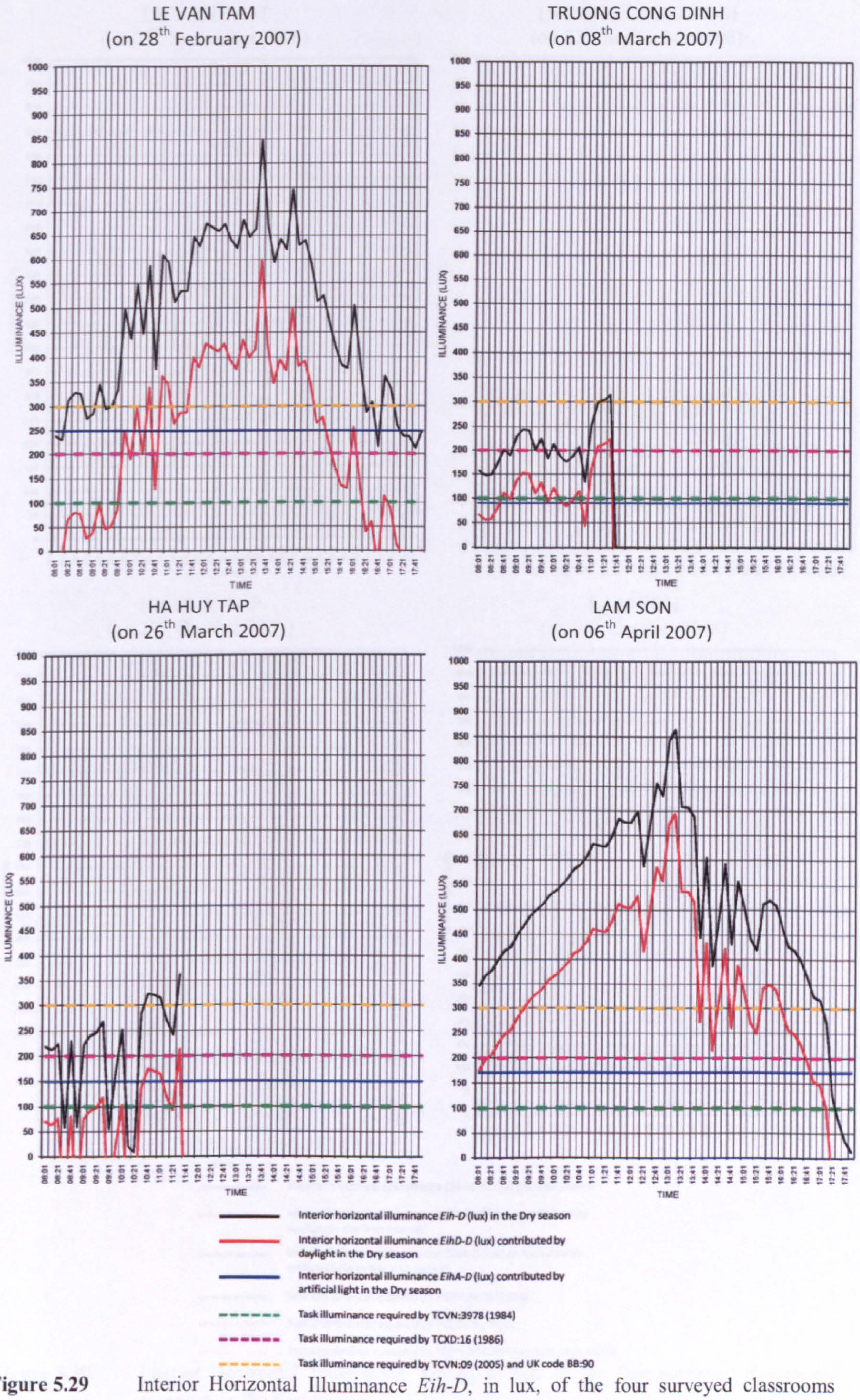


Figure 5.29 Interior Horizontal Illuminance *Eih-D*, in lux, of the four surveyed classrooms recorded in the Dry Season

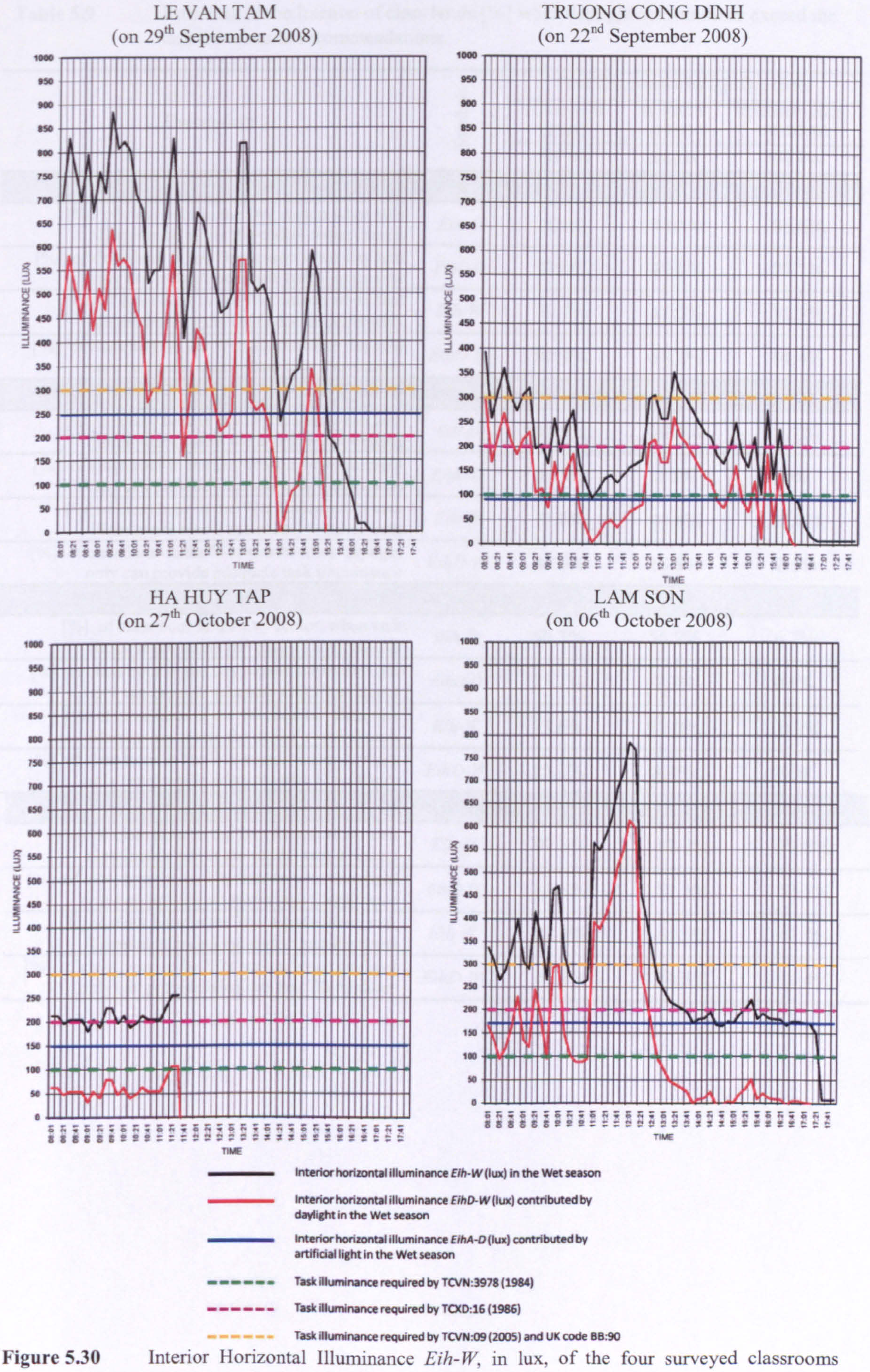


Figure 5.30 Interior Horizontal Illuminance *Eih-W*, in lux, of the four surveyed classrooms recorded in the Wet Season.

Table 5.9 Estimates of the fraction of class hours [%] when daylight contributions exceed the task illuminance recommendations.

Descriptions	Symbol	Task illuminance by lighting codes		
		TCVN:3978 (1984)	TCXD:16 (1986)	TCVN:09 (2005) UK-BB:90
		100 lux	200 lux	300 lux
LE VAN TAM SCHOOL				
[%] of class hour in the Dry season when task illuminance meets the codes' requirements	*Eih-D*	100%	97.5%	86.6%
[%] of class hour in the Dry season when daylight only can provide adequate task illuminance	*EihD-D*	77.0%	49.4%	27.2%
[%] of class hour in the Wet season when task illuminance meets the codes' requirements	*Eih-W*	70.7%	61.5%	51.9%
[%] of class hour in the Wet season when daylight only can provide adequate task illuminance	*EihD-W*	87.9%	68.6%	44.4%
TRUONG CONG DINH SCHOOL				
[%] of class hour in the Dry season when task illuminance meets the codes' requirements	*Eih-D*	43.5%	20.9%	1.7%
[%] of class hour in the Dry season when daylight only can provide adequate task illuminance	*EihD-D*	30.1%	2.5%	0%
[%] of class hour in the Wet season when task illuminance meets the codes' requirements	*Eih-W*	77.0%	41.8%	13.0%
[%] of class hour in the Wet season when daylight only can provide adequate task illuminance	*EihD-W*	46.0%	13.8%	2.5%
HA HUY TAP SCHOOL				
[%] of class hour in the Dry season when task illuminance meets the codes' requirements	*Eih-D*	60.3%	56.9%	6.7%
[%] of class hour in the Dry season when daylight only can provide adequate task illuminance	*EihD-D*	25.1%	1.7%	0.8%
[%] of class hour in the Wet season when task illuminance meets the codes' requirements	*Eih-W*	73.6%	51.0%	10.9%
[%] of class hour in the Wet season when daylight only can provide adequate task illuminance	*EihD-W*	15.1%	8.4%	0%
LAM SON SCHOOL				
[%] of class hour in the Dry season when task illuminance meets the codes' requirements	*Eih-D*	92.9%	88.3%	79.5%
[%] of class hour in the Dry season when daylight only can provide adequate task illuminance	*EihD-D*	82.8%	71.1%	53.1%
[%] of class hour in the Wet season when task illuminance meets the codes' requirements	*Eih-W*	82.4%	61.5%	41.0%
[%] of class hour in the Wet season when daylight only can provide adequate task illuminance	*EihD-W*	48.1%	30.5%	18.4%

Table 5.9 shows the estimates of the fraction of class hours when there is adequate daylight (when *Eih-D* is higher than the task illuminance recommended by the codes) and artificial light can be switched off, and thus energy is saved. In the case of Le Van Tam and Lam Son School, daylight can provide sufficient illuminance for 30% to 40% of the class hours. However, there are differences in the daylight contribution on task illuminance of each school. The *EihD* makes up as high as 40% of task illuminance of Le Van Tam School, and 78% of task illuminance of Lam Son School. In Truong Cong Dinh School this percentage is only 13% and in Ha Huy Tap School it is only 5.7%.

5.4.3. The Interior Vertical Illuminance *Eiv*

The interior vertical illuminance *Eiv* was recorded by the photocell mounted at position P2. The mean values generated from the site measurements during the surveys are presented in table 5.10. Table 5.11 shows the contribution of daylight *(EivD)* and artificial light *(EivA)* on the total vertical illuminance. The typical daily readings of each school in each season are shown in figure 5.31 (the Dry season) and figure 5.32 (the Wet season). As seen in these figures, the vertical illuminance is quite high and in some cases it is higher than the task illuminance.

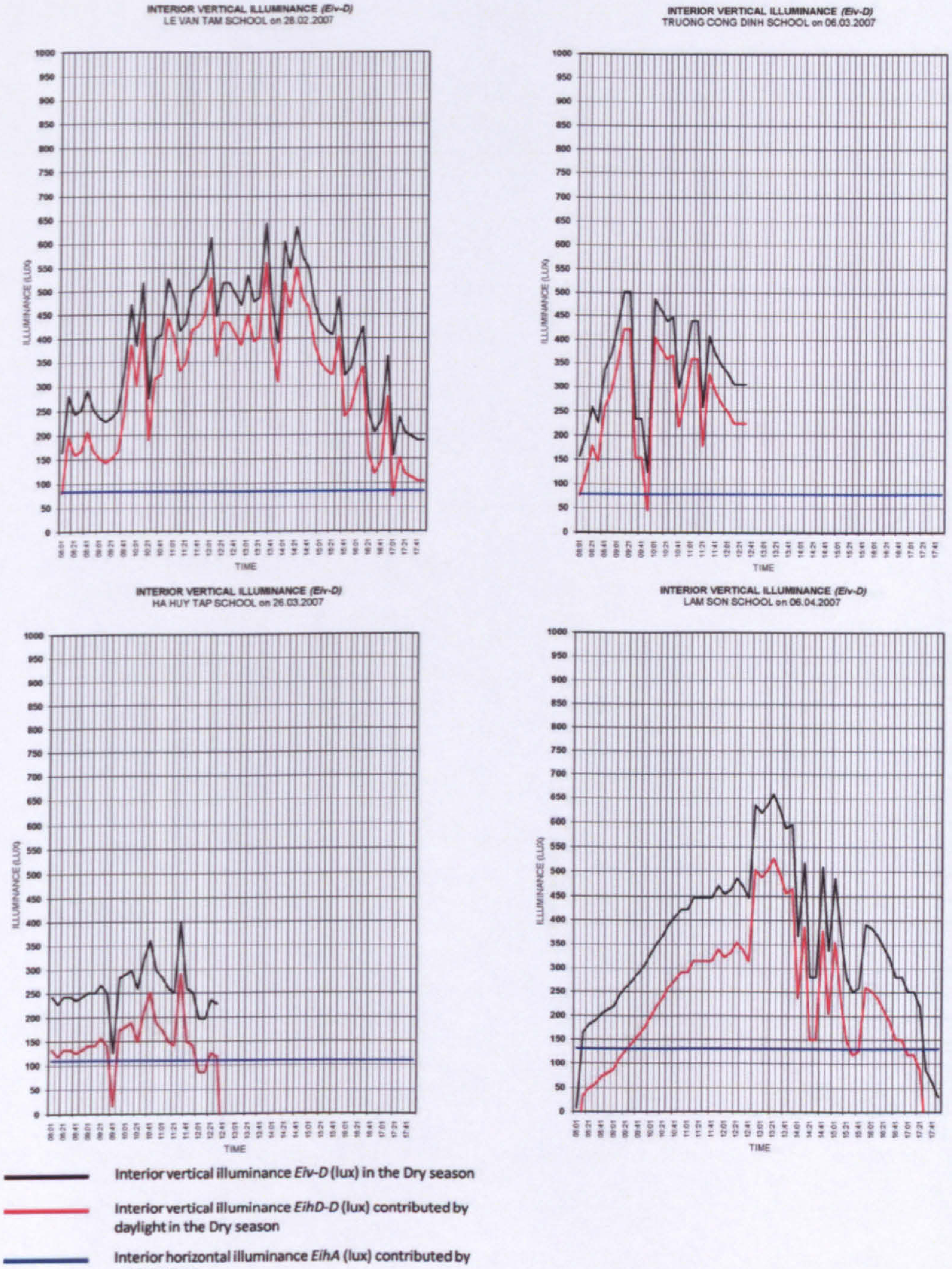


Figure 5.31

Graphs showing the Interior Vertical Illuminance *Eiv-D* in the Dry Season for the four classroms. Contribution from daylight *EivD-D* is plotted in red line and contribution from artificial light *EivA* is plotted in blue line

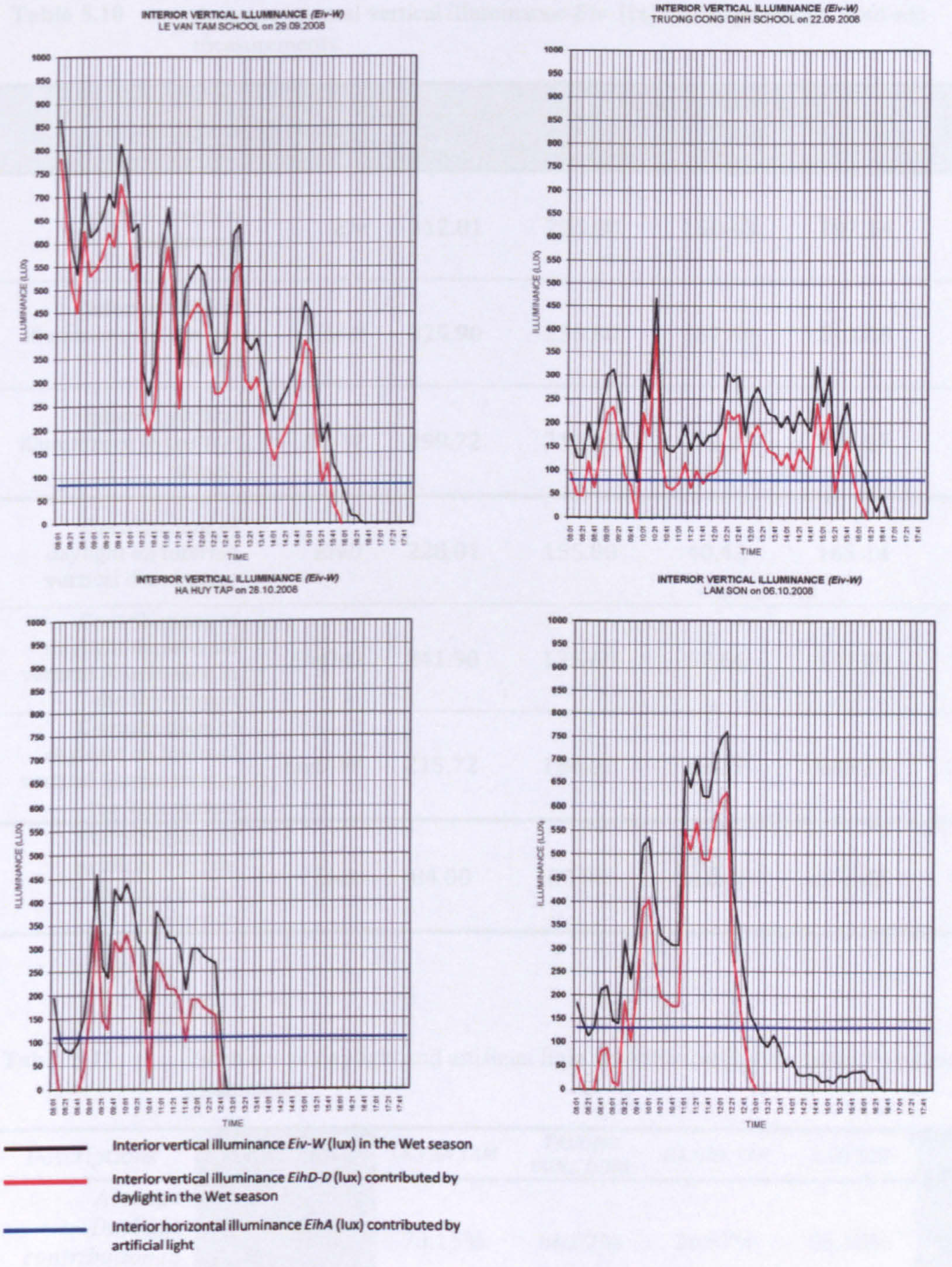


Figure 5.32

Graphs showing the Interior Vertical Illuminance *Eiv-W* in the Wet Season for the four classrooms. Contribution from daylight *EivD-W* is plotted in red line and contribution from artificial light *EivA* is plotted in blue line.

Table 5.10 Average internal vertical illuminance *Eiv* [lx] values generated from site measurements.

Descriptions	Symbols	Illuminance [lx]				
		Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son	All Schools
Internal vertical illuminance	*Eiv*	312.81	235.80	150.43	297.14	249.04
Internal vertical illuminance in the Dry season	*Eiv-D*	325.90	255.60	167.60	313.00	265.53
Internal vertical illuminance in the Wet season	*Eiv-W*	299.72	216.01	133.25	281.27	232.56
Contributions of daylight on Internal vertical illuminance	*EivD*	228.81	155.80	40.43	165.14	147.54
Contributions of daylight on Internal vertical illuminance in the Dry season	*EivD-D*	241.90	175.60	57.60	181.00	164.03
Contributions of daylight on Internal vertical illuminance in the Wet season	*EivD-W*	215.72	136.01	23.25	149.27	131.06
Contributions of artificial light on Internal vertical illuminance	*EivA*	84.00	80.00	110.00	132.00	101.50

Table 5.11 Estimates of daylight and artificial light contribution [%] on internal vertical illuminance.

Descriptions	*Equations*	*LE VAN TAM*	*TRUONG CONG DINH*	*HA HUY TAP*	*LAM SON*	*ALL SCHOOLS*
Average Daylight contribution in both seasons	$\frac{EivD}{Eiv}x100\%$	73.15%	66.07%	26.87%	55.58%	59.24%
Average Daylight contribution in the Dry season	$\frac{EivD-D}{Eiv-D}x100\%$	74.23%	68.70%	34.37%	57.83%	61.77%
Average Daylight contribution in the Wet season	$\frac{EivD-W}{Eiv-W}x100\%$	71.97%	62.96%	17.45%	53.07%	56.36%
Average Artificial light contribution in both seasons	$\frac{EihA}{Eih}x100\%$	26.85%	33.93%	73.13%	44.42%	40.76%

5.5. Analyses

5.5.1. Overview

Significant differences have been found between the results predicted by the codes, particularly the Vietnamese codes, and the values measured on site (as in table 5.12). This suggests that either the methods recommended by the codes are not appropriate or the situation in reality is much more complex than in theory.

Table 5.12 Comparison of daylight contributions estimated by different theoretical methods and by site measurements.

Descriptions	Daylight contribution on task illuminance, expressed by Daylight factor DF [%] and converted to illuminance [lx] at P3			
	Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
Estimated DF [%] by ĐRASTN equation (as in table 5.1)	1.41 %	0.87 %	0.66 %	1.63 %
Equivalent task illuminance (at design sky = 4000 lux)	56.43 lux	34.80 lux	26.40 lux	65.20 lux
Estimated DF [%] by Danhiluc chart method (CIE overcast sky, as given in table 5.2)	1.35 %	0.77 %	0.51 %	1.41 %
Equivalent task illuminance (external horizontal illuminance = 4000 lux)	54.00 lux	31.08 lux	20.40 lux	56.4 lux
Estimated DF [%] by the Danhiluc chart method (uniform sky, as given in table 5.3)	2.11 %	1.03 %	0.73 %	1.92 %
Equivalent task illuminance (external horizontal illuminance = 4000 lux)	84.4 lux	41.2 lux	29.2 lux	76.8 lux
Estimated DF [%] by the Waldgram diagram method (uniform sky, as in table 5.5, impact of trees are included)	2.04 %	1.78 %	1.04 %	2.92 %
Equivalent task illuminance (external horizontal illuminance = 4000 lux)	81.60 lux	71.20 lux	41.60 lux	116.80 lux
Mean site measurements, *EihD* as in table 5.9	**129.16 lux**	**39.50 lux**	**17.73 lux**	**236.98 lux**

It should be noted that the theoretically estimated values, particularly those given by Vietnamese codes, are calculated strictly from the referencing table of values provided by the codes (see appendix J). It is understood that there are already significant differences between results predicted by the Vietnamese codes and those given by the Waldgram diagram (see section 5.3.3 of chapter 5, page 197). This could be attributed to the fact that the design sky value of 4000 lux is not appropriate for HCMC, but the task illuminance results predicted by the Waldgram diagram method and the onsite measurements are not concurrent. In reality, it is found that the conditions are more complex, and thus all the specific issues cannot be addressed. Therefore, it is recommended that these values would be more meaningful when used as theoretical estimates rather than as realistic estimates.

First, it should be noted that the window transmittance index τ_l used in the estimates shown in table 5.12 is calculated as an average transmittance factor of the fully opened half (100% transmission) and the half closed window area (varying transmission factor of the glazing, as per table 4.9 table 4.12, chapter 4, page 164-168). This assumption theoretically is correct, but in reality the window transmittance index τ_l seems to be much lower. As observed on site, the classroom windows are poorly maintained and they are quite dirty. Furthermore, there are noticeable numbers of window bars installed for security purposes (see table 4.12, page 168). These bars obstruct part of the view. It should also be noted that the students themselves also block much of the daylight arriving the desktop. Taking these situations into consideration, it is more realistic to use the *realistic window transmittance index* τ_r instead of τ_l in the comparison between the theoretically estimated and the reality measurement. τ_r takes into account reduction due to dirt and poor maintenance (i.e. 20%), reduction due to window bars (i.e. 20%) and reduction due to obstruction by the students (i.e. 40%). This means the *realistic glazing transmittance index* τ_r is only a fraction of τ_l, and it is calculated as:

$$\tau_r = \tau_1 \times 0.8 \times 0.8 \times 0.6 = \tau_1 \times 0.384$$

The estimates of the *realistic glazing transmittance index* τ_r of each school classroom are presented in table 5.13. It should be noted that Ha Huy tap School classroom has no glazing, therefore the τ_l is taken as τ_l=1.

Table 5.13 Estimates of realistic glazing transmittance index τ_r.

Description	Window	School			
		Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
Glazing transmittance factor τ_1 as per the code definition	1	0.83	0.78	1.00	0.80
	2	0.83	0.78	1.00	0.80
	3	0.83	0.78	1.00	0.80
	4	1	1	1	1
Realistic glazing transmittance factor τ_r $\tau_r = \tau_1$ x 0.8 x0.8 x0.6	1	0.32	0.30	0.38	0.31
	2	0.32	0.30	0.38	0.31
	3	0.32	0.30	0.38	0.31
	4	0.384	0.384	0.384	0.384

It should be noted that *glazing transmittance index* τ_1 is different from the *window transmittance index* τ_{cs} (see appendix J). In the Vietnamese codes, it is defined that $\tau_{cs} = \tau_{1.}\ \tau_{2.}\ \tau_{3.}\ \tau_{4.}\ \tau_{5.}$ If τ_1 is replaced by τ_r to provide more realistic estimates, τ_{cs} in the *ĐRASTN* and *Danhiluc chart* calculation is given by $\tau_{cs} = \tau_{r.}\ \tau_{2.}\ \tau_{3.}\ \tau_{4.}\ \tau_{5.}$ In this case τ_{cs} still includes all other window characteristic defined by the code (i.e. $\tau_{2,}\ \tau_{3,}\ \tau_{4,}\ \tau_5$).

Another factor to note is that the values given by the Waldgram diagram method presented in table 5.12 are estimated from windows with no glazing. To include the reduction due to glazing, these values should be multiplied by the *realistic glazing transmittance index* τ_r of each school respectively. In the case of Ha Huy Tap school classroom, the reduction due to wooden windows has already been included in the values presented in table 5.12.

Taking these situations into consideration, all the theoretical estimates presented in table 5.12 are recalculated by multiplying them with the respective τ_r as shown in table 5.13, and the results are shown in table 5.14. In this table, *ĐRASTNr* [%] is the realistic adjusted value of *ĐRASTN* , *ĐRASTN*$_{Du}$*r* [%] is the realistic adjusted value of *ĐRASTN*$_{Du}$, and *SFr* [%] is the realistic adjusted value of the equivalent sky factor *SF* given by the Waldgram diagram method. These values perhaps represent the realistic conditions better, and they are more realistically comparable to the values taken from the site measurements.

Table 5.14 Adjusted theoretical estimates of the daylight contributions.

Description	Window	School: Le Van Tam	School: Truong Cong Dinh	School: Ha Huy Tap	School: Lam Son
ĐRASTN [%] by equation (As in table 5.1 and in table D.1 and D.2 of appendix D)	1	0.39	0.24	0.18	0.47
	2	0.39	0.24	0.18	0.47
	3	0.31	0.23	0.13	0.42
	4	0.31	0.16	0.17	0.28
	Total	***1.40***	***0.87***	***0.66***	***1.64***
ĐRASTNr [%] $ĐRASTN_r = ĐRASTN \times \tau_r$	1	0.12	0.07	0.07	0.15
	2	0.12	0.07	0.07	0.15
	3	0.10	0.07	0.05	0.13
	4	0.12	0.06	0.07	0.11
	Total	***0.47***	***0.27***	***0.25***	***0.53***
$ĐRASTN_{Du}$ [%] by Danhiluc chart in uniform sky (As in table 5.3 and in table D.3-D.6 of appendix D, the sky coefficient *q* is reset to 1)	1	0.7	0.41	0.13	0.85
	2	0.7	0.41	0.27	0.31
	3	0.41	0.13	0.33	0.13
	4	0.3	0.08	0.0	0.63
	Total	***2.11***	***1.03***	***0.73***	***1.92***
$ĐRASTN_{Du}r$ [%] $ĐRASTN_{Du}r = ĐRASTN_{Du} \times \tau_r$	1	0.22	0.12	0.05	0.26
	2	0.22	0.12	0.10	0.10
	3	0.13	0.04	0.13	0.04
	4	0.12	0.03	0.00	0.24
	Total	***0.69***	***0.32***	***0.28***	***0.64***
Sky Factor SF [%] at P3 given by Waldgram Diagram (as in table 5.5)	1	0.70	0.55	0.76	1.12
	2	0.70	0.55	0.56	1.13
	3	0.39	0.36	1.13	0.34
	4	0.25	0.31	0.11	0.33
	Total	***2.04***	***1.78***	***1.04(*)***	***2.92***
Sky Factor SFr [%] at P3 $SFr = SF \times \tau_r$	1	0.22	0.17	0.29	0.35
	2	0.22	0.17	0.21	0.35
	3	0.12	0.11	0.43	0.11
	4	0.10	0.12	0.04	0.13
	Total	***0.67***	***0.56***	***0.97***	***0.93***

Second, it seems inappropriate to use the external horizontal illuminance at 4000 lux, as recommended by the codes. The climatic daylight data provided by the local Meteorology Station shows that the horizontal diffuse illuminance *(Eeh)* in HCMC is much higher.

Table 5.15 presents the estimated horizontal diffuse illuminance calculated from the sets of data provided by the local Meteorology Station shown in table 2.3 of chapter 2. These values present realistic conditions and perhaps it would be more appropriate to use the readings recorded between 09h00 and 15h00 in the calculations. This is because the earlier and later readings may include the impact of direct sunlight due to low sun angles. The *EihD* should be calculated from the average values of *Eeh* of the specific month when the measurements are taken rather than the annual average value.

Table 5.15 Estimates of average diffuse horizontal illuminance provided by the local Meteorology Station.

Time	Descriptions	Average [lx]
From 07h00 to 17h00	Annual average diffuse horizontal illuminance from 07h00-17h00	**20277**
	Average diffuse horizontal illuminance from 07h00-17h00 in the Dry season (December-April)	**18838**
	Average diffuse horizontal illuminance from 07h00-17h00 in the Wet season (May-November)	**21022**
	Average diffuse horizontal illuminance from 07h00-17h00 in February	**19782**
	Average diffuse horizontal illuminance from 07h00-17h00 in March	**18200**
	Average diffuse horizontal illuminance from 07h00-17h00 in April	**21864**
	Average diffuse horizontal illuminance from 07h00-17h00 in September	**22091**
	Average diffuse horizontal illuminance from 07h00-17h00 in October	**22182**
	Average diffuse horizontal illuminance from 07h00-17h00 in November	**19891**
From 09h00 to 15h00	Annual average diffuse horizontal illuminance from 09h00-15h00	**25752**
	Average diffuse horizontal illuminance from 09h00-15h00 in the Dry season (December-April)	**23994**
	Average diffuse horizontal illuminance from 09h00-15h00 in the Wet season (May-November)	**26579**
	Average diffuse horizontal illuminance from 09h00-15h00 in February	**25443**
	Average diffuse horizontal illuminance from 09h00-15h00 in March	**22714**
	Average diffuse horizontal illuminance from 09h00-15h00 in April	**27443**
	Average diffuse horizontal illuminance from 09h00-15h00 in September	**27929**
	Average diffuse horizontal illuminance from 09h00-15h00 in October	**28271**
	Average diffuse horizontal illuminance from 09h00-15h00 in November	**25786**

Considering all these issues, table 5.16 presents a more appropriate comparison between predictions given by the theoretical methods and the actual values measured on site.

Table 5.16 Comparison of daylight contributions estimated and adjusted by different theoretical methods and the values given by site measurements.

	Description	School			
		Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
Average external diffuse horizontal illuminance from 09h00-15h00 of the month when the Dry season survey was conducted. (as in table 5.15)	Month when the survey conducted	*February*	*March*	*March*	*April*
	Illuminance [lx]	25443	22714	22714	27443
Average external diffuse horizontal illuminance from 09h00-15h00 of the month when the Wet season survey was conducted (as in table 5.15)	Month when the survey conducted	*September*	*September*	*October*	*October*
	Illuminance [lx]	27929	27929	28271	28271
	ĐRASTNr [%] (as in table 5.14)	0.47	0.27	0.25	0.53
	Predicted task illuminance [lx] in the Dry season	**119**	**62**	**57**	**145**
	Predicted task illuminance [lx] in the Wet season	**131**	**77**	**71**	**150**
	ĐRASTN$_{Du}$r [%] (as in table 5.14)	0.69	0.32	0.28	0.64
	Predicted task illuminance [lux] in the Dry season	**177**	**72**	**63**	**176**
	Predicted task illuminance [lux] in the Wet season	**194**	**88**	**78**	**181**
	SFr [%] (as in table 5.14)	0.67	0.56	0.97	0.93
	Predicted task illuminance [lx] in the Dry season	**170**	**127**	**221**	**255**
	Predicted task illuminance [lx] in the Wet season	**187**	**156**	**275**	**263**
Mean site measurements [lux] from 9h00 to 15h00	Dry season, *EihD-D*	**242**	**113***	**99***	**405**
	Wet season, *EihD-W*	**157**	**39***	**97***	**178**

(*) Since Truong Cong Dinh and Ha Huy Tap classroom are used only during the morning shift, this value is the mean of readings from 09h00 to 11h30 only.

It is found that the results given by the Vietnamese code and the mean site measurements in the Wet season from 09h00 to 15h00 are quite similar. In the case of Truong Cong Dinh School, since trees are excluded in both *ĐRASTN* and Danhiluc chart, it is difficult to estimate the tree reflected light accurately. In the case of Ha Huy Tap classroom, because the louvers block most of the direct light, the daylight entering the interior is mainly diffused reflected light and it seems that the predicted values as per the Vietnamese codes are quite close to what are recorded on site. This can be attributed to the fact that the impact of these wooden louvered windows is addressed properly in both *ĐRASTN* and Danhiluc chart calculations, but it was not possible to plot them in the Waldgram diagram because they would have blocked the entire window area.

Overall, the theoretical predictions are quite close to the mean values recorded on site in the Wet season (from 9h00-15h00) when the sky is more diffuse. However, there are significant differences in the Dry season. Particularly in Le Van Tam and Lam Son School, the mean measurements are much higher than the theoretical prediction. It is understood that the overhangs block much of the direct sunlight and the students would close the blinds or curtains when direct sunlight falls on their desk as it would be difficult to work under such conditions. Therefore, the differences could be due to reflected light, particularly reflected sunlight.

To understand the situation more clearly, it is necessary to trace the route that daylight travels to the interior. Both the site documentations and the theoretical analysis indicate that the windows on wall 1 facing externally provide main daylight contributions (see table 5.17). Therefore, the analysis focuses on this side for the investigation of the situation.

Table 5.17 Estimates of daylight contributions by windows on each side wall to task illuminance at P3 (using Waldgram diagrams).

Estimates of the daylight contributions of windows on each side wall	Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
Windows on wall 1	68.69 %	65.64 %	49.45 %	76.75 %
Windows on wall 2	31.31 %	34.36 %	50.55 %	23.25 %

Some studies suggest that perhaps daylight factor approach is not appropriate for a warm climate, primarily because it excludes sunlight and also underestimates the role of external reflected light, particularly the ground reflected component (Cabús, 2002). To identify the problem, it is necessary to review the route taken by daylight from the sky to travel into the interior.

Based on the literature on the split-flux theory from which daylight factor was developed, daylight from sky, after transmitting through the windows, and falling on the task plane at a given point, is dependent on the room geometry and the room reflectance factor. These factors are not so significantly different in these surveyed classrooms that they make any critical changes on daylight contributions. Furthermore, in a dense metropolitan city like HCMC, buildings are fighting each other for sky access and natural ventilation, and hence the external landscape, particularly the external ground surface, plays a crucial role here.

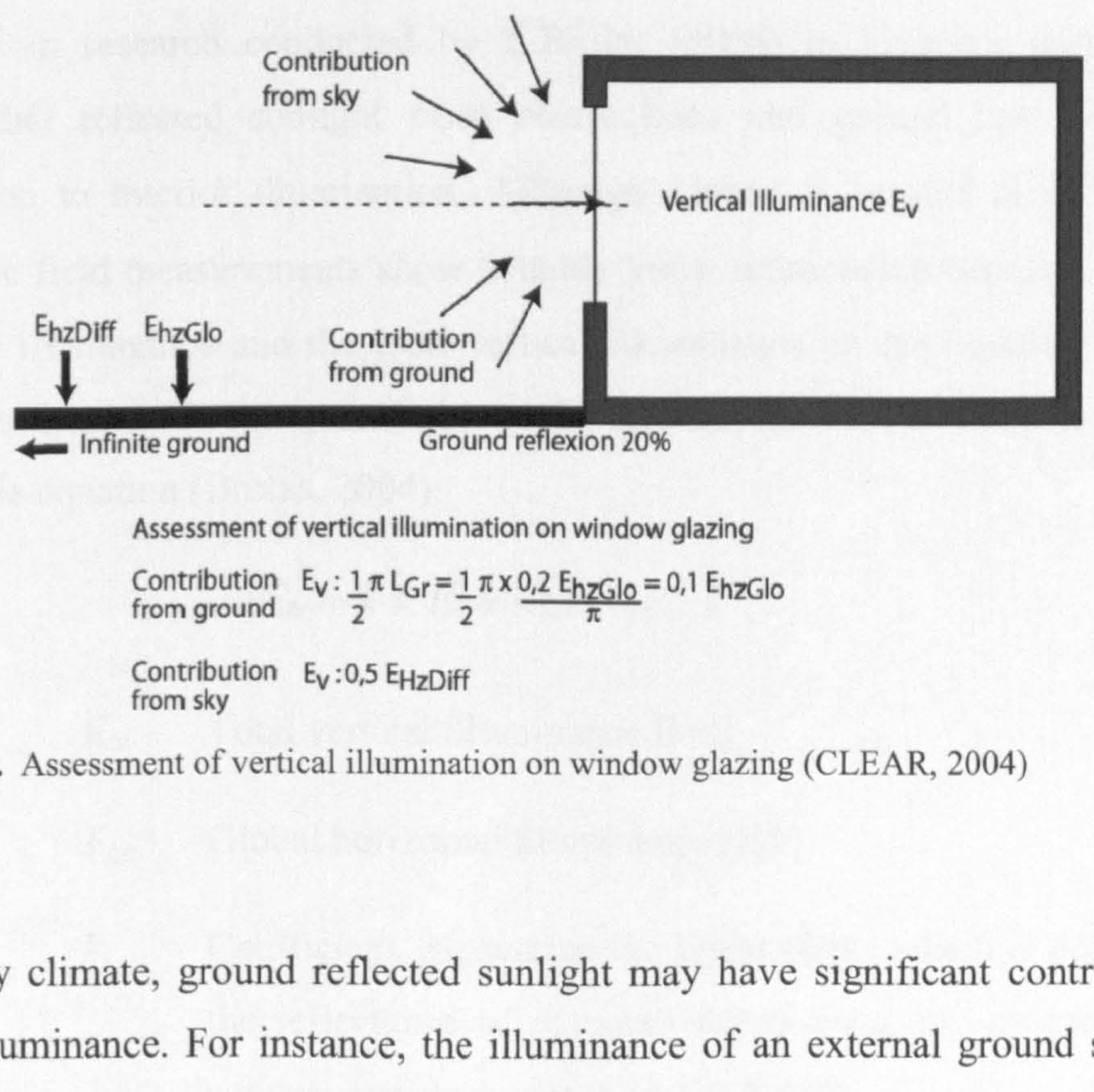


Figure 5.33. Assessment of vertical illumination on window glazing (CLEAR, 2004)

In a sunny climate, ground reflected sunlight may have significant contribution to interior illuminance. For instance, the illuminance of an external ground surface lit by direct sunlight may reach 100 000 lux. If the ground reflectance factor is 20%, the reflected sunlight is 20 000 lux which is a considerable value. For instance, figure 5.34 shows the contributions of sky light and ground reflected light in Europe, the further to the South in Europe (more sunlight) the more important the ground reflected light is.

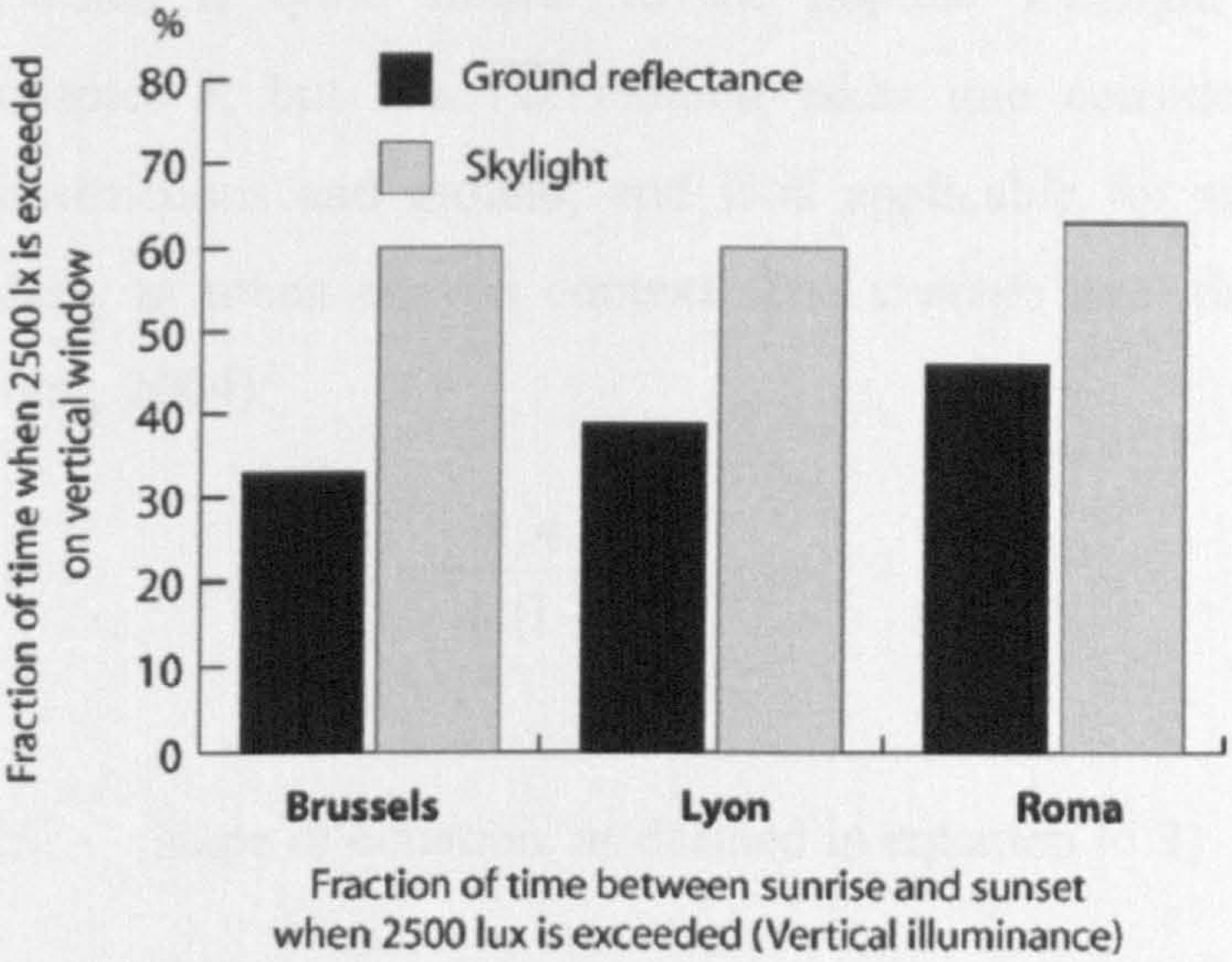


Figure 5.34. The importance of ground reflected light in different locations (CLEAR, 2004)

Results from research conducted by L.Brotas (2004) in Lisbon's urban canyon indicate that reflected sunlight from obstructions and ground has considerable contribution to interior illumination. Although Lisbon is located at 38°42'N and 9°8'W, the field measurements show a stable linear relationship between the global horizontal illuminance and the total vertical illuminance on the building's facades, even when there is no direct sunlight on the facades. This relationship is expressed by a simple equation (Brotas, 2004):

$$E_{tv} = k \times Egh + C \quad (5.3)$$

Where: E_{tv}: Total vertical illuminance [lux]

E_{gh}: Global horizontal illuminance [lux]

k: Coefficient, expressing the linear slope, which is dependent of the reflectance of external obstructions, the geometry of the canyon, and the position on the facade.

C: Constant, expressing the contribution of the diffuse sky illuminance to the buildings and it is more important at higher floors.

Furthering these findings, Brotas (2004) proposes an *Average Total Daylight Factor* method *($\overline{TD}$)*, which is quite similar to the popular Daylight factor method introduced in chapter 3; but this $\overline{TD}$ method takes into consideration reflected sunlight from obstructions and ground, and it is applicable for sunny climate in Europe, particularly in urban canyon context. The average total daylight factor is obtained by (Brotas, 2004):

$$\overline{TD} = \frac{k.A_w.\tau}{A_r.(1-\rho)} \qquad (5.4)$$

Where: k: slope of equation, as defined in equation (5.3)

τ: Diffuse transmittance of the glazing, express as a decimal

A_w: Total window's net glazed area [m^2]

A_r: Total area of the interior surfaces including walls, floor, ceiling, and windows [m^2]

ρ: Area-weighted average reflectance of the interior surfaces, expressed as a decimal.

A research conducted by Ricardo Carbús (2002) reveals that in tropical climate, under direct sunlight, the ground luminance can be brighter than that from the sky. The impact of ground reflected light is related the ground area next to the window. Ricardo Carbús (2002) divides the ground area in front of the window into nine bands to study the impact of each band, and concludes that, independent of room pattern, the zone from 0.5m to 7m (zone A-B in figure 5.35) from the facade provides most of the ground reflected light to the window.

Moreover, Ricardo Carbús (2002) also indicates that overhang, which is found in all the four surveyed schools, is the best type of shading (among light shelf and horizontal louvers) that takes advantage of ground reflected component (see figure 5.36) . The overhang in a Vietnamese school is often painted in light finishes so it is likely that the ground reflected light is maximized. Therefore, the ground reflected component is quite important in the HCMC classroom illuminance, especially in the Dry season when sunlight is strong.

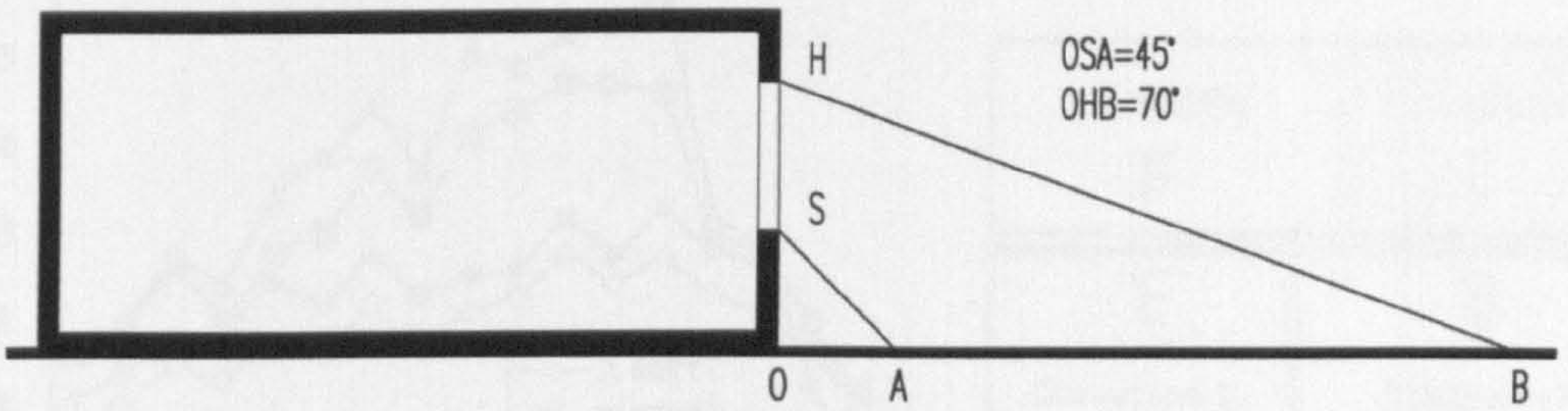


Figure 5.35. Important ground area that has significant influence on interior illumination. The ground area in front of the window, defined by zone A-B contributes most of the ground reflected light.

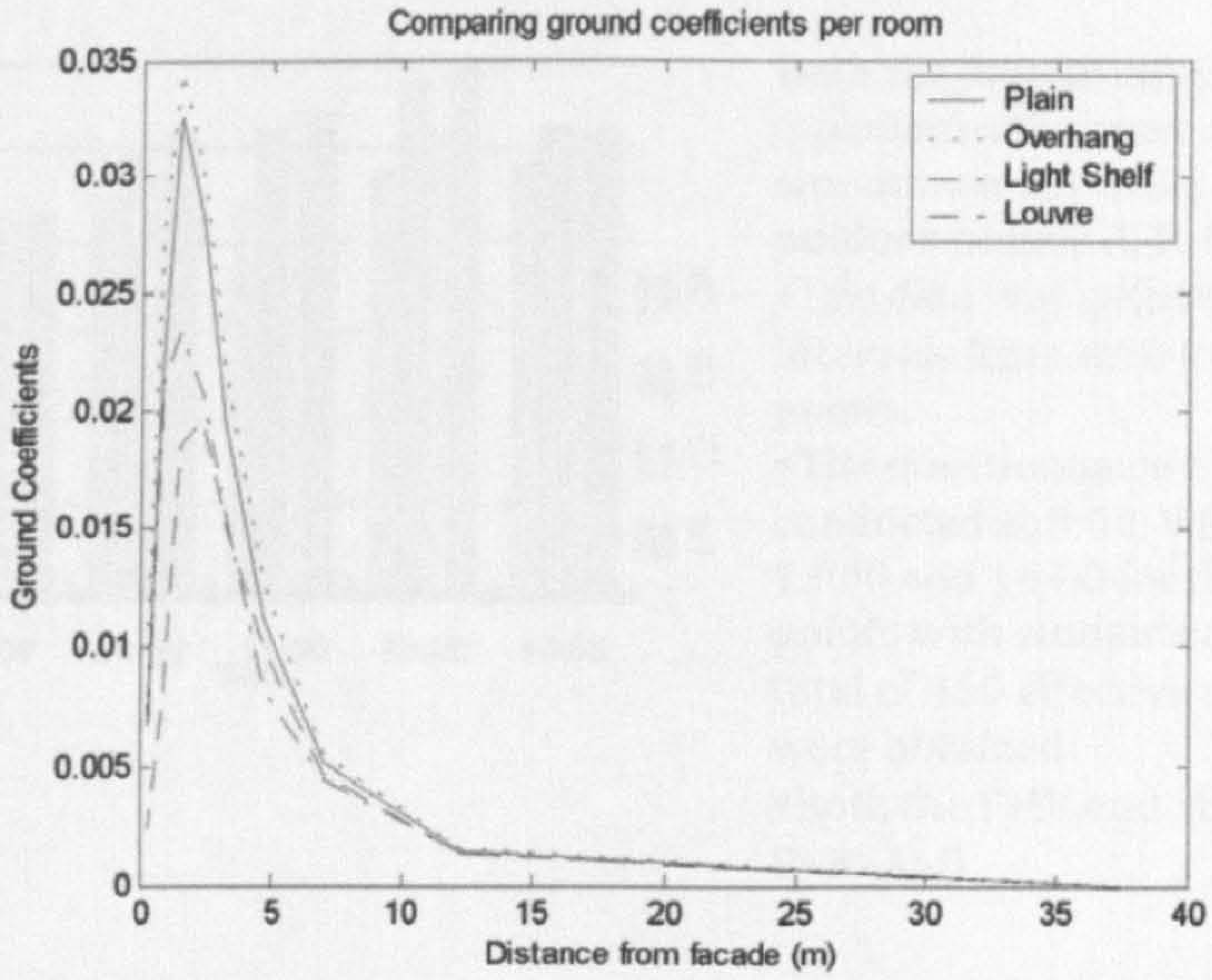
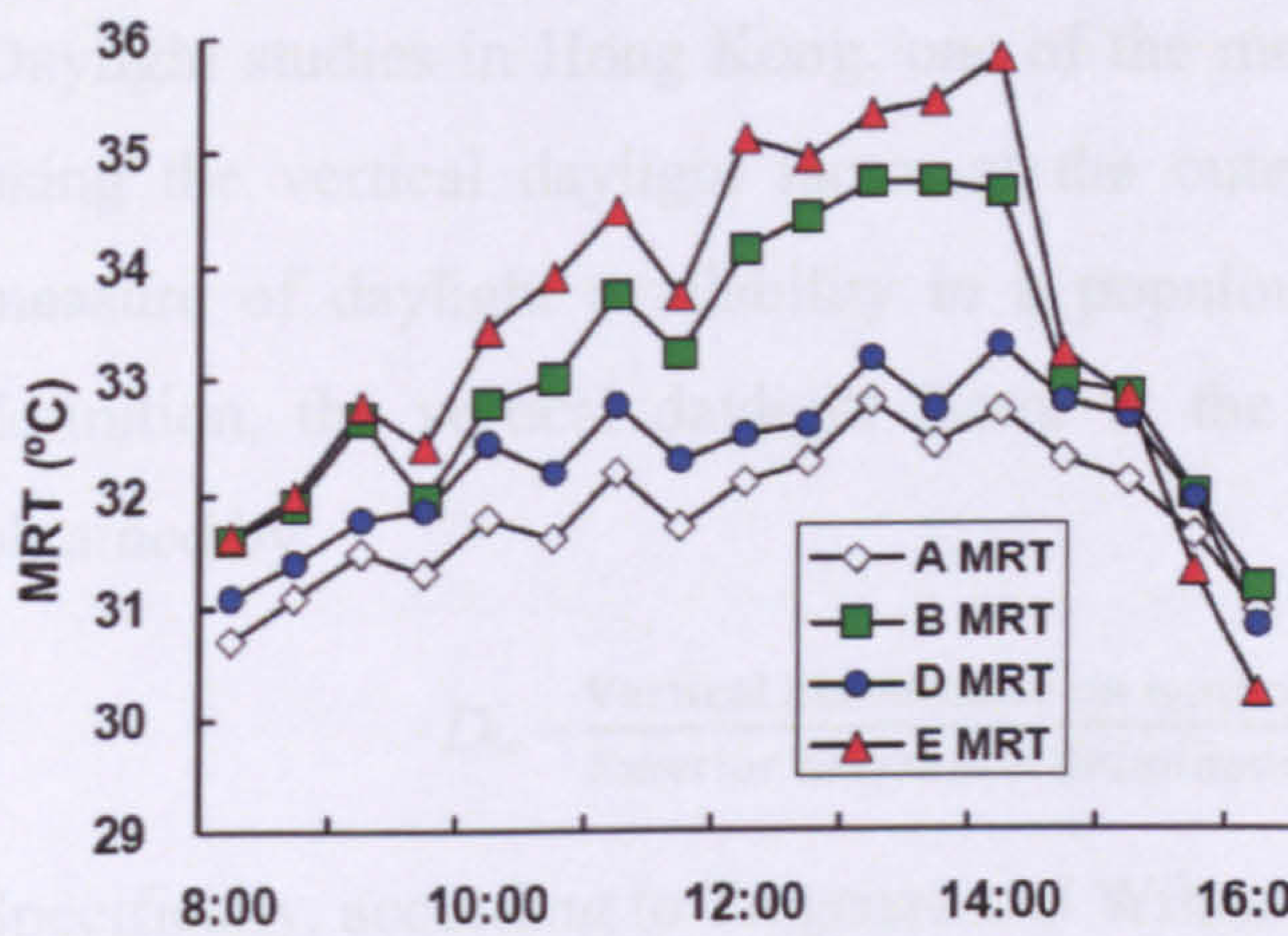
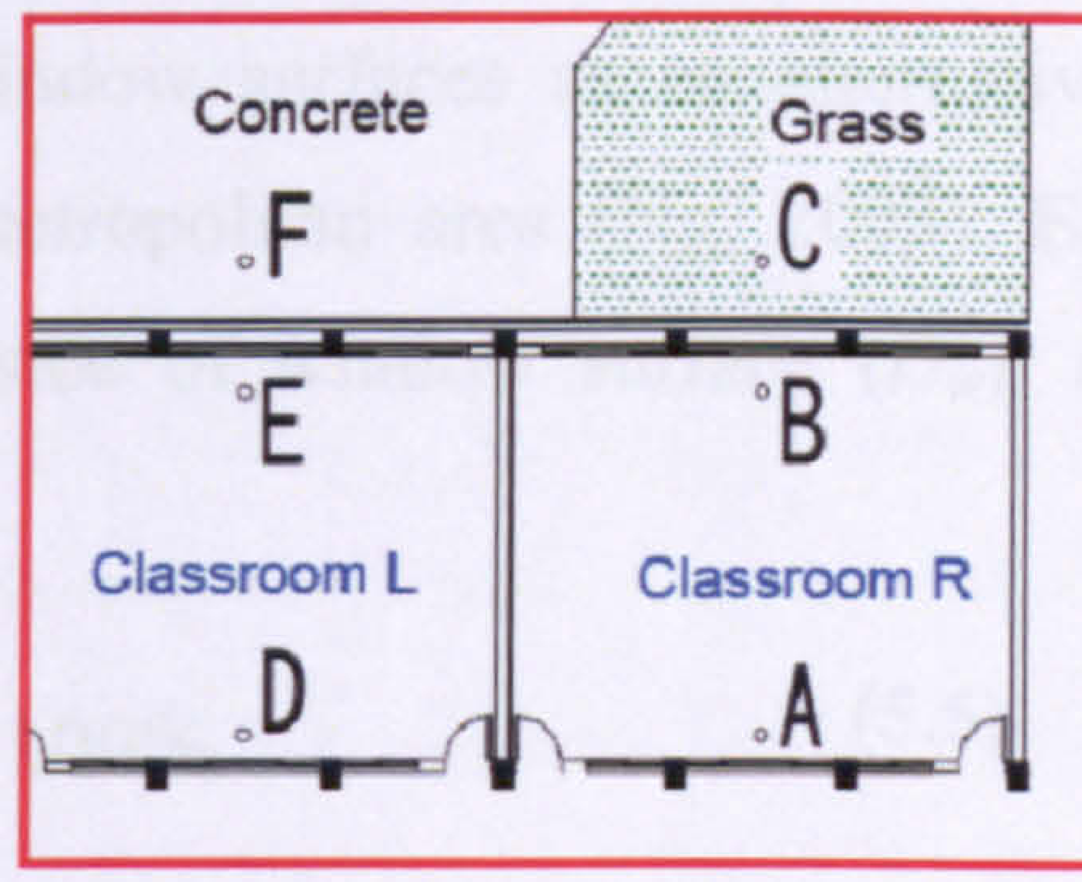
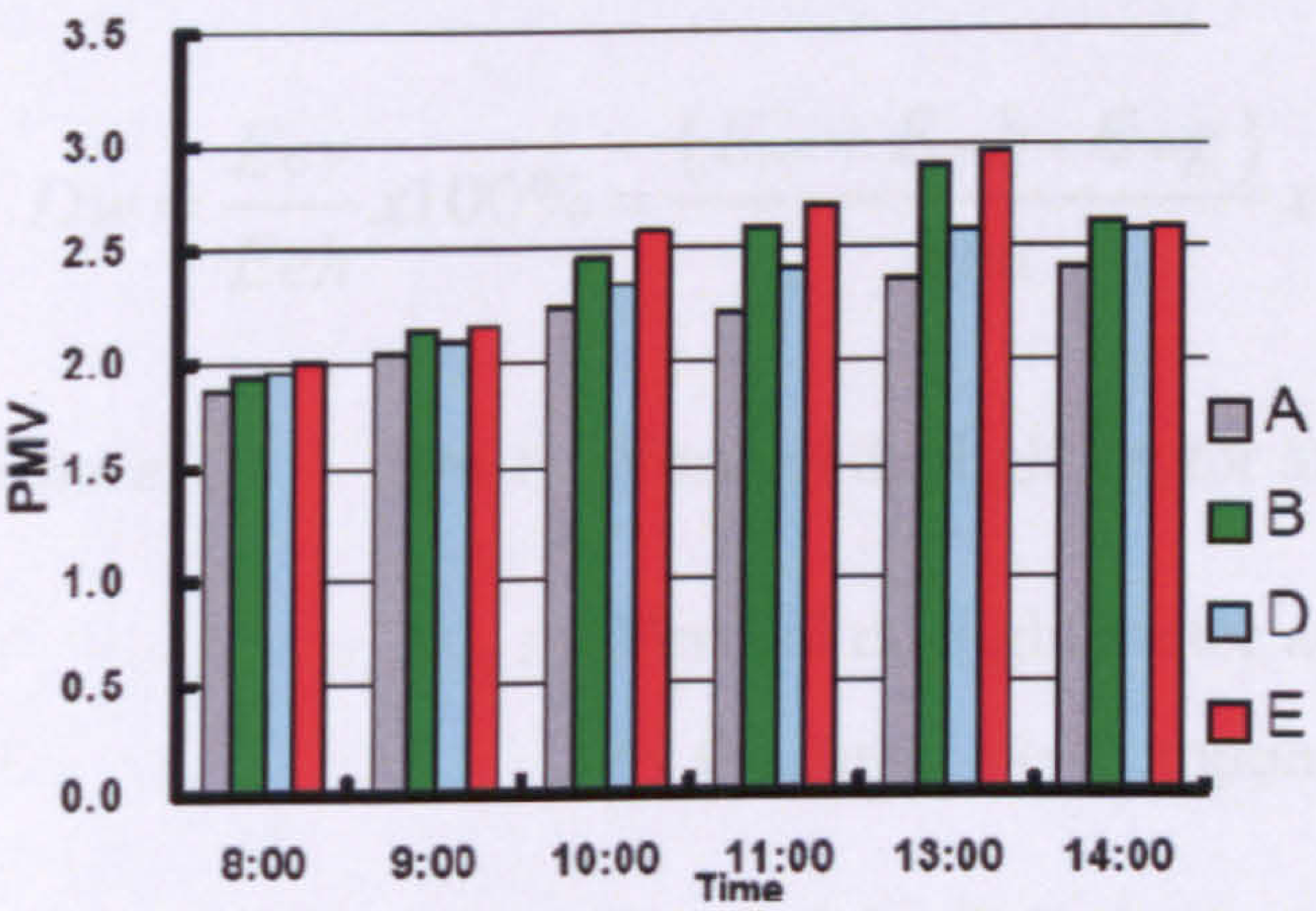


Figure 5.36 Comparing ground coefficients *(gc)* by room pattern as a function of distance from window (Cabús, 2002)

A field survey conducted by Lin et al (2008) found that the external ground surface material outside classrooms affects the indoor thermal environment both physiologically and psychologically. In this field survey, Lin et al conducted a site measurement and a comfort survey in two classrooms in Taiwan (latitude 23.5^{o}N) with different external ground surface materials: one with concreted paved surface and another with green grass surface. The results are summarised in figure 5.37. It is found that classrooms with concrete surface outside had higher indoor temperatures than those with grass outside and the students are more comfortable in classrooms with greenery outside than in those with concrete outside. These differences relate to the reflected solar radiation. Therefore it is apparent that the role of external reflected light should not be underestimated in a sunny climate.



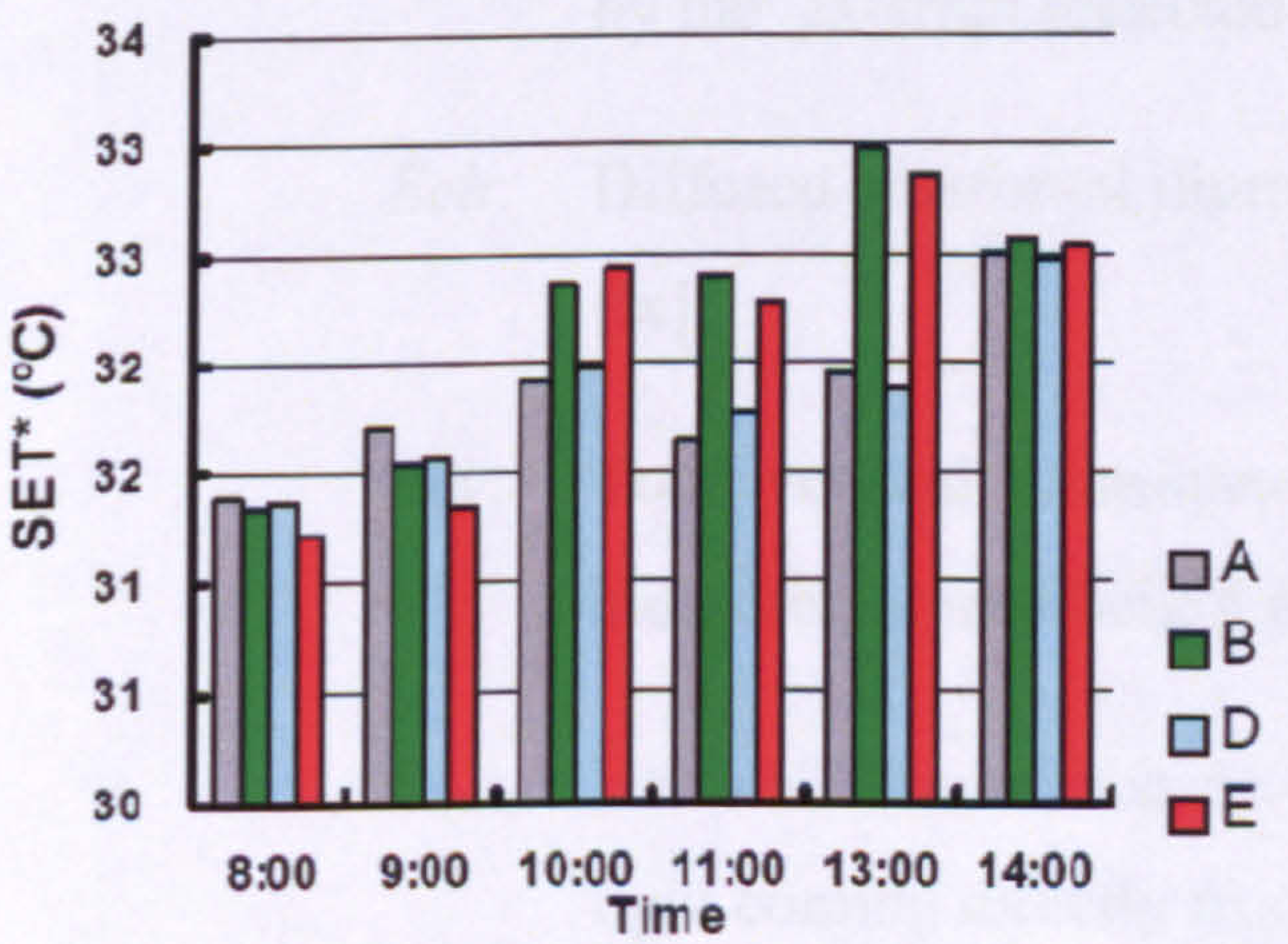




Classroom plan

Both the measurements and questionnaires were conducted simultaneously at six indoor and outdoor points: A, B, C, D, E and F.

- The data was gathered at one-minute intervals from 8:00 to 17:30 for six points.
- The questionnaire investigation was conducted at 8:00, 9:00, 10:00, 11:00, 13:00 and 14:00 for the four indoor points with students as respondents. A total of 450 effective questionnaires were obtained
- Both the PMV and SET* shows: E>B>A>D



MRT: Mean Radiant Temperature [^{o}C]

PMV: ASHRAE Predicted Mean Vote

SET*: Standard Effective Temperature [^{o}C]

Figure 5.37 Summary of a field survey on the effect of external ground surface materials on indoor thermal comfort in Taiwanese school classrooms (Lin et al, 2008).

Daylight studies in Hong Kong, one of the most dense cities in the world, suggests using the vertical daylight factor at the outer window surfaces as an alternative measure of daylight availability in a populous metropolitan area (Ng, 2003). By definition, the vertical daylight factor at the outside of window surface (D_w), is obtained by:

$$D_w = \frac{\text{Vertical illuminance on window}}{\text{Exterior horizontal illuminance}} \times 100\% \tag{5.5}$$

Specifically, according to Tregenza and Wilson (2011):

$$Dw = \frac{Eev}{Eeh} x100\% = \frac{\left(E_{ws} + E_{wr}b + E_{wr}g\right)}{Eeh} x100\% = D_{ws} + D_{wr}b + D_{wr}g \tag{5.6}$$

Where:

Dw : Vertical daylight factor at the outside of window surface [%].

D_{ws} : Vertical daylight factor at the outside of window surface given by the direct sky component [%].

$D_{wr}b$: Vertical daylight factor at the outside of window surface given by the external reflected light from buildings [%].

$D_{wr}g$: Vertical daylight factor at the outside of window surface given by the external reflected light from ground [%].

Eeh: Diffused horizontal illuminance from an unobstructed sky [lx].

Eev: Total vertical illuminance at the outside of window surface, measured at mid-height of the window [lx].

E_{ws} : Vertical illuminance received at outer window surface from light coming directly from the sky [lx] .

$E_{wr}b$: Vertical illuminance received at outer window surface from reflected light coming from buildings and trees [lx]

$E_{wr}g$: Vertical illuminance received at outer window surface from reflected light coming from the ground [lx]

In this theory, sunlight is also excluded. However, in real site measurements, the vertical illuminance on the outer window surface (i.e. Eev) also consists of direct sunlight E_{sun}, reflected sunlight from buildings $E_{sun}b$ and the ground $E_{sun}g$.

Because there is no available site measurement for Eeh, the typical 20-year sky values, either the diffuse illuminance $Eeh_{diffuse}$ (sunlight excluded) or horizontal global illuminance Eeh_{global} (sunlight included) provided by the local Meteorology Station can be used to substitute the Eeh.

If the C_{sky} is ratio which correlates the illuminance at the face of the window to the illuminance on a horizontal plane received from an unobstructed sky, then the vertical daylight factor is obtained by:

$$D_w = C_{sky} . 100\%$$

By definition, C_{sky} is calculated under uniform sky with constant luminance L_z, called $C_{uniform}$, is obtained by:

$$C_{unifrom} = \frac{Eev_{unifrom}}{Eeh_{unifrom}} = \frac{0.5\pi L_z}{\pi L_z} = 0.5$$

In the site measurements, because sunlight is included, the vertical daylight factor Dw is therefore obtained by:

$$Dw = D_{ws} + D_{wr}b + D_{wr}g + D_{sun} + D_{sun}b + D_{sun}g \qquad (5.7)$$

$$\rightarrow \quad Dw = (C_{ws} + C_{wr}b + C_{wr}g + C_{sun} + C_{sun}b + C_{sun}g) x 100\% \qquad (5.8)$$

Where: Dw, D_{ws}, $D_{wr}b$, $D_{wr}g$ are as defined in equation (5.4)

D_{sun} : Vertical daylight factor at the outside of window surface given by the sunlight [%].

$D_{sun}b$: Vertical daylight factor at the outside of window surface given by the reflected sunlight from buildings [%].

$D_{sun}g$: Vertical daylight factor at the outside of window surface given by the reflected sunlight from ground [%].

Various forms of C_{sky} are defined in table 5.18

Table 5.18 Definitions of various forms of C_{sky}

$C_{sky} = \frac{Ews}{Eeh_{diffuse}}$	C_{sky} correlating the ratio of direct vertical illuminance on the window surface coming from diffuse sky , and the unobstructed horizontal diffuse sky illuminance.
$C_rb = \frac{E_{wr}b}{Eeh_{diffuse}}$	C_rb correlating the ratio of reflected illuminance on the window surface coming from external buildings to the unobstructed horizontal diffuse sky illuminance.
$C_rg = \frac{E_{wr}g}{Eeh_{diffuse}}$	C_rg correlating the ratio of reflected illuminance on window surface coming from ground, to unobstructed horizontal diffuse sky illuminance.
$C_{sun} = \frac{E_{sun}}{Eeh_{diffuse}}$	C_{sun} correlating the ratio of direct sunlight on the window surface to the unobstructed horizontal diffuse sky illuminance.

$C_{diffuse} = \frac{Eev}{Eeh_{diffuse}}$	$C_{diffuse}$ correlating the ratio of total vertical illuminance on the window surface to the unobstructed horizontal diffuse sky illuminance.
$C_{diffuse}D$	is $C_{diffuse}$ measured in the Dry season.
$C_{diffuse}W$	is $C_{diffuse}$ measured in the Wet season.
$C_{global} = \frac{Eev}{Eeh_{global}}$	C_{global} correlating the ratio of total vertical illuminance on the window surface to the unobstructed horizontal global sky illuminance.
$C_{global}D$	is C_{global} measured in the Dry season.
$C_{global}W$	is C_{global} measured in the Wet season.
$C_{sun}b = \frac{E_{sun}b}{Eeh_{diffuse}}$	$C_{sun}b$ correlating the ratio of reflected sunlight from buildings to the unobstructed horizontal diffuse sky illuminance.
$C_{sun}g = \frac{E_{sun}g}{Eeh_{diffuse}}$	$C_{sun}g$ correlating the ratio of reflected sunlight from the ground to the unobstructed horizontal diffuse sky illuminance.

Figure 5.38 shows the regressive graph of Eev to $Eeh_{diffuse}$. Although the data is quite scattered, this suggests that, in the real situation of HCMC urban context (as presented by these four schools), typically $C_{diffuse}$=0.3. This means, under uniform sky condition, the average sky access is 60% approximately.

Although this plotting includes the impact of the overhangs, it provides an overview of the average conditions. It should be noted that the presence of each component in equation (5.7) varies at any given time of the day. For example, if there is no sunlight and no external obstruction, then Dw is only the sum of D_{ws} and $D_{wr}g$.

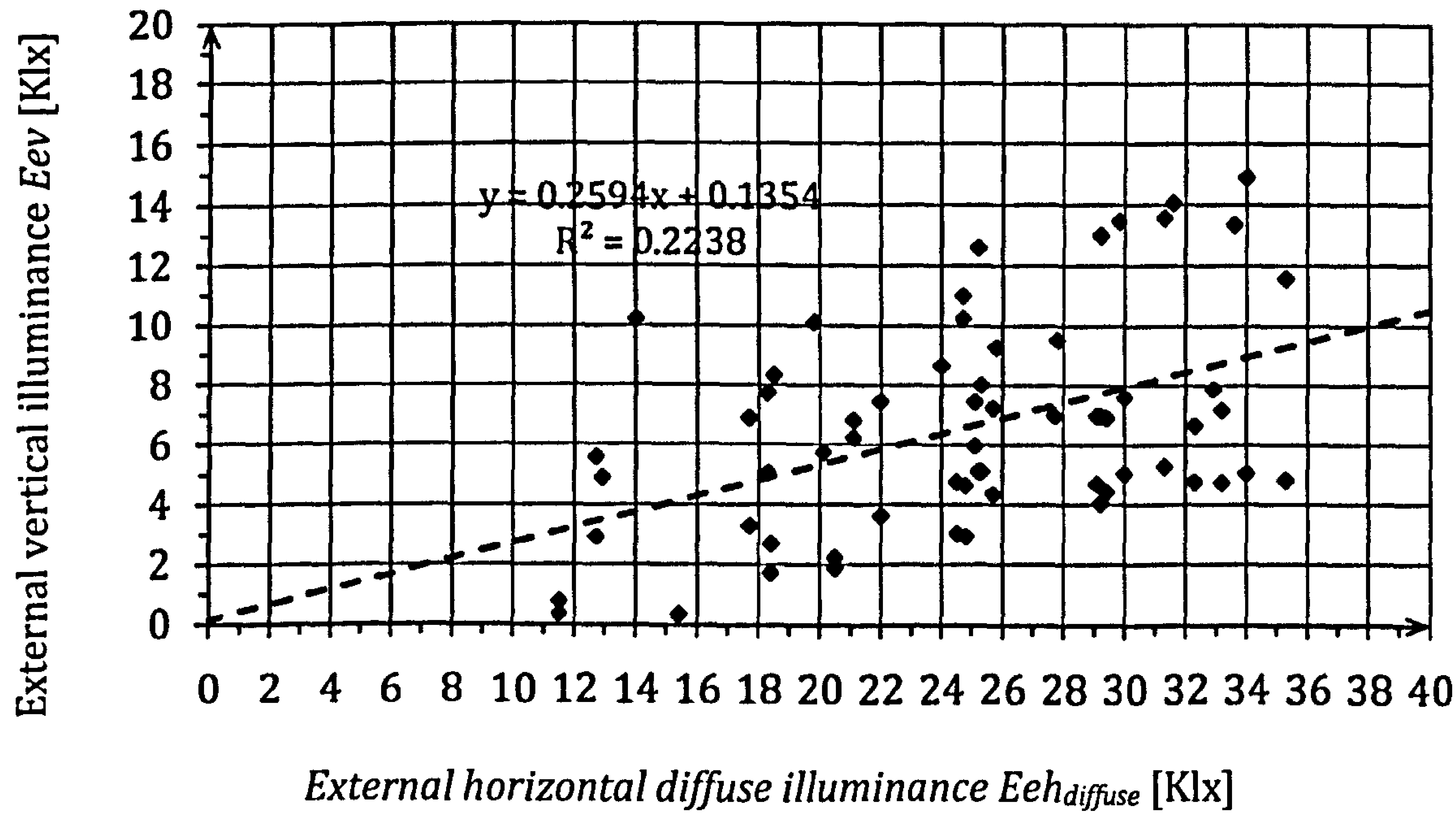


Figure 5.38 Regressive plotting of the External vertical illuminance *Eev* and the External horizontal illuminance *Eeh*.

Data presented in table 5.19 reveals further details on the daylight context of each site. It should be noted that the external horizontal diffuse illuminance $Eev_{diffuse}$ values do not change too much in both seasons, but $C_{diffuse}$ is significantly different in both seasons, and varied in each school context.

In Le Van Tam School, where *Eev* is measured on the West facade, the ratio in the morning (9h00 to 12h00) is quite similar in both seasons. In the Dry season, $C_{diffuse}$ gradually grows in the afternoon (after 12h00) to nearly double by the end of the day. This indicates the impact of sunlight; perhaps from either direct sunlight or external reflected sunlight, or as a combination of both.

In Truong Cong Dinh School, $C_{diffuse}$ is quite similar in both seasons. Although *Eev* is measured on the East facade, the impact of sunlight seems to be small, illustrated in the fact that there is a small growth of $C_{diffuse}$ in only the morning readings in the Dry season (more specific, from 9h00 to 11h00). The whole daylight context seems to be much diffused.

In Ha Huy Tap School, $C_{diffuse}$ measured on the East facade in the Dry season grows in both the morning and afternoon readings. In the morning when direct sunlight is present, the difference is small. This indicates that external obstructions perhaps provide some shading in the morning and reflect sunlight in the afternoon.

In Lam Son School, where main windows face South, $C_{diffuse}$ in the morning is quite similar in both seasons. This ratio, however, increases quite a lot in the afternoon readings of the Dry season.

The readings presented on table 5.19 together with the full site and classroom daylight shadow plotting visualized in computer presented in appendix P are analysed in the next sections.

Table 5.19 Plotting of C_{sky} ratios from site measurements

School		Le Van Tam					Truong Cong Dinh					Ha Huy Tap					Lam Son				
Orientation		*West*					*East*					*East*					*South*				
		Illuminance			*C ratio*		*Illuminance*			*C ratio*		*Illuminance*			*C ratio*		*Illuminance*			*C ratio*	
Season	***Time***	*Eev* [lx]	Diffuse [Klx]	Global [klx]	$C_{diffuse}$	C_{global}	*Eev* [lx]	Diffuse [Klx]	Global [klx]	$C_{diffuse}$	C_{global}	*Eev* [lx]	Diffuse [Klx]	Global [klx]	$C_{diffuse}$	C_{global}	*Eev* [lx]	Diffuse [Klx]	Global [klx]	$C_{diffuse}$	C_{global}
DRY SEASON	9	5735	20.1	41.0	**0.29**	**0.14**	6797	21.1	47.5	**0.32**	**0.14**	6225	21.1	47.5	**0.30**	**0.13**	10980	24.7	55.1	**0.44**	**0.20**
	10	6977	27.7	65.5	**0.25**	**0.11**	5964	25.1	77.9	**0.24**	**0.08**	7435	25.1	77.9	**0.30**	**0.10**	13007	29.2	87.3	**0.45**	**0.15**
	11	7859	32.9	88.4	**0.24**	**0.09**	5049	18.3	103.9	**0.28**	**0.05**	7712	18.3	103.9	**0.42**	**0.07**	14052	31.6	107.3	**0.44**	**0.13**
	12	9281	25.8	101.2	**0.36**	**0.09**	4690	29.1	121.5	**0.16**	**0.04**	6961	29.1	121.5	**0.24**	**0.06**	13350	33.6	110.2	**0.40**	**0.12**
	13	8644	24.0	92.1	**0.36**	**0.09**	4346	25.7	112.1	**0.17**	**0.04**	7222	25.7	112.1	**0.28**	**0.06**	13464	29.8	105.1	**0.45**	**0.13**
	14	9526	27.8	70.4	**0.34**	**0.14**	3644	22.0	79.1	**0.17**	**0.05**	7435	22.0	79.1	**0.34**	**0.09**	10229	24.7	76.5	**0.41**	**0.13**
	15	10114	19.8	43.6	**0.51**	**0.23**	3301	17.7	49.8	**0.19**	**0.07**	6879	17.7	49.8	**0.39**	**0.14**	8317	18.5	48.7	**0.45**	**0.17**
	16	10212	14.0	20.0	**0.73**	**0.51**	2925	12.7	24.0	**0.23**	**0.12**	5572	12.7	24.0	**0.44**	**0.23**	4902	12.9	21.6	**0.38**	**0.23**
WET SEASON	9	7990	25.3	46.3	**0.32**	**0.17**	5098	25.3	46.3	**0.20**	**0.11**	5098	25.2	48.7	**0.20**	**0.10**	12598	25.2	48.7	**0.50**	**0.26**
	10	7582	30.0	73.0	**0.25**	**0.10**	5033	30.0	73.0	**0.17**	**0.07**	5261	31.3	68.7	**0.17**	**0.08**	13578	31.3	68.7	**0.43**	**0.20**
	11	6650	32.3	84.5	**0.21**	**0.08**	4771	32.3	84.5	**0.15**	**0.06**	5049	34.0	82.9	**0.15**	**0.06**	14902	34.0	82.9	**0.44**	**0.18**
	12	7157	33.2	88.0	**0.22**	**0.08**	4739	33.2	88.0	**0.14**	**0.05**	4820	35.3	81.5	**0.14**	**0.06**	11585	35.3	81.5	**0.33**	**0.14**
	13	6895	29.4	80.3	**0.23**	**0.09**	4428	29.4	80.3	**0.15**	**0.06**	4052	29.2	63.0	**0.14**	**0.06**	6977	29.2	63.0	**0.24**	**0.11**
	14	4641	24.8	52.1	**0.19**	**0.09**	2958	24.8	52.1	**0.12**	**0.06**	3056	24.5	47.4	**0.12**	**0.06**	4755	24.5	47.4	**0.19**	**0.10**
	15	2222	20.5	33.5	**0.11**	**0.07**	1895	20.5	33.5	**0.09**	**0.06**	1732	18.4	29.3	**0.09**	**0.06**	2696	18.4	29.3	**0.15**	**0.09**
	16	343	15.4	16.7	**0.02**	**0.02**	343	15.4	16.7	**0.02**	**0.02**	768	11.5	13.1	**0.07**	**0.06**	359	11.5	13.1	**0.03**	**0.03**

5.5.2. Analyses of the daylight context of Le Van Tam School

Generally, as seen in the site section illustrated in figure 5.39, there is no obstruction higher than the reference point P1. Therefore in this case, the total vertical illuminance at the window surface, *Eev,* is the sum of direct light from sky and ground reflected light:

$$Eev = E_{ws} + E_{wr}g + E_{sun} + E_{sun}g$$

$$\text{or:} \quad C = C_{sky} + C_{r}g + C_{sun} + C_{sun}g$$

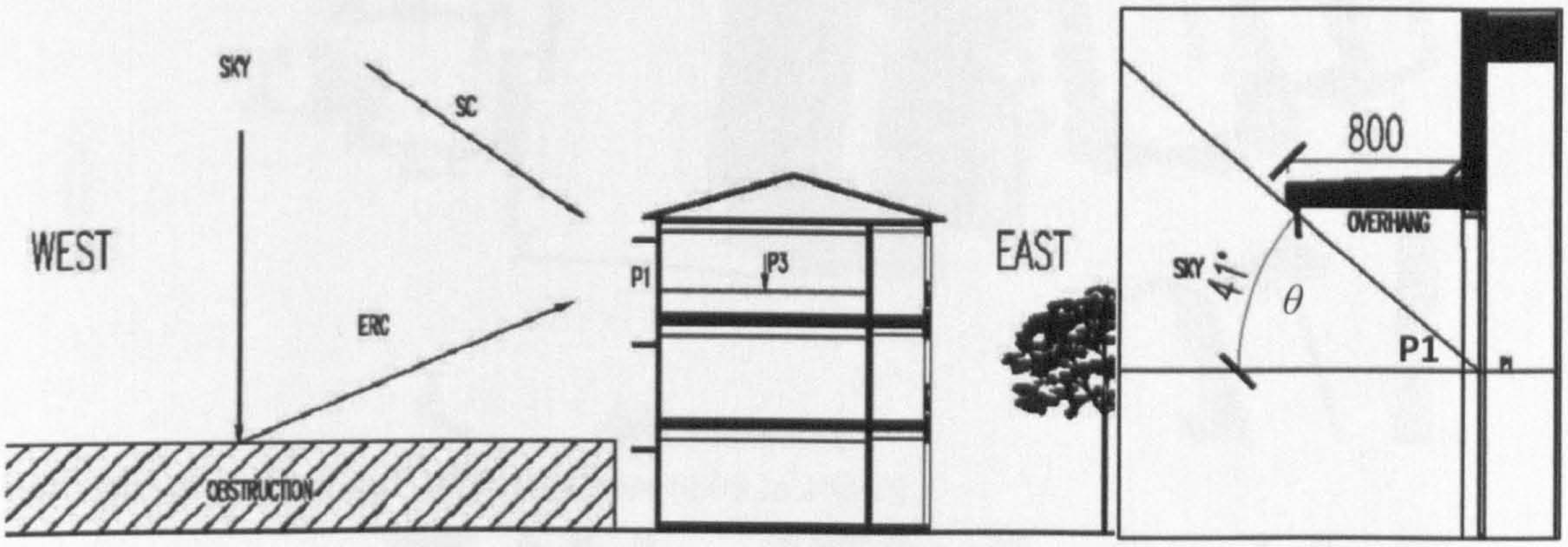
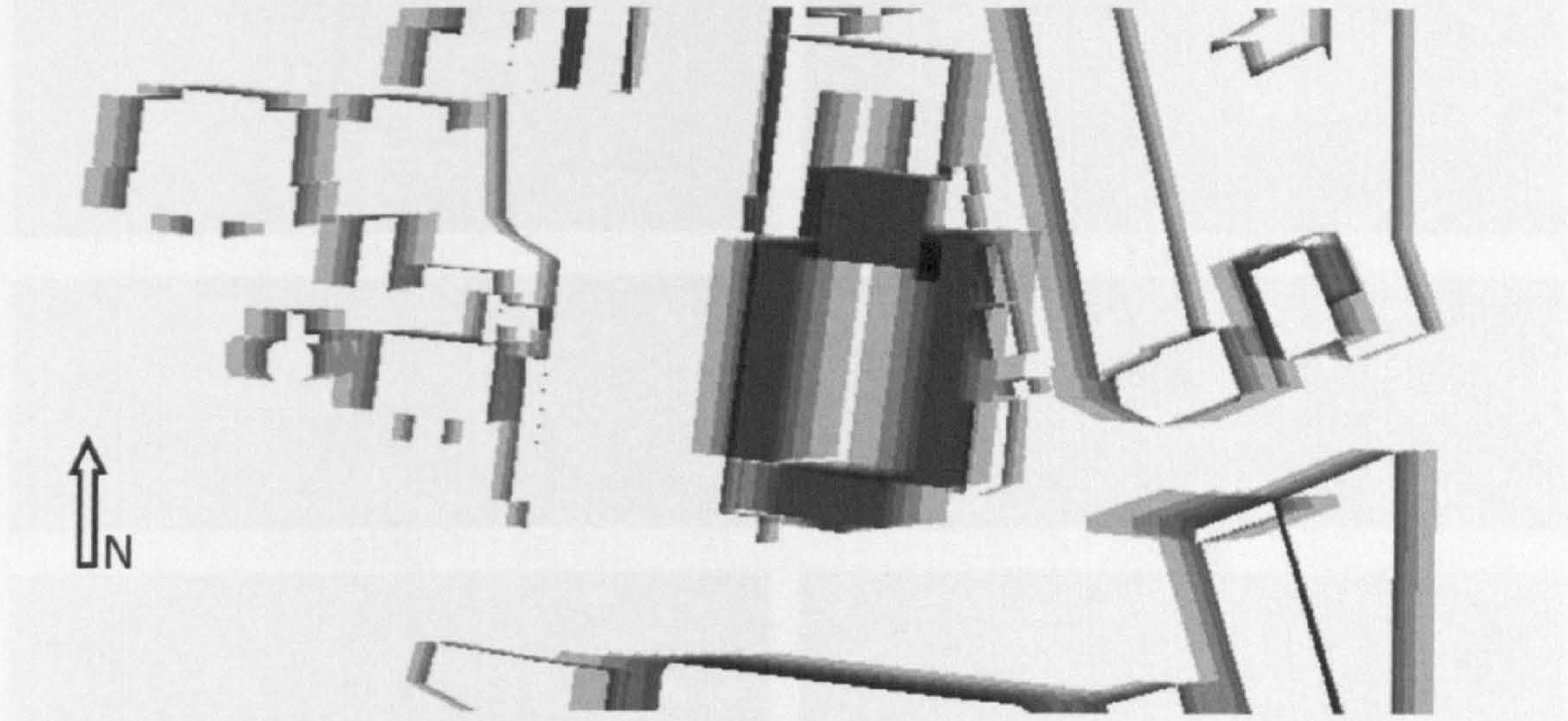


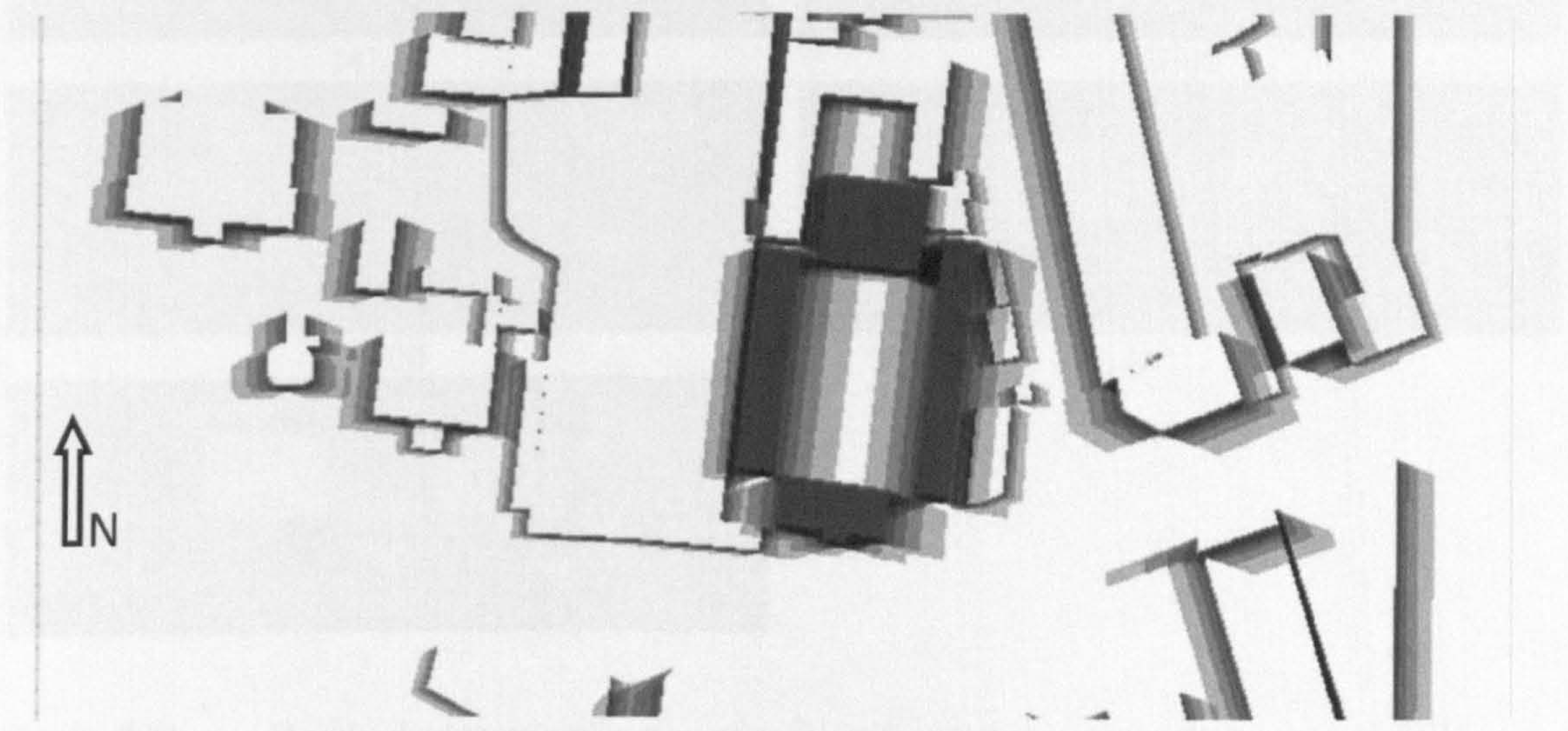
Figure 5.39 Le Van Tam School's daylight component on West facade.

Furthermore, figure 5.40 shows the computerized shadow visualization of the site context during the survey months (February and October). It is shown that as a result of orientation the contribution of sunlight is significant in the afternoon, especially in the Dry season when sky is clear most of the time.

EQUINOX (21ST MARCH and 21st SEPEMBER) from 8h00 to 16h00



JUNE SOLSTICE (21ST JUNE) from 8h00 to 16h00



DECEMBER SOLSTICE (21ST JUNE) from 8h00 to 16h00

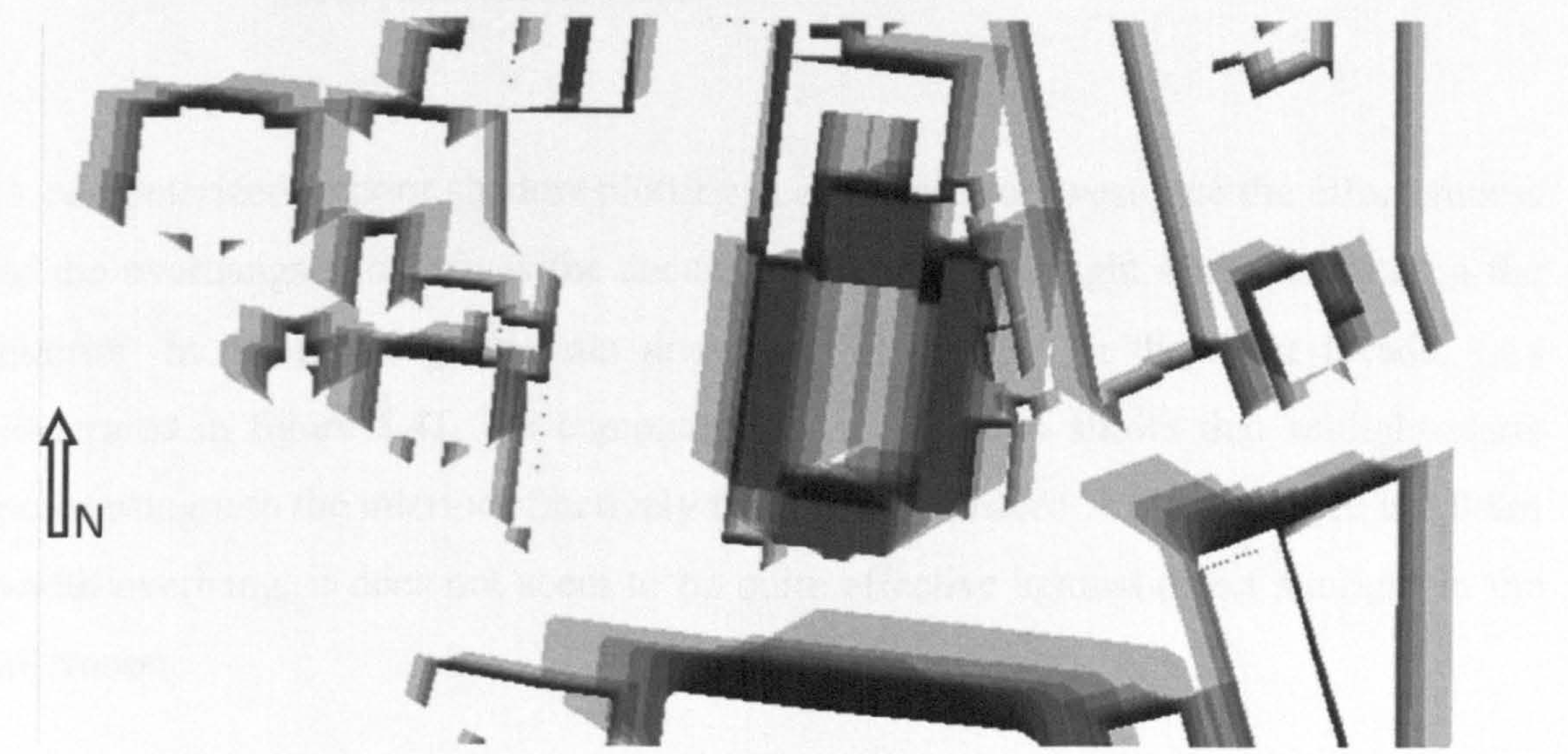


Figure 5.40 Le Van Tam School site's shadow plotting.

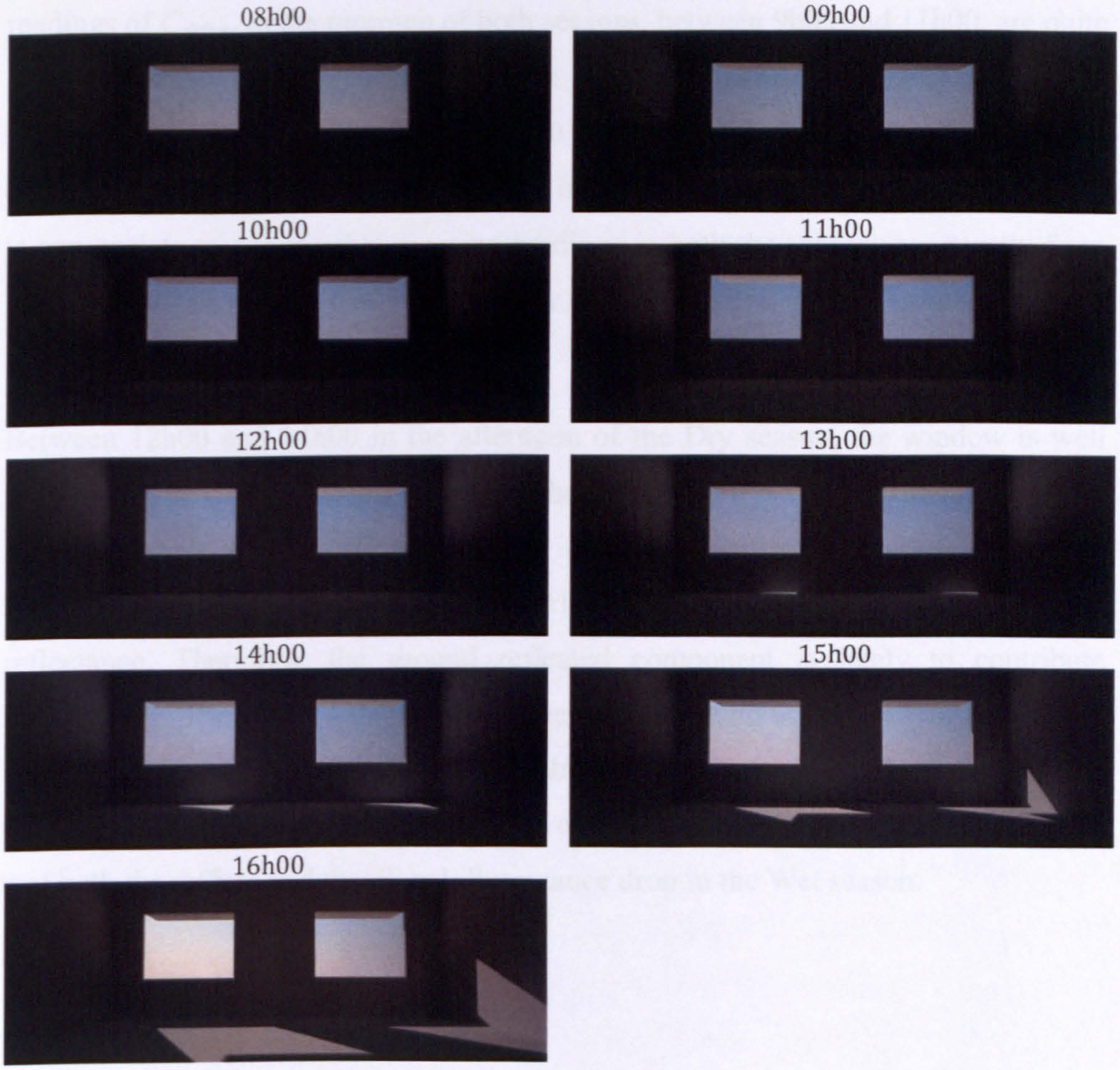


Figure 5.41 Hourly shadow visualization of Le Van Tam School classroom interior on 21st March , from 8h00 to 16h00.

A computerized interior shadow plotting is employed to investigate the effectiveness of the overhangs and defines the accurate time when sunlight starts penetrating the interior. In the morning, the sun does not fall directly on the West facade. As illustrated in figure 5.41, the computerized visualization shows that sunlight starts penetrating into the interior effectively from 13h00 onward. Although there is a 0.8m width overhang, it does not seem to be quite effective against direct sunlight in the afternoon.

Comparing these results and the data collected onsite, as presented in table 5.19, provides some interesting results. Figure 5.42 giving a clearer interpretation of table 5.19, shows the comparisons of $C_{diffuse}$ and C_{global} readings in both the seasons. The readings of $C_{diffuse}$ in the morning of both seasons, between 9h00 and 11h00, are quite similar. It starts growing in the afternoon in the Dry season, but fades in the Wet season. In the Dry season, between 12h00 and 14h00, $C_{diffuse}$ grows slightly. Then after 14h00, $C_{diffuse}$ is significantly higher in the Dry season. From these readings, it is appropriate to assume that morning readings in both the seasons are mostly from light from the sky, these readings probably consist of direct sky and ground reflected light from the sky.

Between 12h00 and 14h00 in the afternoon of the Dry season, the window is well protected from direct sunlight by the overhang, but there is still considerable growth of $C_{diffuse}$. This means that this reading can only be from the ground reflected sunlight. The main windows 1 and 2 overlook the neighbouring roof top with high reflectance. Therefore, the ground reflected component is likely to contribute significantly. Then from 14h00 onward, the drastic growth is the result of both direct sunlight and ground reflected sunlight. In the Wet season, it often rains in the afternoon and the sky is quite cloudy. It is obvious in the data presented in table 5.19 that both the diffuse and the global illuminance drop in the Wet season.

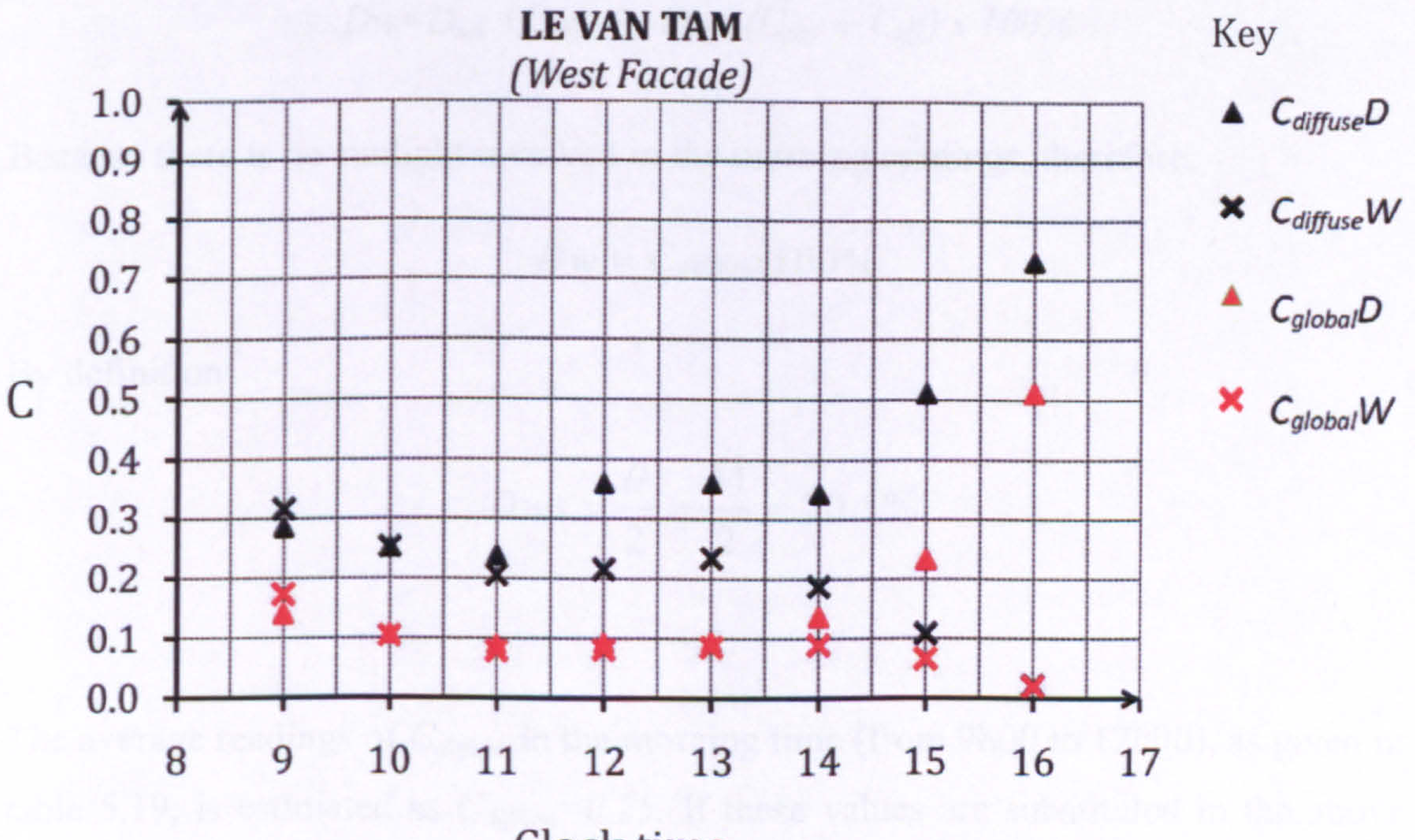


Figure 5.42 Plotting of various *C* ratios of Le Van Tam School classroom during class hours.

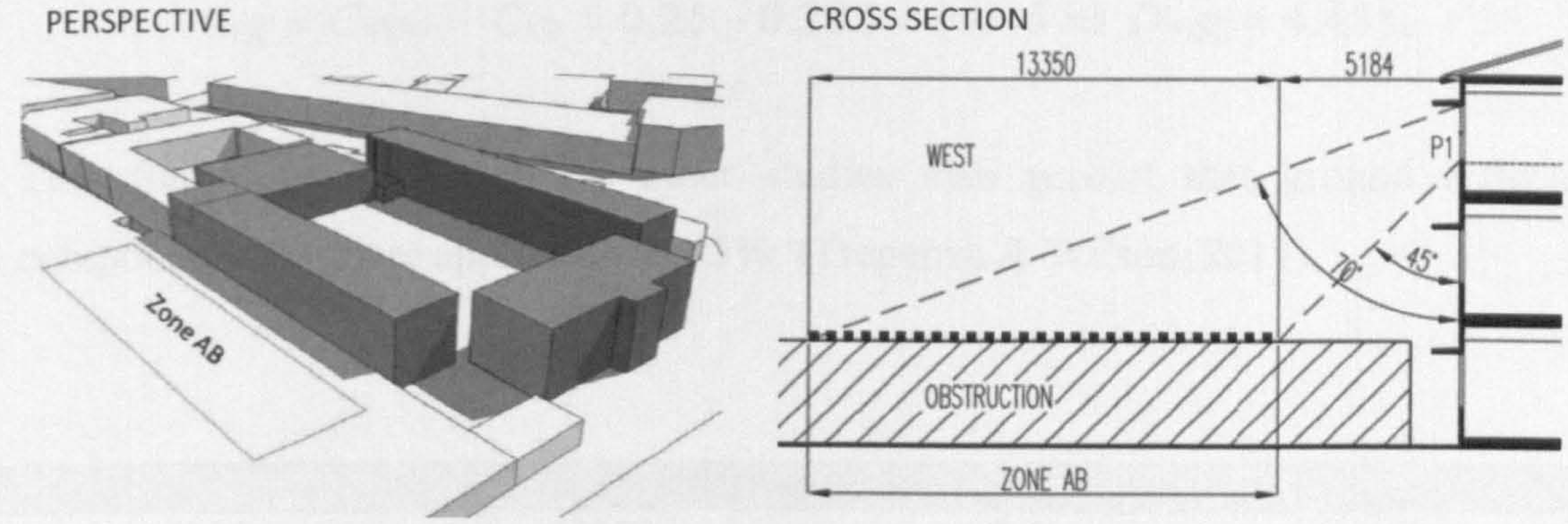


Figure 5.43 The important ground reflected zone A-B band on Le Van Tam's West facade.

Based on the findings by R.Carbús (2001), introduced in earlier sections, the significant zone A-B next to the West facade in this case is limited between 5.18m and 18.53m offset line from the facade, which is the neighbouring roof (see figure 5.43). Therefore, the ground reflected light has a large influence on classroom illumination in this case.

Because the main windows are on the West facade, it should be noted that there is no direct sunlight on this side in the morning. There are also no high external obstructions on this facade. Hence, the *Dw* readings recorded in the morning consist only of direct light from sky and sky reflected light from the ground:

$$Dw = D_{ws} + D_r g \rightarrow Dw = (C_{sky} + C_r g) \times 100\%$$

Because there is no sunlight involved in the morning readings, therefore:

$$Dw = C_{diffuse} x 100\%$$

By definition:

$$Dws = \frac{\theta}{2} = \frac{41}{2} = 20.5\%$$

The average readings of $C_{diffuse}$ in the morning time (from 9h00 to 12h00), as given in table 5.19, is estimated as $C_{diffuse}=0.25$. If these values are substituted in the above equations, it is estimated that the ground reflected light component from diffuse sky, D_{wrg}, is obtained by:

$$C_rg = C_{diffuse} - C_{sky} = 0.25 - 0.205 = 0.045 \Rightarrow D_{wr}g = 4.45\%$$

This finding is acceptable as other studies also predict that ground reflected component contribute approximately 5%. (Tregenza & Wilson, 2011).

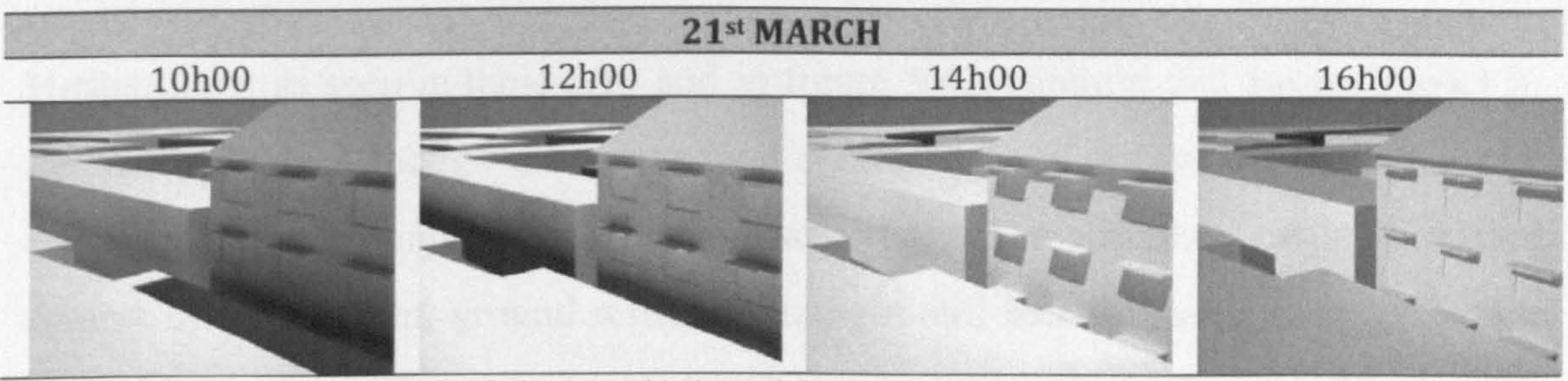


Figure 5.44 Computerised shadow plotting of the external context of Le Van Tam School

As shown in figure 5.42, between 12h00 and 16h00 in the Dry season the sunlight contribution becomes important. However, as shown in figure 5.41, because of the overhang protection, direct sunlight starts penetrating the room only from 14h00 onward. Therefore between 12h00 and 14h00, the growth of $C_{diffuse}$ is mainly due to ground reflected sunlight. The average readings of $C_{diffuse}$ between 12h00 and 14h00 in the Dry season, as shown in table 5.19, is estimated as $C_{diffuse} = 0.35$.

Between 12h00 and 14h00 in the Dry season, $C_{diffuse}$ would be the sum of:

$$C_{diffuse} = C_{sky} + C_rg + C_{sun}g$$

Because C_{sky} and C_rg relate to the contribution of diffuse sky therefore they remain the same throughout the day. As estimated above, $C_{sky} = 0.025$ and $C_rg = 0.045$, therefore the $C_{sun}g$ during this time is $C_{sun}g \approx 0.1$, this means $D_{sun}g \approx 10\%$.

From 14h00 onward during the Dry season, $C_{diffuse}$ is the sum of:

$$C_{diffuse} = C_{sky} + C_rg + C_{sun}g + C_{sun}$$

The sunlight contribution, C_{sun}, can be estimated after taking out all other components as given above from the $C_{diffuse}$ readings presented in table 5.19. Of course, as the position of the sun changes and the sky conditions also change, the sunlight impact will vary a lot during the time.

Although the window is well shaded, these findings show that the ground reflected sunlight credits for approximately 30% of the total vertical illuminance received at the outer surface of the windows. And overall, the total ground reflected components make up about 42% of the total vertical illuminance. It is estimated that HCMC has 2497 hours of sunny days annually, so it is likely that ground reflected light is a very important factor contributing to task illuminance.

Furthermore, as seen in table 5.19 and in figure 5.42, sunlight still has an impact in the Wet season. Although during the Wet season, the sky is cloudier, there are still considerable sunny intervals. If it is assumed that the windows are well shaded against direct sunlight, ground reflected sunlight still has a significant influence on room illumination. However, ground reflected components, both from the sky and sunlight, is ignored in both the *ĐRASTN* and the Danhiluc chart method introduced by the Vietnamese codes. It is understood that these methods are developed for overcast sky model which is more appropriate for temperate climate. Their validity for tropical climate should be reviewed.

Once the daylight availability on the window surfaces is identified, the light lost due to glazing and increment due to inter-reflectance can be estimated. When travelling into the interior, the light is partly lost because of the glazing and internal blinds (defined by the diffuse transmittance of the glazing τ) and inter-reflected by the interior surfaces (defined by the room geometry and surface reflectance). Therefore, the equation for the average daylight factor thus becomes (Tregenza & Wilson, 2011):

$$\bar{D} = D_w \frac{A_w \, \tau}{A_r(1-\rho)} \Rightarrow \tau = \frac{\bar{D} \, A_r(1-\rho)}{D_w A_w} \tag{5.9}$$

Where:

D_w: Vertical daylight factor measure at mid-height of outer window surface [%]

A_w: Total window area [m^2]

A_r: Total room surface area [m^2]

ρ: Mean reflectance of the enclosing room surfaces, in decimal

However, windows 1 and 2 only contribute part of the total *EihD*. We can use the known contribution value of windows 1 and 2 (as given in table 5.17, page 225) along with the site measurements of *EihD,* to find out the transmittance value of the glazing of windows 1 and 2. According to table 5.17, windows on wall 1 contribute 68.69% of the total daylight. The readings of *EihD* used in this calculation are the average *EihD-W* reading of morning time in the Wet season (from 9h00 to 12h00). During this time the sunlight impact, which varies, is minimal therefore average *EihD-W* reading represents the stable conditions of diffuse sky better. From equation (5.9), the transmittance factor τ is estimated as:

$$\tau = \overline{D}\frac{A_r(1-\rho)}{D_w A_w} \times \frac{100}{68.69} = \left(\frac{289.63}{29200}\right) \times \frac{200.96 \times (1-0.52)}{0.25 \times 6.3} \times \frac{100}{68.69} = 0.42$$

The *diffuse glazing transmittance factor,* τ value, found above seems to be quite small. This means only 42% of the light received on the windows' outer surface finally reaches the task plane. However, it should be noted that the reduction by glazing transmittance here, represents several reduction factors such as the glazing transmittance factor, dirt on the glazing, window bars and internal blinds that left partly opened. Because these site measurements were recorded during normal operational class hours and there are 40-50 students in each classroom, as a consequence the students themselves also obstruct the light.

This analysis of the daylight context of Le Van Tam School reveals several problems. The shading device seems to be ineffective and it does not offer good protection against sunlight penetration (from 14h00 onward, sunlight starts penetrating the interior from the West facade). Crucially, it is discovered that ground reflected light contributes significantly to the room illuminance, but is not addressed well in the current codes. There are also questions on the validity of using overcast sky model in the case of HCMC, where tropical sunny climate is dominant.

5.5.3. Analyses of the daylight context of Truong Cong Dinh School

The daylight context on the East facade of Truong Cong Dinh School is very much diffused, as it is dictated by the impact of the trees. On this facade, there is no obstruction higher than the window sill. However, there is a park with rows of low trees on the opposite site and high trees are also planted along the street. There is a small direct access to the sky from the gap between the crowns of the lower and higher trees. Trees do not totally block the daylight access. Trees allow part of the direct light from the sky to travel through the leaves, defined by the fraction of the visible sky through tree crown p_{sc}, and reflects part of the light received from sky. Trees also obscure other building facades and shade the ground. As a consequence they reduce the external reflected light significantly.

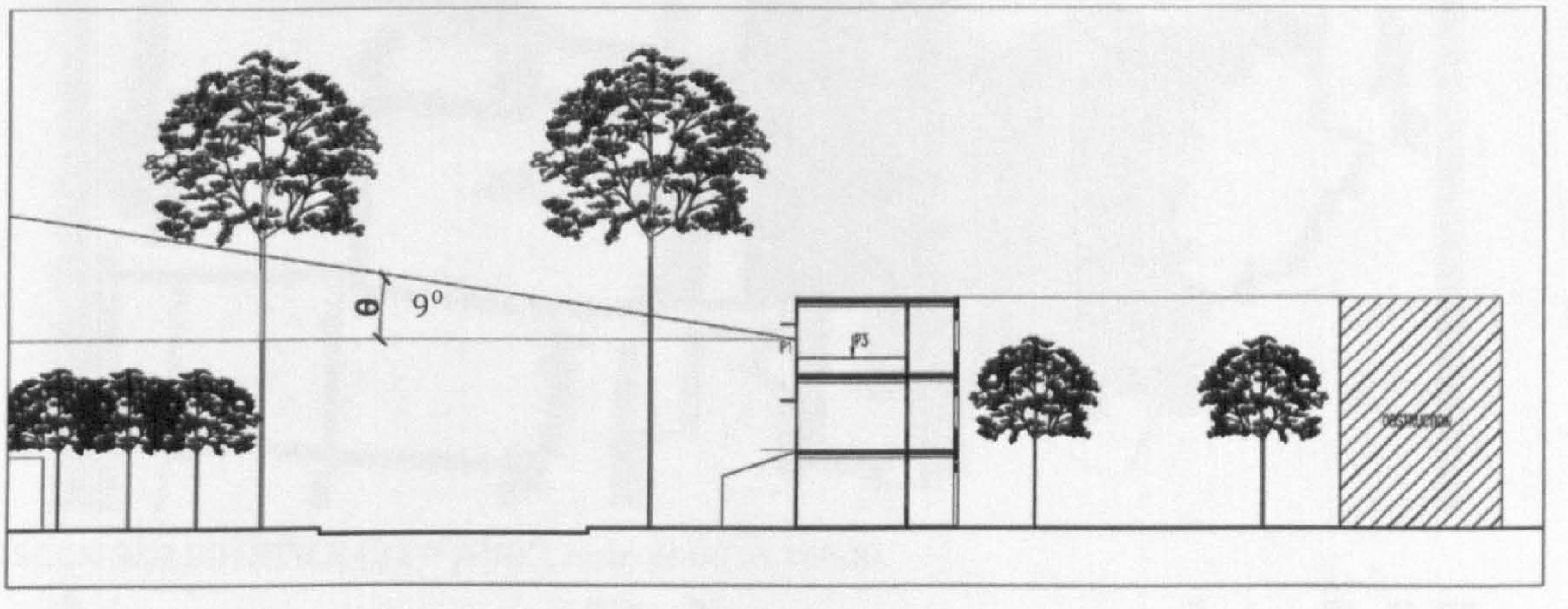


Figure 5.45 Truong Cong Dinh School's site section showing main obstructions.

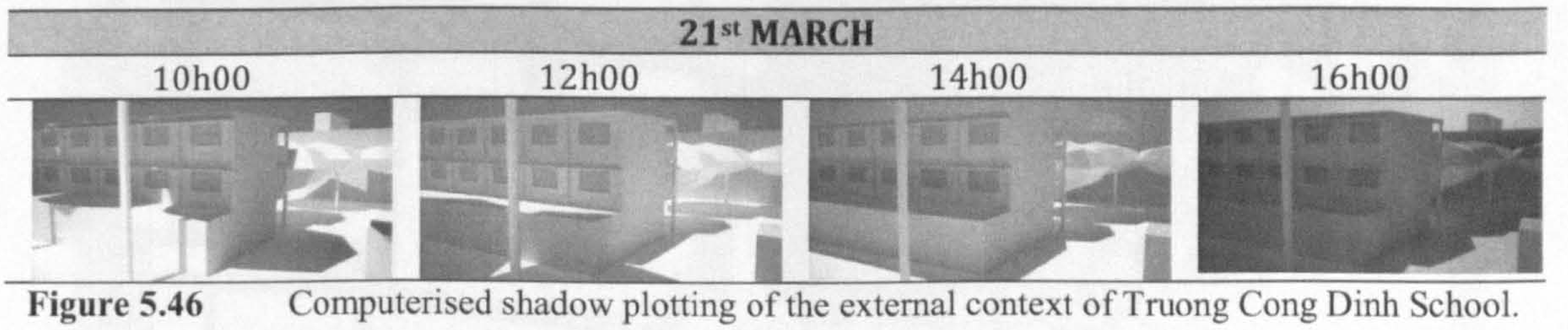
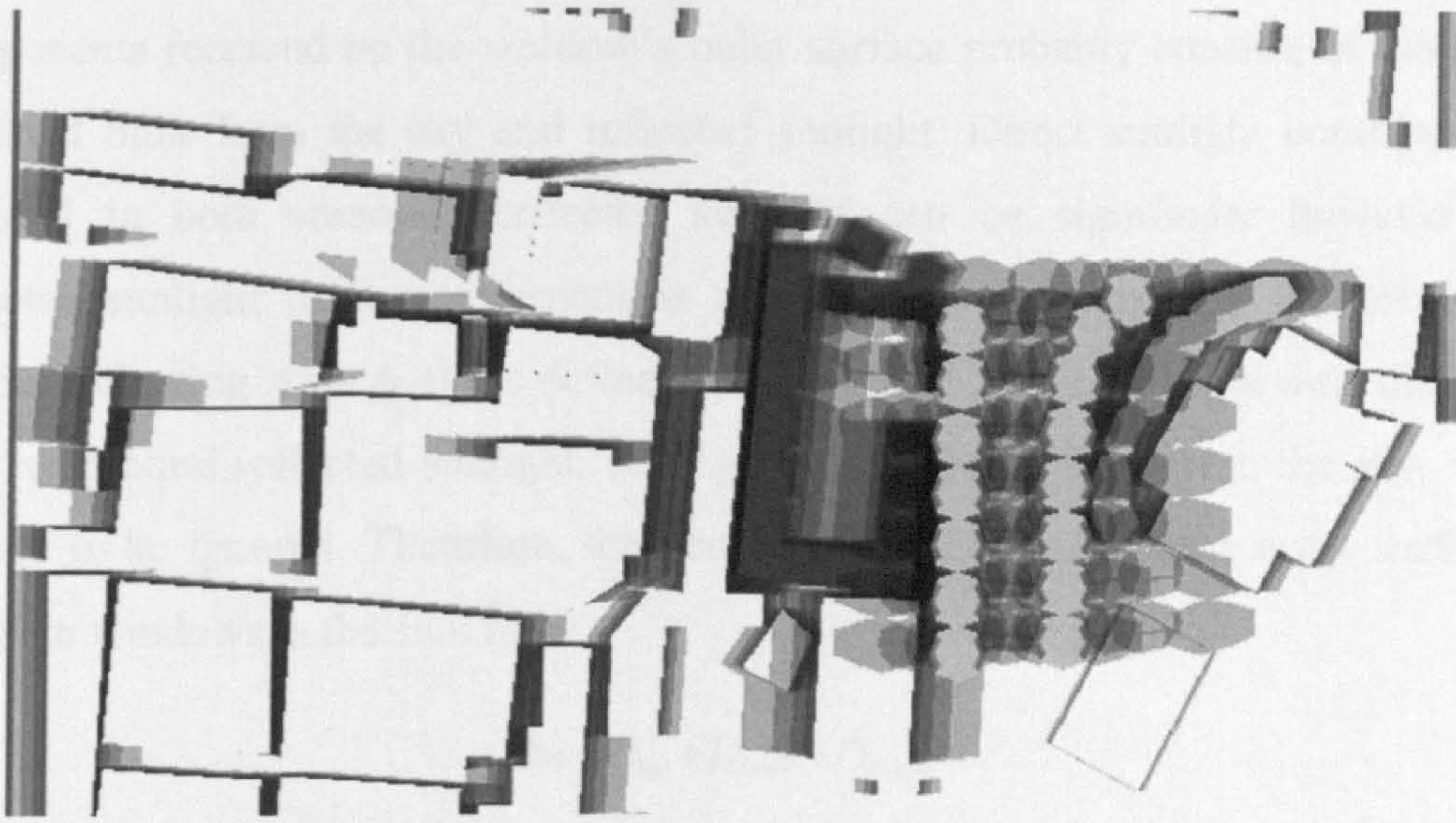
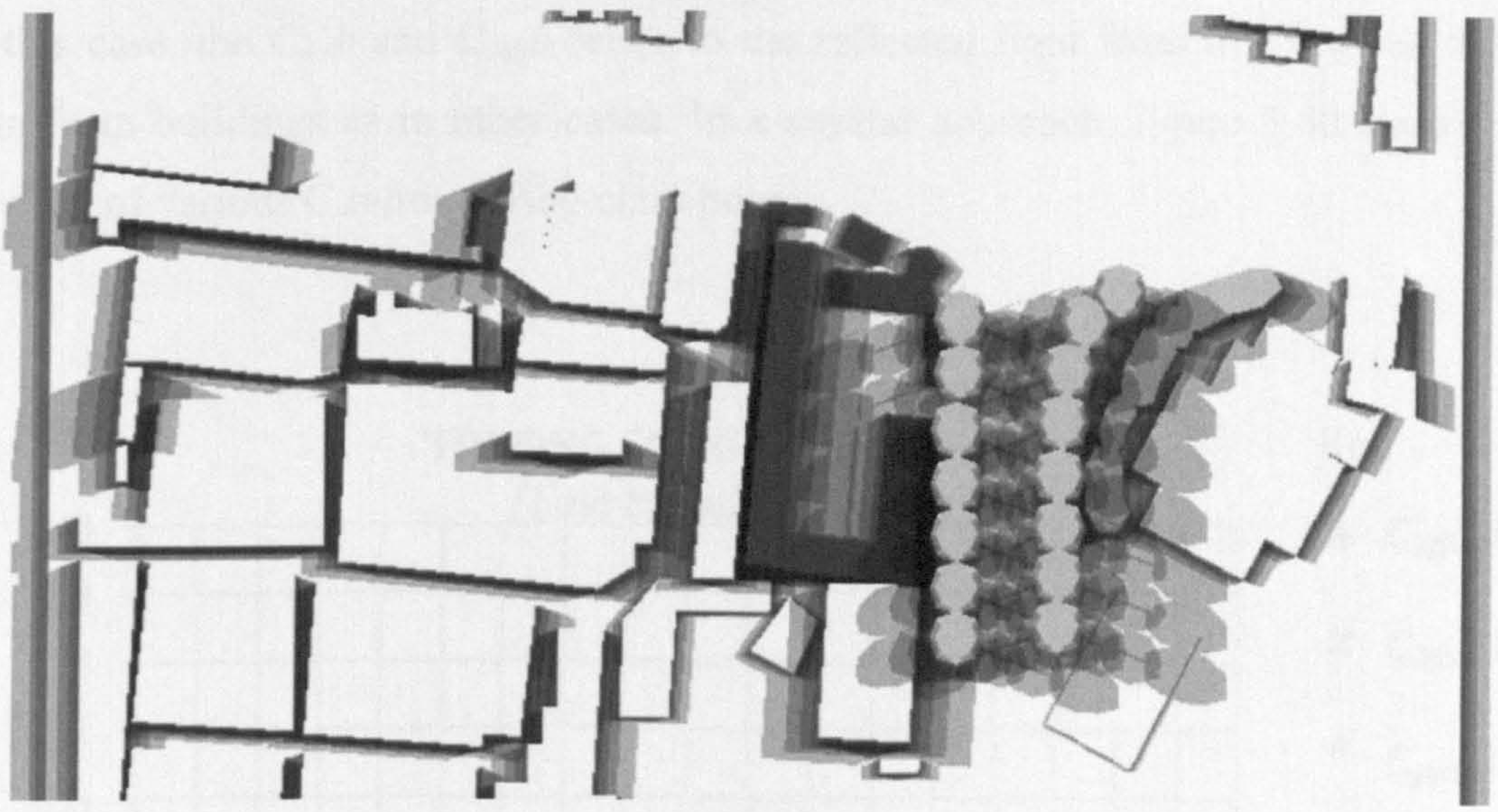


Figure 5.46 Computerised shadow plotting of the external context of Truong Cong Dinh School.

EQUINOX (21ST MARCH and 21st SEPEMBER) from 8h00 to 16h00



JUNE SOLSTICE (21ST JUNE) from 8h00 to 16h00



DECEMBER SOLSTICE (21ST JUNE) from 8h00 to 16h00

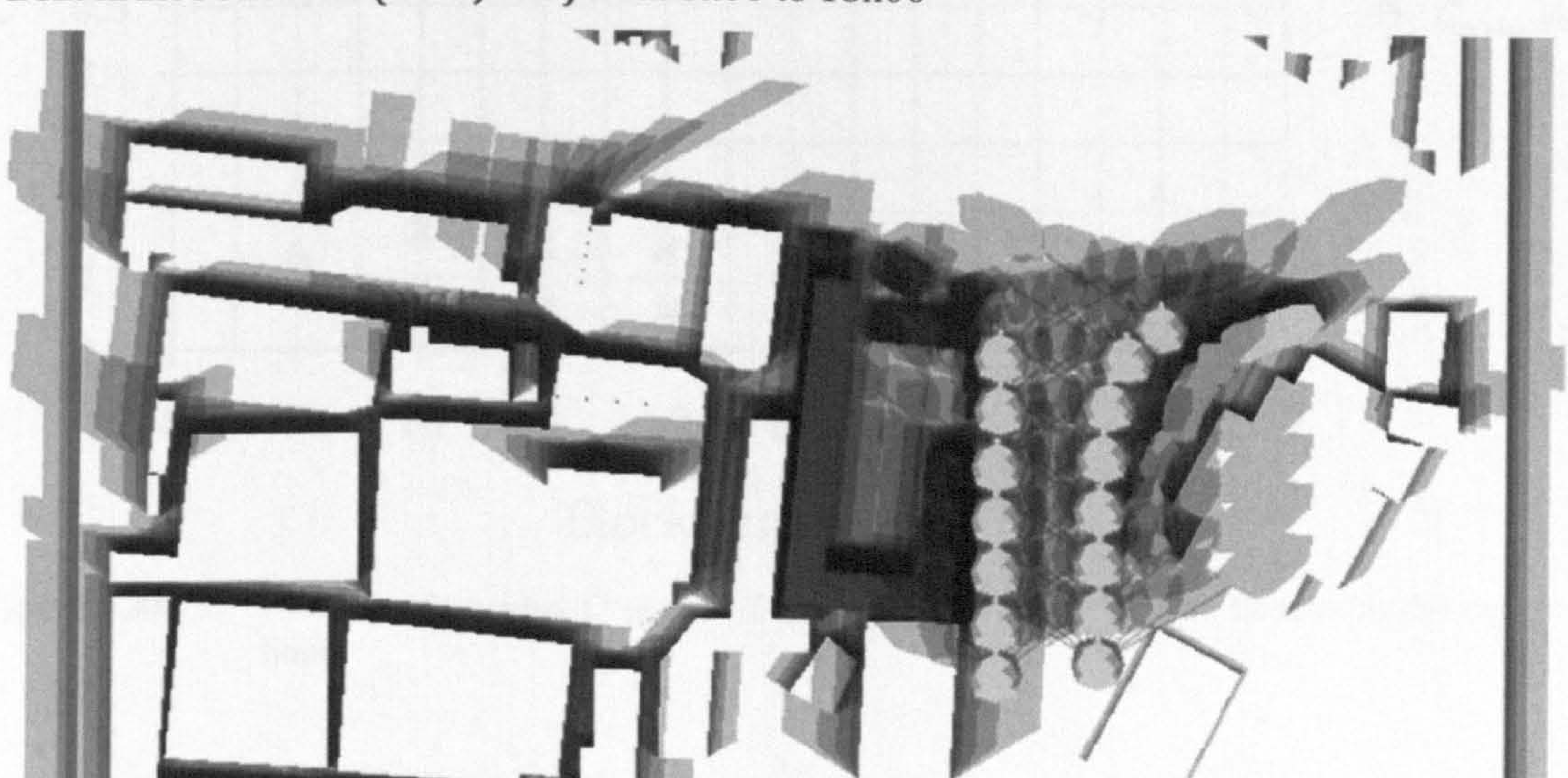


Figure 5.47 Truong Cong Dinh School site's shadow plotting.

As seen in figure 5.45, analyses of the site context shows that main daylight components received on the window's outer surface probably consists of direct and reflected light from the sky and reflected sunlight. Direct sunlight contribution is minimal in both seasons. Reflected sunlight can be significant however only reflected sunlight from tree crowns is considerable. The ground, specifically the ground reflecting zone A-B (as defined in figure 5.35, page 229) , is well shaded by trees so ground reflected sunlight, even ground reflected light from the sky, is low enough to be ignored. Therefore, the vertical daylight factor at the outer surface of the main windows is the sum of:

$$Dw=D_{ws}+D_{wr}b+D_{sun}b$$

$$\text{or} \quad C=C_{sky}+C_{wr}b+C_{sun}b$$

In this case, the $C_{wr}b$ and $C_{sun}b$ relate to the reflected light from tree crowns rather than from buildings as in other cases. In a similar approach, figure 5.48 shows the plotting of various C ratios during class hours.

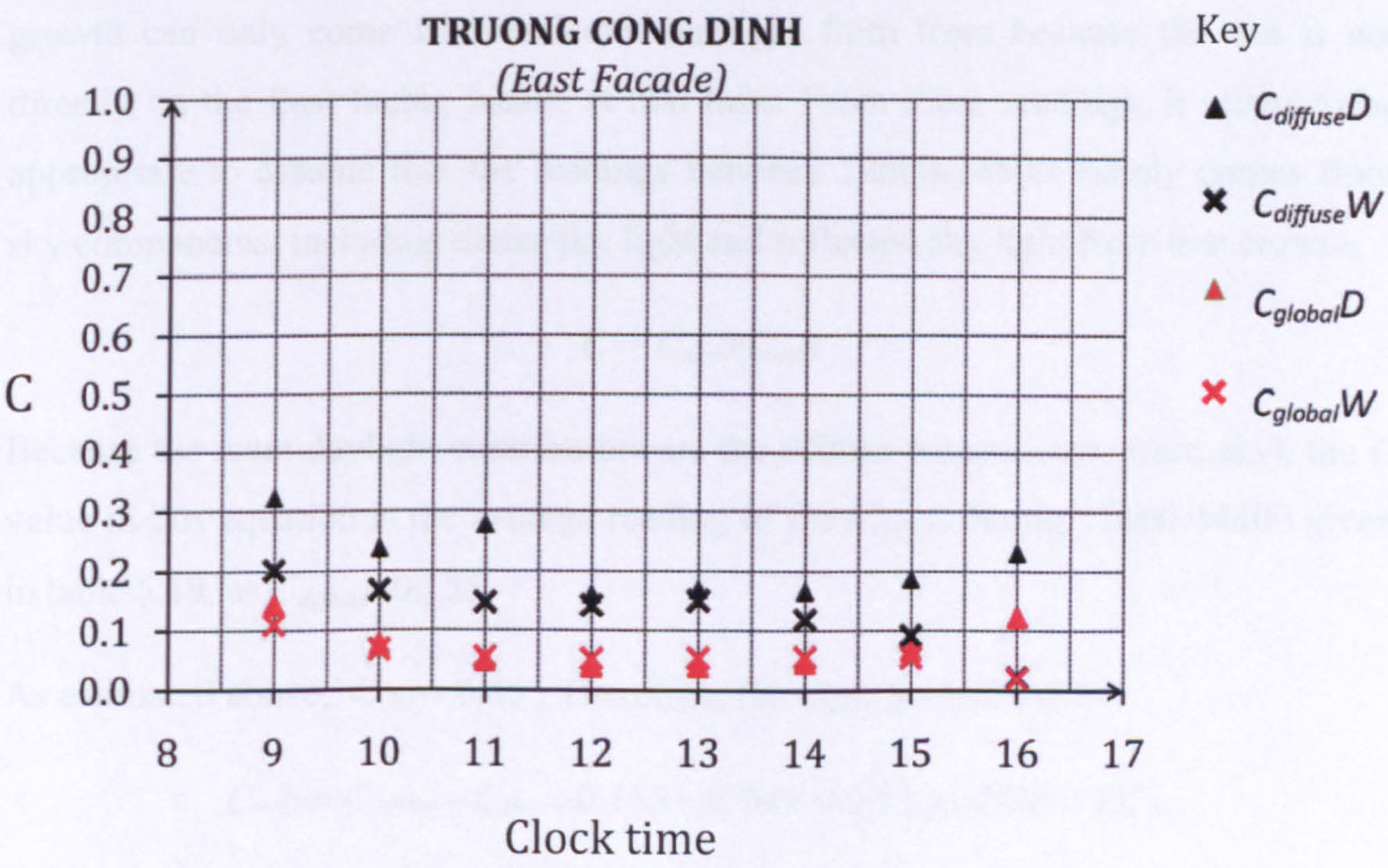


Figure 5.48 Plotting of various *C* ratios of Truong Cong Dinh School classroom during class hours

By definition, the contributions from sky light are estimated as:

$$C_{sky} = \frac{\theta}{200} = \frac{9}{200} = 0.045 \Rightarrow Dws = 4.5\%$$

The angle θ in this case is the angle defined by the space between the high and the low tree crowns (as in figure 5.45).

In figure 5.48, differences are found in both the morning and afternoon readings of the Dry season. Because these main windows are on the East facade, in the Dry season, the growth in the morning (09h00-12h00) can probably be the result of sunlight. Although direct view is mostly obscured by the trees, part of the sunlight can still travel through the spaces between trees leaves (tree foliage 80%, meaning 20% of sunlight reaching the tree crowns will travel through).

From 12h00 onward, sunlight does not directly fall on the main facade. From 12h00 to 14h00 the $C_{diffuse}$ and C_{global} drop and this signifies that the sun is moving away. The reflected sunlight during this time is small due to the sun incident angle. However, between 14h00-15h00 in the Dry season, $C_{diffuse}D$ is grows again. This growth can only come from reflected sunlight from trees because the sun is not directly on the East facing facade at that time. From these readings, it seems to be appropriate to assume that the readings between 12h00-14h00 mainly comes from sky components, including direct sky light and reflected sky light from tree crowns.

$$C = C_{sky} + C_{wr}b$$

Because the main daylight contributors are the diffuse components (from sky), the C value in this equation is the average reading of the $C_{diffuse}$ during 12h00-14h00 given in table 5.19, as $C_{diffuse}$=0.155.

As estimated above, $C_{sky} = 0.45$. Therefore, the $C_{wr}b$ is obtained by:

$$C_{wr}b = C_{diffuse} - C_{sky} = 0.155 - 0.045 = 0.11 \Rightarrow D_{wr}b = 11\%$$

Then the reflected sunlight from trees can be estimated by taking out C_{sky} and $C_{r}b$ from the average $C_{diffuse}$ readings during the Dry season between 14h00-15h00, as $C_{diffuse}$=0.185. Therefore, the reflected sunlight from tree crowns is obtained by:

$$C_{sun}b = C_{diffuse} - C_{sky} - C_{r}b = 0.185 - 0.155 = 0.03 \Rightarrow D_{sun}b = 3.0\%$$

Because the sun is moving, the contribution of direct sunlight and reflected sunlight vary throughout the day. The above estimates are the average values at a specific time, but these values provide meaningful information on how the daylight context on the outer window surfaces of Truong Cong Dinh is. At peak time (i.e. 9h00) in the Dry season, $C_{diffuse}$ is 0.32 (see table 5.19). The contribution from the sky (both direct and reflected light) is approximately 0.145 (as C_{sky}=0.045 and $C_{wr}b$=0.11). This means that despite the main facade being heavily obstructed, the sunlight contribution is estimated to be approximately 0.175; which is 55% of the total light received on outer window surfaces. In the Wet season the $C_{diffuse}$ measured at 9h00 is 0.20. This means sunlight contribution is smaller, but still make considerable contribution of approximately 27.5% of the total vertical illuminance at P1.

In the next section the *diffuse transmittance factor of the glazing* τ is estimated using the same approach as used for Le Van Tam School. According to table 5.17, windows on wall 1 contribute 65.64% of the total daylight. It should be noted that the classroom in Truong Cong Dinh School is used only in the morning shift, so the *Eih* in this case is calculated as *Eih-W* at 10h30 in the Wet season (middle of the morning shift). Then the τ is obtained by:

$$\tau = \bar{D}\frac{A_r(1-\rho)}{D_w A_w}\times\frac{100}{65.64} = \left(\frac{99.19}{31150}\right)\times\frac{194\times(1-0.48)}{15.5\times 6.44}\times\frac{100}{65.64} = 0.49$$

In summary, despite the heavily obstructed external context, sunlight still has a considerable role in this case. However, the scenario in this case is much more stable than it is in other schools. It seems that trees are an effective tool in stabilizing the sunlight impact. If sunlight is excluded and much of the direct sky access is blocked, the reflected light from tree crowns is the main daylight contributor and it credits for 70% of the total light reaching the window. In a tropical urban context, trees are often an important element of the landscape. However, trees vary in types, shapes, and depending on the time of the year, it is difficult to estimate the impact of trees accurately. It is noted that both sunlight and impact of trees are excluded in the current daylight codes despite their significant role in classroom illumination.

5.5.4. Analyses of the daylight context of Ha Huy Tap School

In Ha Huy Tap School there are several obstructions on the main facade facing East. As seen in figure 5.49, the light coming to the window's outer surface probably consists of direct light from the sun and the sky and external reflected light from the buildings and the grounds. However the ground area contributing meaningful illuminance is quite small and the street canyon is narrow, thus most of the time the ground will be shaded. As illustrated in figure 5.49, what is left of the important ground reflecting zone A-B is quite small and thus the ground reflected component is small enough to be ignored.

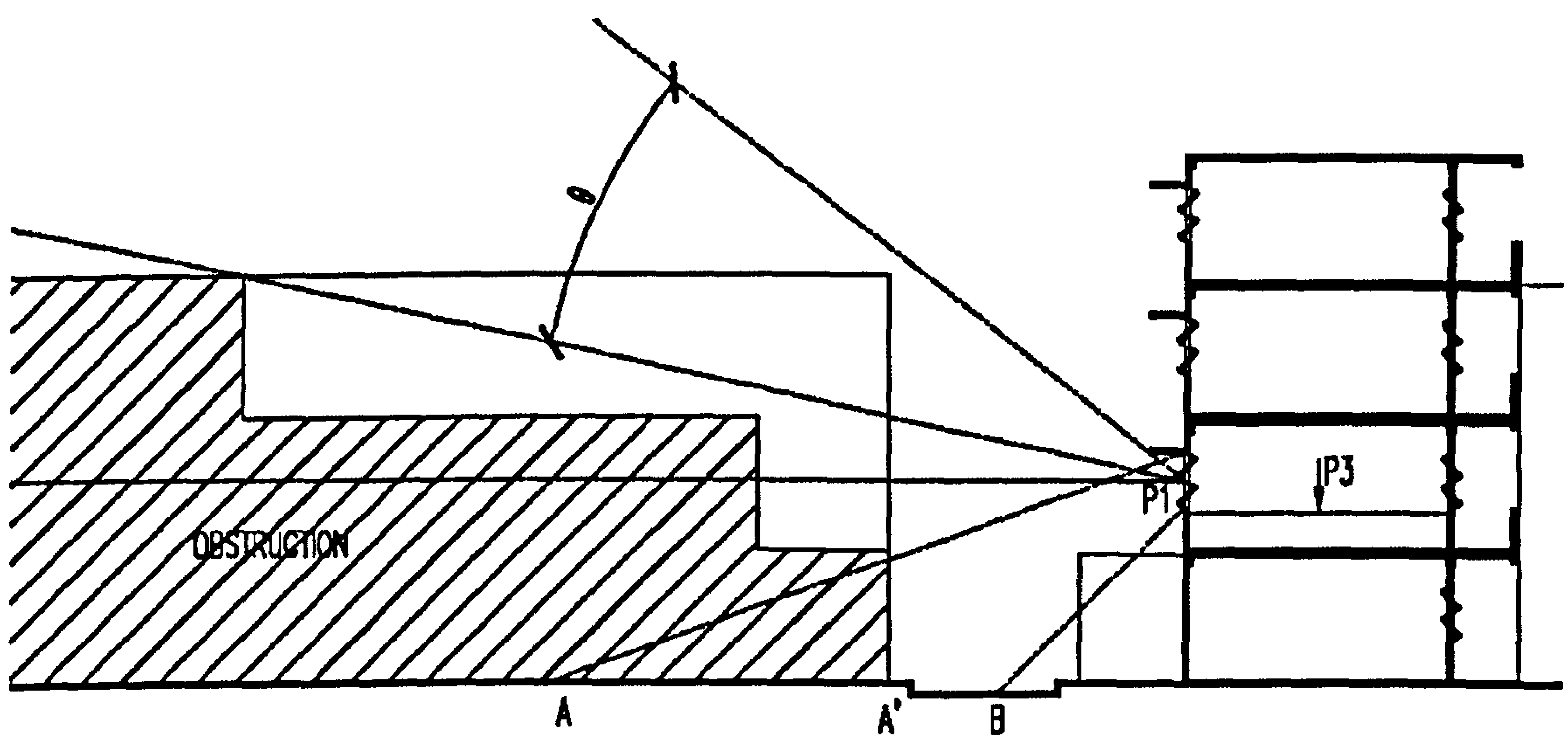


Figure 5.49 Ha Huy Tap School's site section showing main obstructions.

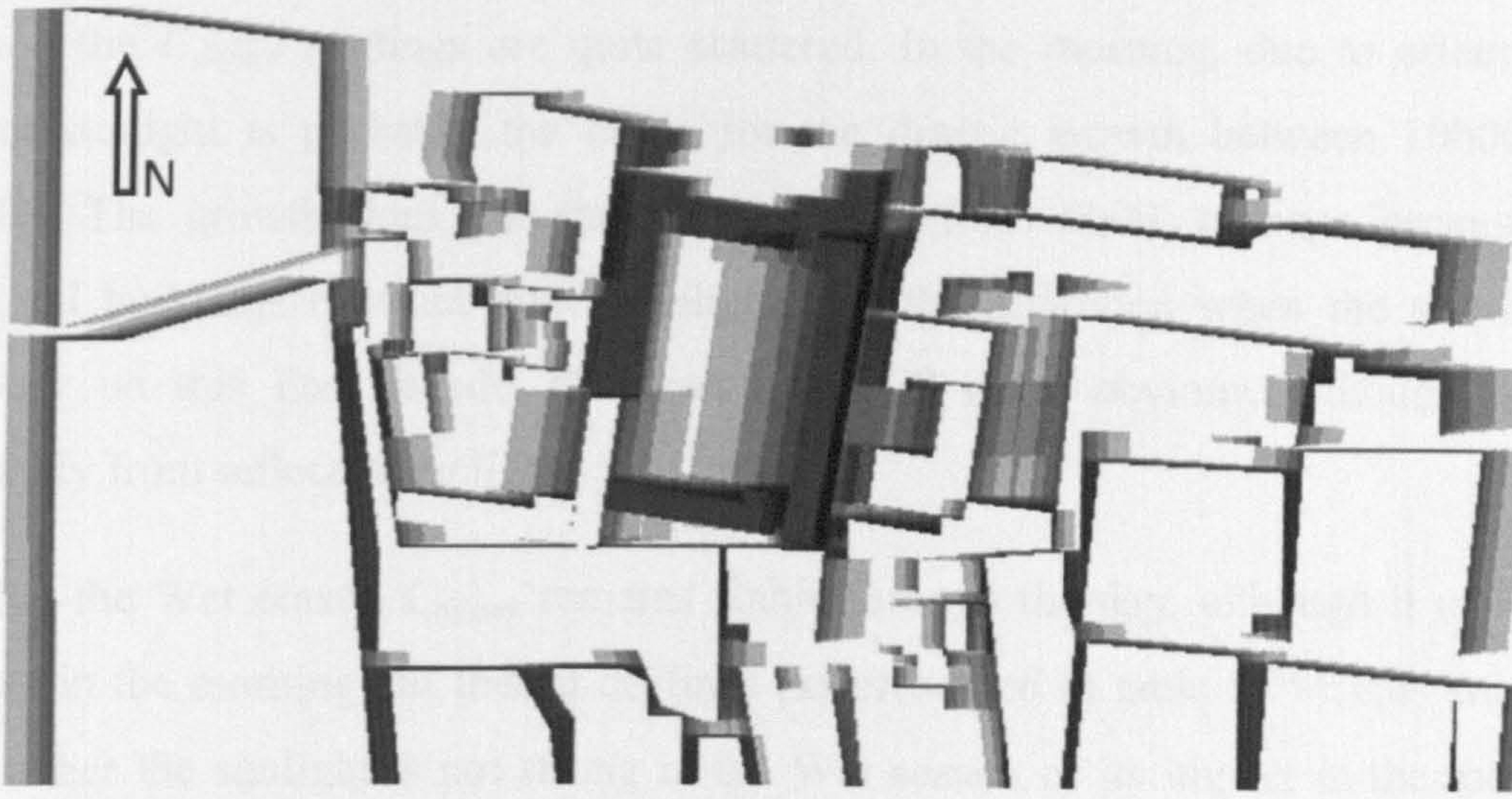
Therefore, the vertical daylight factor on the outer window surface consists of:

$$Dw = D_{ws} + D_{wr}b + D_{sun} + D_{sun}b$$

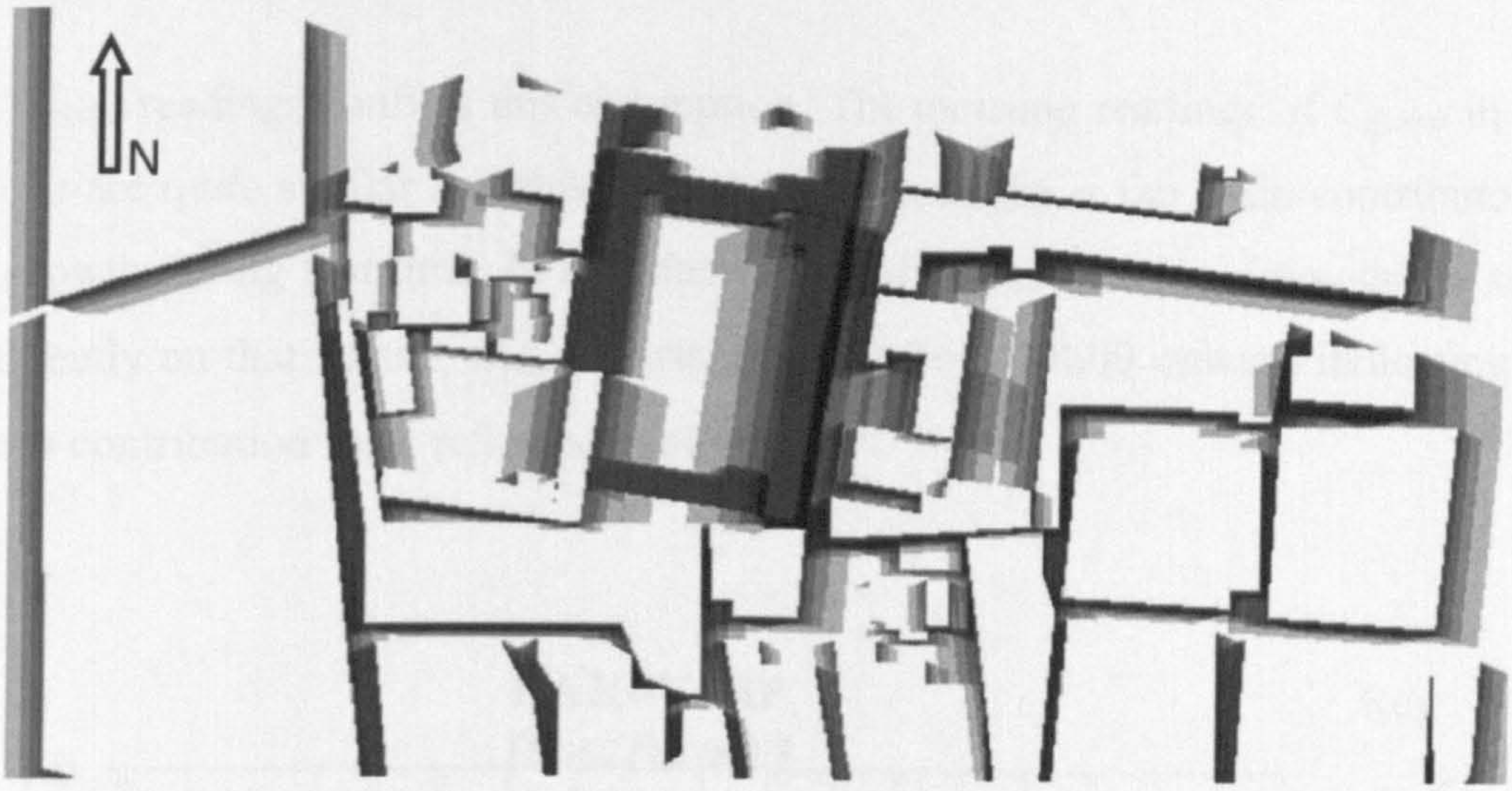
$$\text{or } C = C_{sky} + C_{wr}b + C_{sun}b$$

Figure 5.50 show the site's shadow plotting. In this case, the daylight context on the East facade is also heavily obstructed.

EQUINOX (21ST MARCH and 21st SEPEMBER) from 8h00 to 16h00



JUNE SOLSTICE (21ST JUNE) from 8h00 to 16h00



DECEMBER SOLSTICE (21ST JUNE) from 8h00 to 16h00

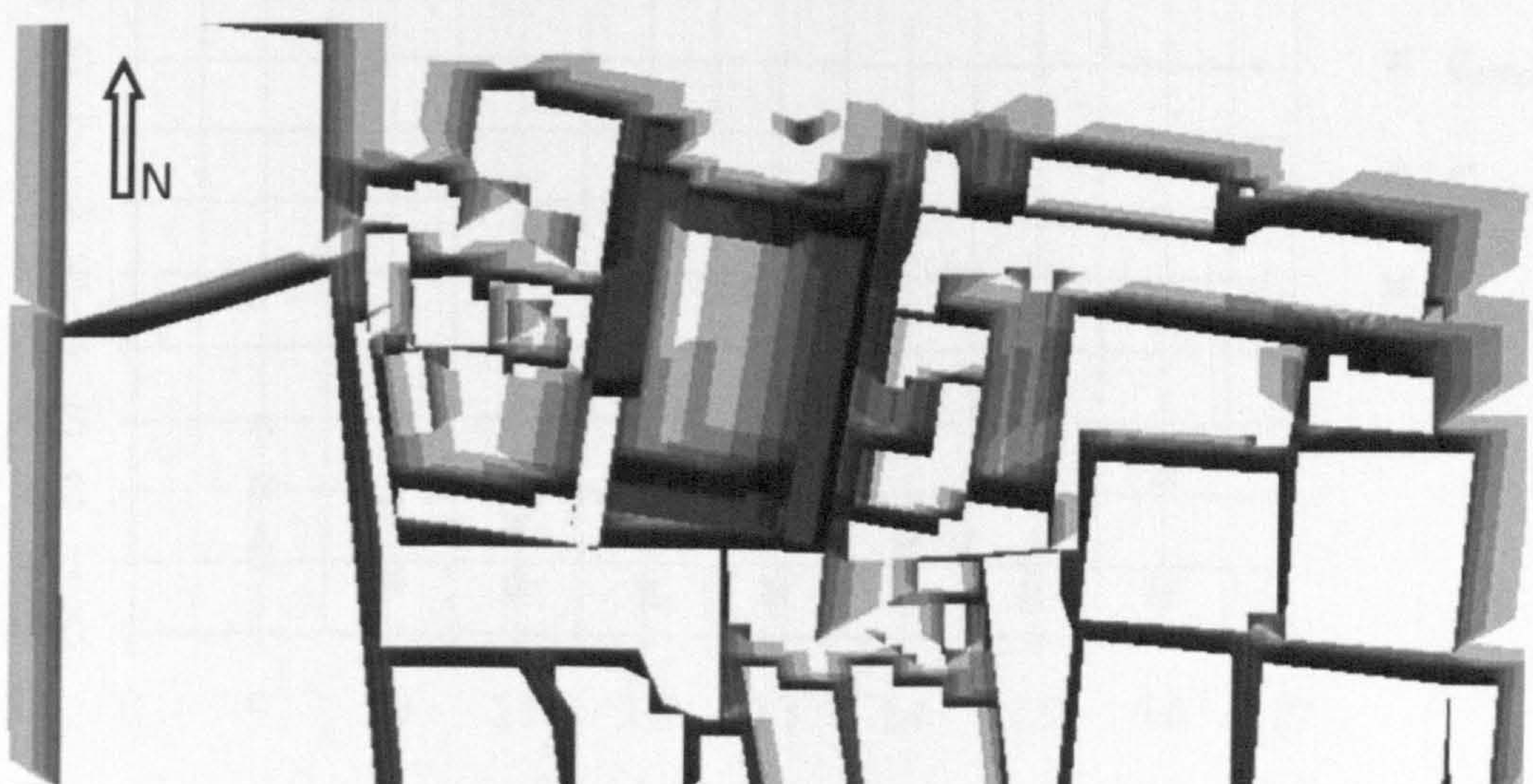


Figure 5.50 Ha Huy Tap School site's shadow plotting.

Figure 5.51 presents the plotting of the C ratios during the class hours. In the Dry season the $C_{diffuse}$ readings are quite scattered. In the morning, due to orientation, direct sunlight is probably the cause for the drastic growth between 10h00 and 11h00. The growth does not start immediately from 9h00, perhaps because the external buildings obstruct direct sunlight. In the afternoon when the sun is not directly on this East facade, the growth is still quite obvious, although this is probably from reflected sunlight.

During the Wet season $C_{diffuse}$ remains stable through the day, although it is a little higher in the morning but then it declines (as presented in table 5.19).This suggests that either the sunlight is not strong in the Wet season or its impact in the morning time is reduced by external obstructions.

The C_{global} readings confirm this assumption. The morning readings of C_{global} in both seasons are quite similar and this indicates that sunlight is the main contributor for any growth during that time. In the afternoon of the Dry season, although the sun is not directly on that facade, C_{global} starts growing from 14h00 onward indicating that there is contribution from reflected sunlight.

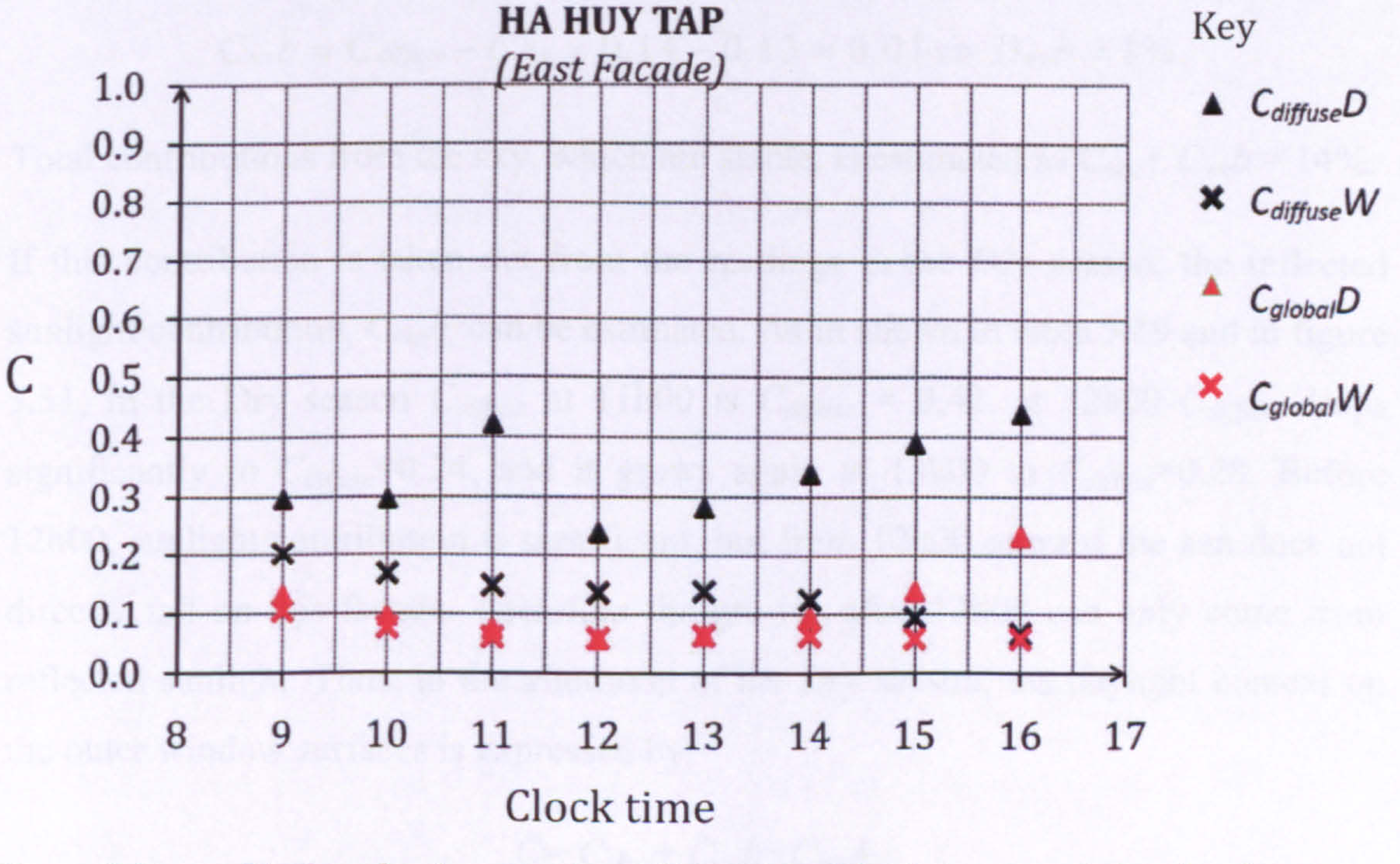


Figure 5.51 Plotting of various *C* ratios of Ha Huy Tap School classroom during class hours.

In summary, in the Dry season, direct sunlight is the main contributor in the morning and in the afternoon reflected sunlight from neighbouring buildings is the main contributor. In the Wet season, light from the sky, both direct and external reflected, is the main contributor.Theoretically, the contribution from direct sky, C_{sky} , can be simply estimated as:

$$C_{sky} = \frac{\theta}{200} = \frac{26}{200} = 0.13 \Rightarrow D_{ws} = 13\%$$

As in figure 5.51, the daylight context in the Wet season is quite diffused and sunlight contribution is minimal, which is confirmed by the readings of both $C_{diffuse}$ and $C_{global,}$ as both of these values remain quite stable throughout the day. Therefore, the daylight reaching the outer window surfaces in the afternoon of the Wet season probably consists only of direct light from the sky and reflected sky light from buildings, expressed as:

$$C = C_{sky} + C_{wr}b$$

Because the average $C_{diffuse}$ reading in the afternoon of the Wet season (from 12h00 to 16h00) is quite small, as seen in table 5.19, $C_{diffuse} \approx$ 0.14. Therefore, the contribution of reflected skylight from building during that time is estimated as:

$$C_{wr}b = C_{diffuse} - C_{sky} = 0.14 - 0.13 = 0.01 \Rightarrow D_{wr}b = 1\%$$

Total contributions from the sky, which are stable, is estimated as $C_{sky} + C_{wr}b = 14\%$.

If this contribution is taken out from the readings in the Dry season, the reflected sunlight contribution, $C_{sun}b$, can be estimated. As in shown in table 5.19 and in figure 5.51, in the Dry season $C_{diffuse}$ at 11h00 is $C_{diffuse}$ = 0.42, at 12h00 $C_{diffuse}$ drops significantly to $C_{diffuse}$=0.24, and it grows again at 13h00 to $C_{diffuse}$=0.28. Before 12h00, sunlight contribution is significant, but from 12h00 onward the sun does not directly fall on this facade. Therefore the growth after 12h00 can only come from reflected sunlight. Thus, in the afternoon of the Dry season, the daylight context on the outer window surfaces is expressed by:

$$C = C_{sky} + C_{wr}b + C_{sun}b$$

If it is assumed that at 12h00 there is no direct sunlight contribution due to the overhang protection, $C_{diffuse}$ at that time (as given in table 5.19) is $C_{diffuse}$ =0.24, then $C_{sun}b$ at that time is estimated as:

$$C_{sun}b = C_{diffuse} - (C_{sky} + C_{wr}b) = 0.24 - 0.14 = 0.1 \Rightarrow D_{sun}b = 10\%$$

It should be noted that this value varies as the sun moves. At peak time, 16h00 in the Dry season, the $C_{sun}b$ can be very high, as $C_{sun}b$ =0.44-0.14=0.3. This means that $D_{sun}b$ = 30% or reflected sunlight contributes 68% of the total vertical daylight on windows.

By the same approach, as in previous estimations, the *glazing diffuse transmittance factor* τ is calculated below. This classroom is used only in the morning shift, so the *Eih* is taken as *EihW* reading at 10h30 in the Wet season (similar to Truong Cong Dinh School). According to table 5.17, windows on wall 1 contribute 49.45% of the total daylight. Therefore, the transmittance factor τ is given by:

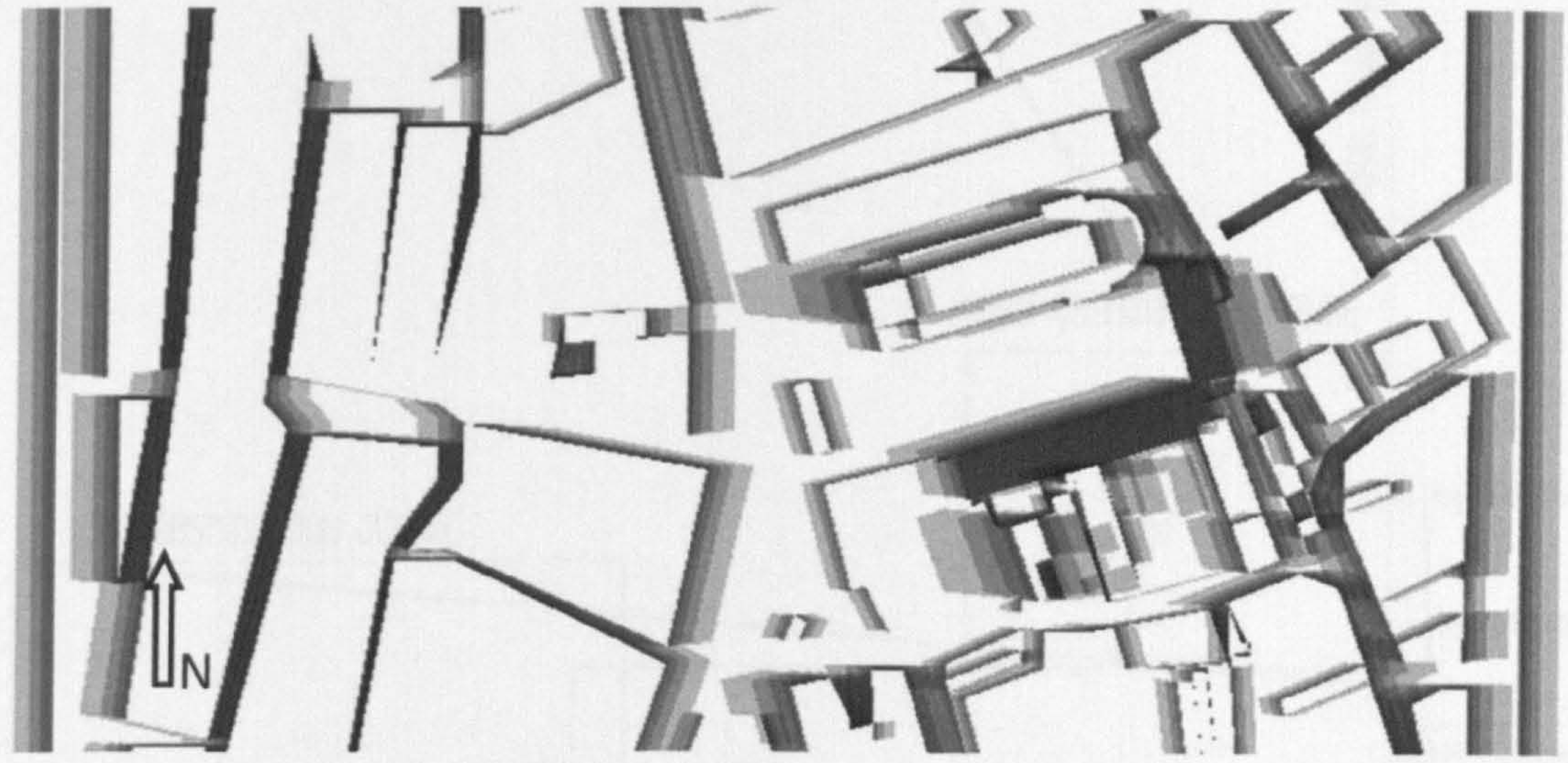
$$\tau = \bar{D}\frac{A_r(1-\rho)}{D_w A_w} \times \frac{100}{49.45} = \left(\frac{63.75}{32650}\right) \times \frac{154.2 \times (1-0.48)}{14 \times 4.8} \times \frac{100}{49.45} = 0.47$$

In summary, this analysis indicates that reflected sunlight plays a significant role. In a dense metropolitan area as in this case, despite the overhangs blocking all direct sunlight, reflected sunlight is still among the major contributors. Reflected sunlight accounts for 42-68% of the total light received on the main windows' outer surfaces. This situation is underestimated in the current daylight codes.

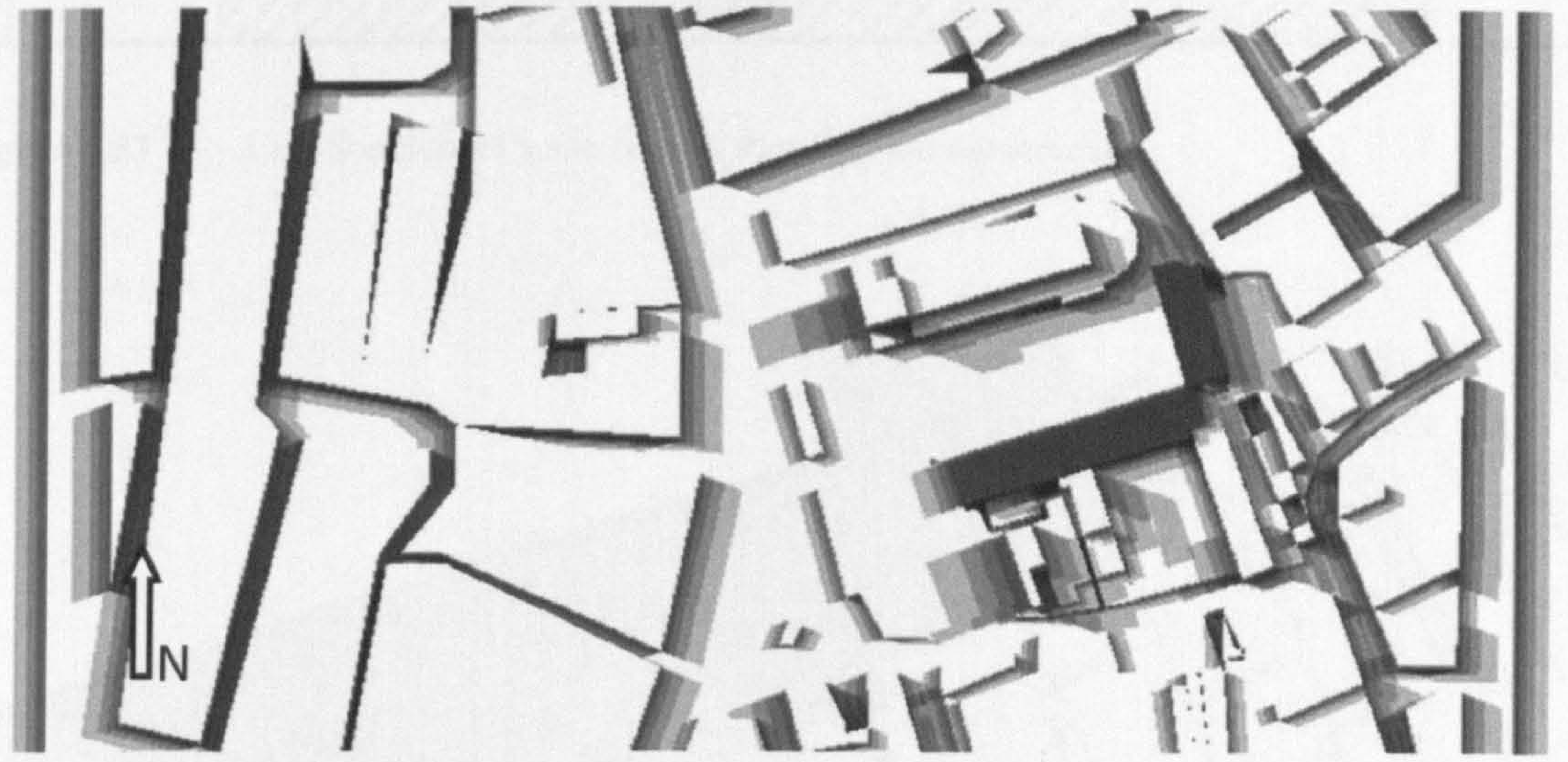
5.5.5. Analyses of the daylight context of Lam Son School

As illustrated in figure 5.52-5.53, the external context is quite complex as the school is surrounded by several buildings of different heights. Similar to Le Van Tam classroom, the main windows open to the neighbouring roof. Directly on the right and the left, there are two tall buildings perpendicular to the school facade. These buildings have considerable impact on the daylight access as they both reduce direct sky access and shade the facade vertically. Therefore, the light reaching the outer window surfaces probably consists of both light from the sky and sunlight. In this case, both reflected light from "ground" and building surfaces seems to make a significant contribution.

EQUINOX (21ST MARCH and 21st SEPEMBER) from 8h00 to 16h00



JUNE SOLSTICE (21ST JUNE) from 8h00 to 16h00



DECEMBER SOLSTICE (21ST JUNE) from 8h00 to 16h00

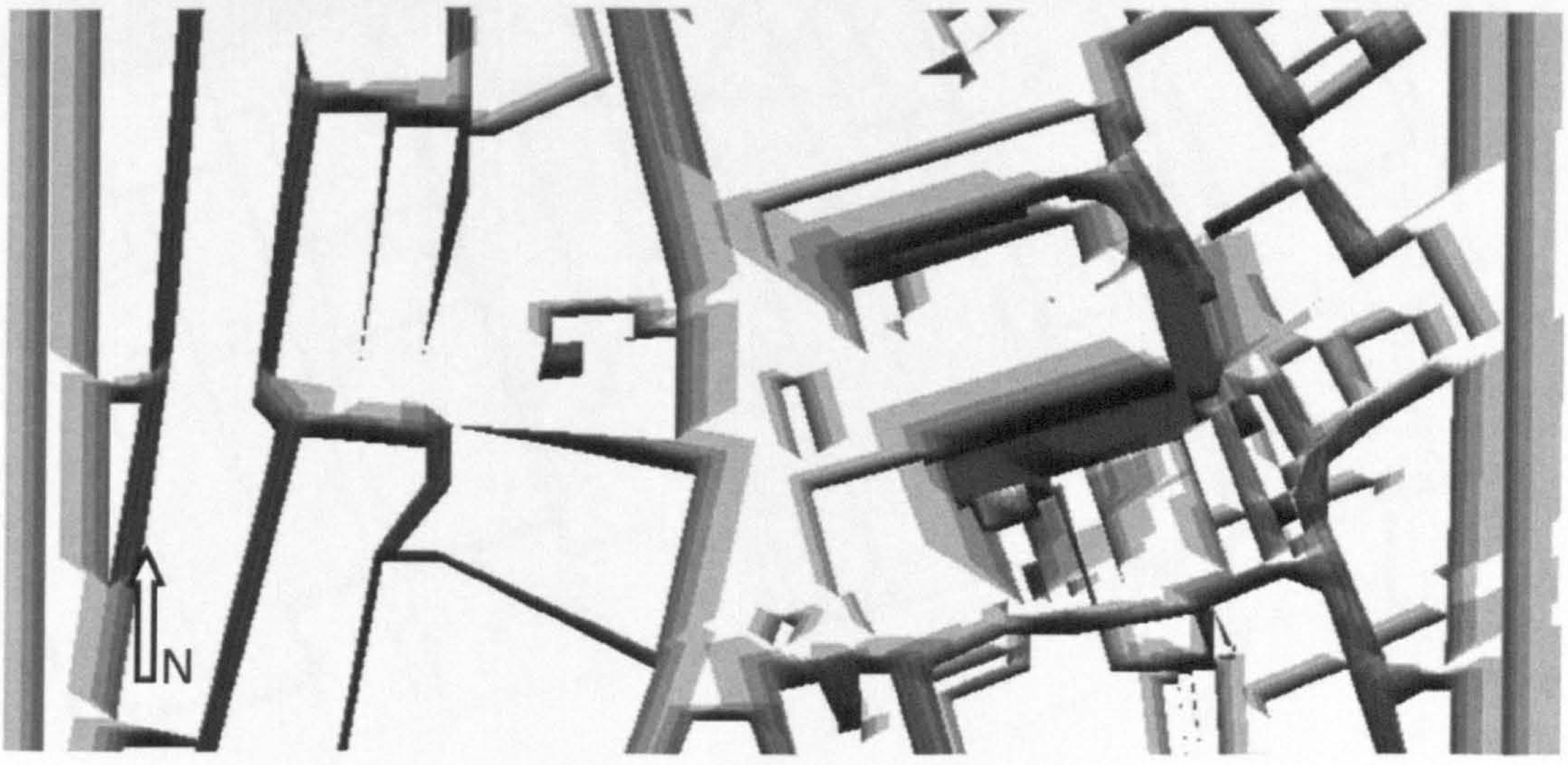


Figure 5.52 Lam Son School site's shadow plotting.

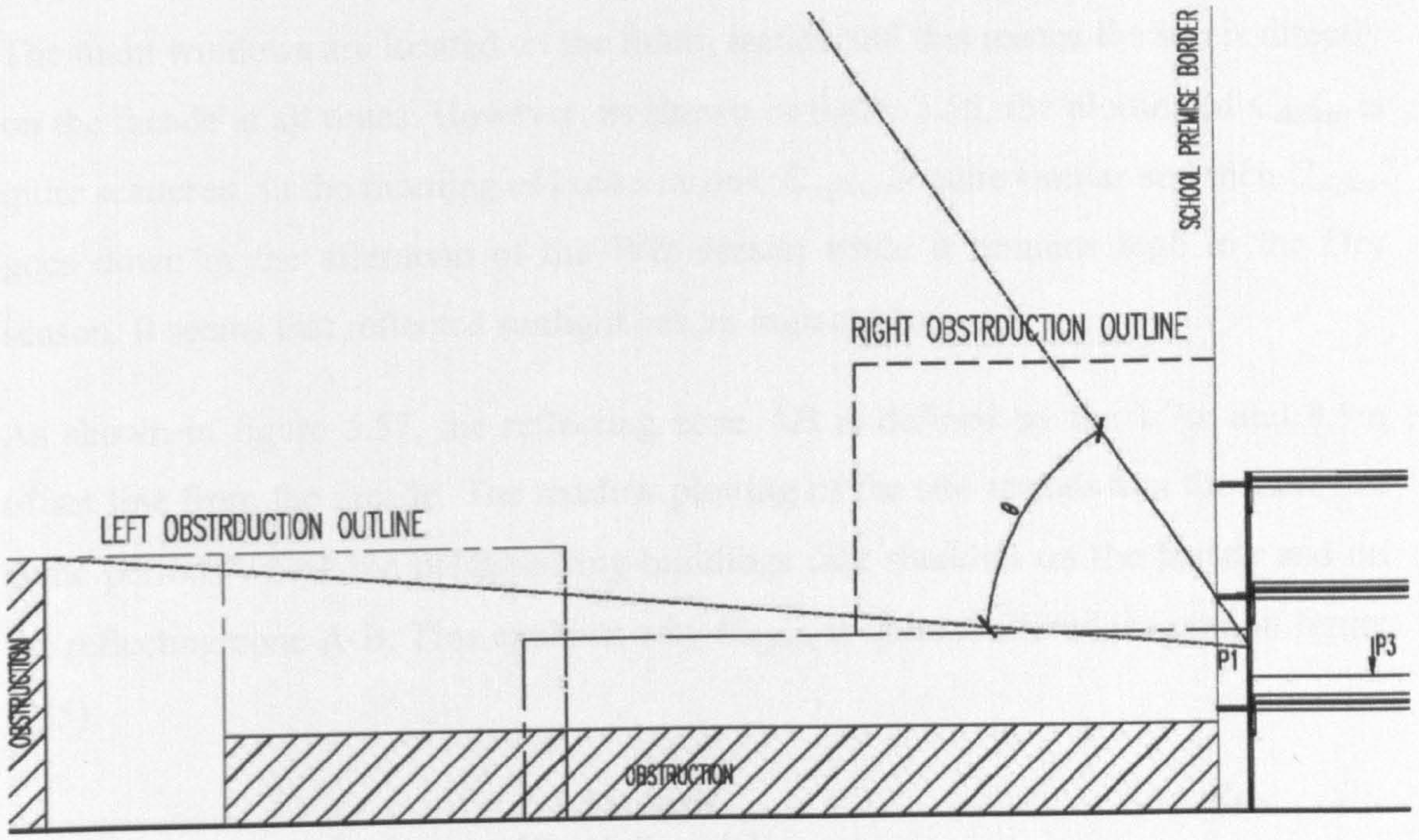


Figure 5.53 Lam Son School's site section showing main obstructions.

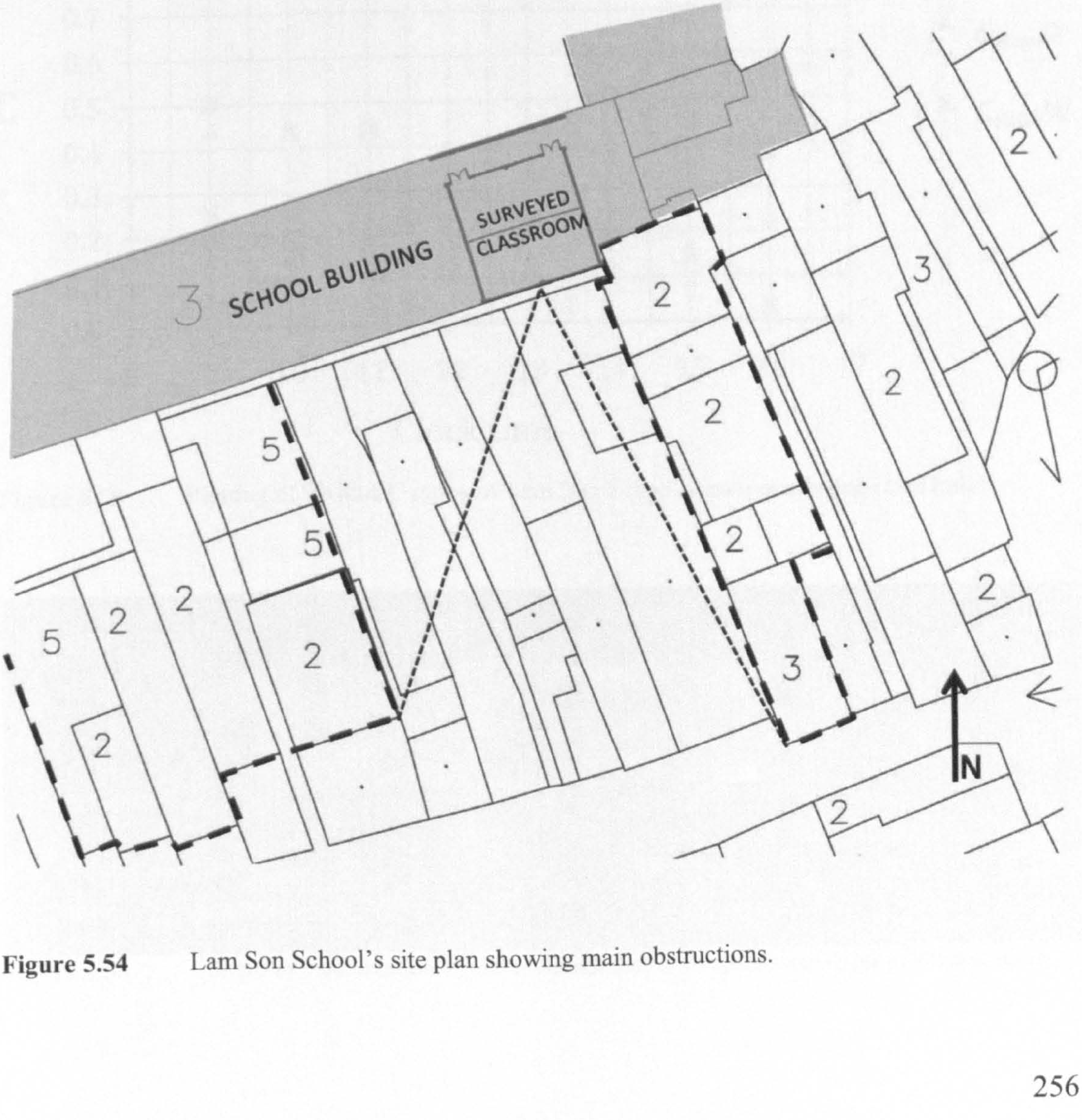


Figure 5.54 Lam Son School's site plan showing main obstructions.

The main windows are located on the South facade and this means the sun is directly on the facade at all times. However, as shown in figure 5.55, the plotting of $C_{diffuse}$ is quite scattered. In the morning of both seasons, $C_{diffuse}$ is quite similar and then $C_{diffuse}$ goes down in the afternoon of the Wet season while it remains high in the Dry season. It seems that reflected sunlight has an impact here.

As shown in figure 5.57, the reflecting zone AB is defined by the 1.7m and 8.5m offset line from the facade. The shadow plotting of the site reveals that the there are some periods where the neighbouring buildings cast shadows on the facade and on the reflecting zone A-B. This explains why $C_{diffuse}$ is quite scattered (as seen in figure 5.55).

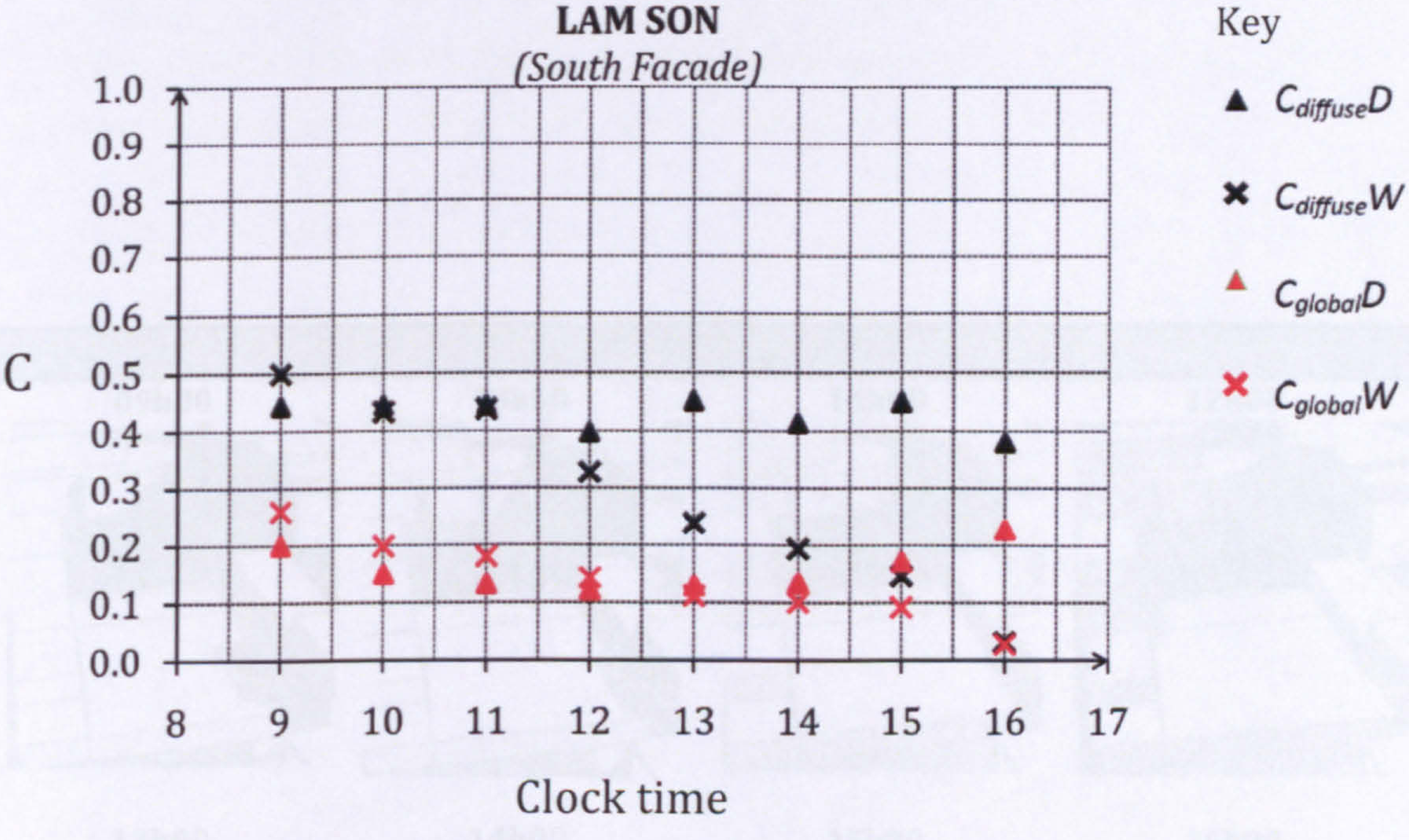


Figure 5.55 Plotting of various *C* ratios of Lam Son School classroom during class hours.

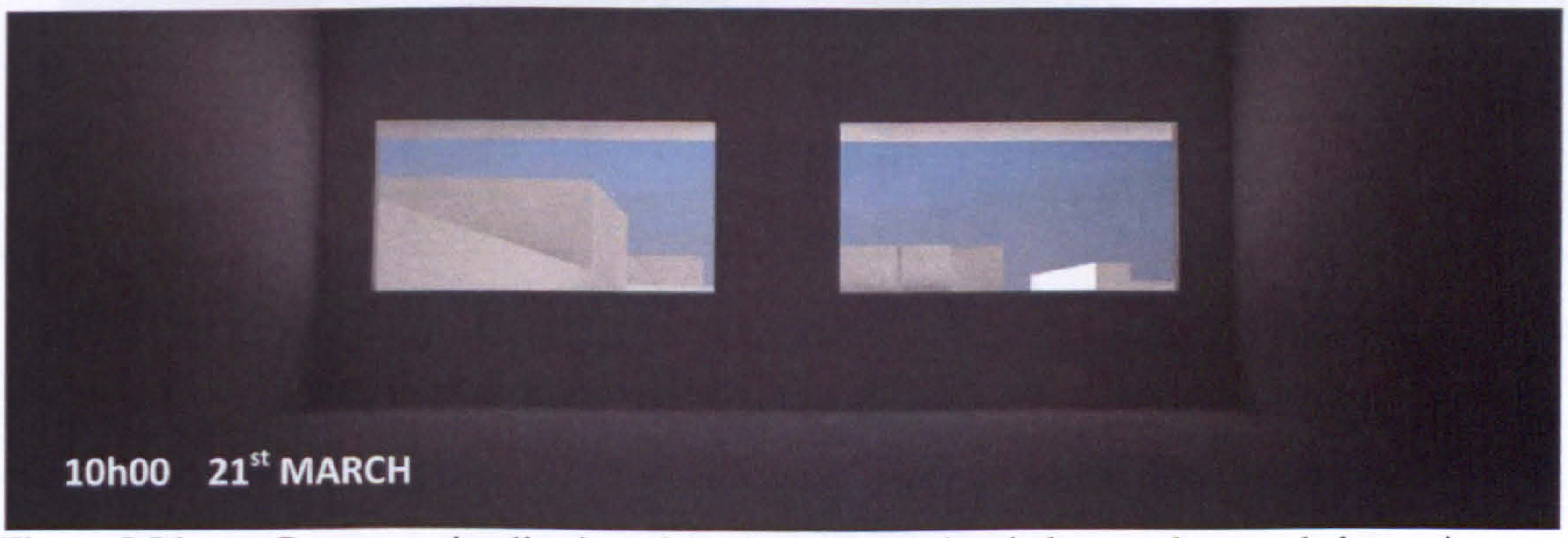


Figure 5.56 Computer visualization of the classroom main windows and external obstructions.

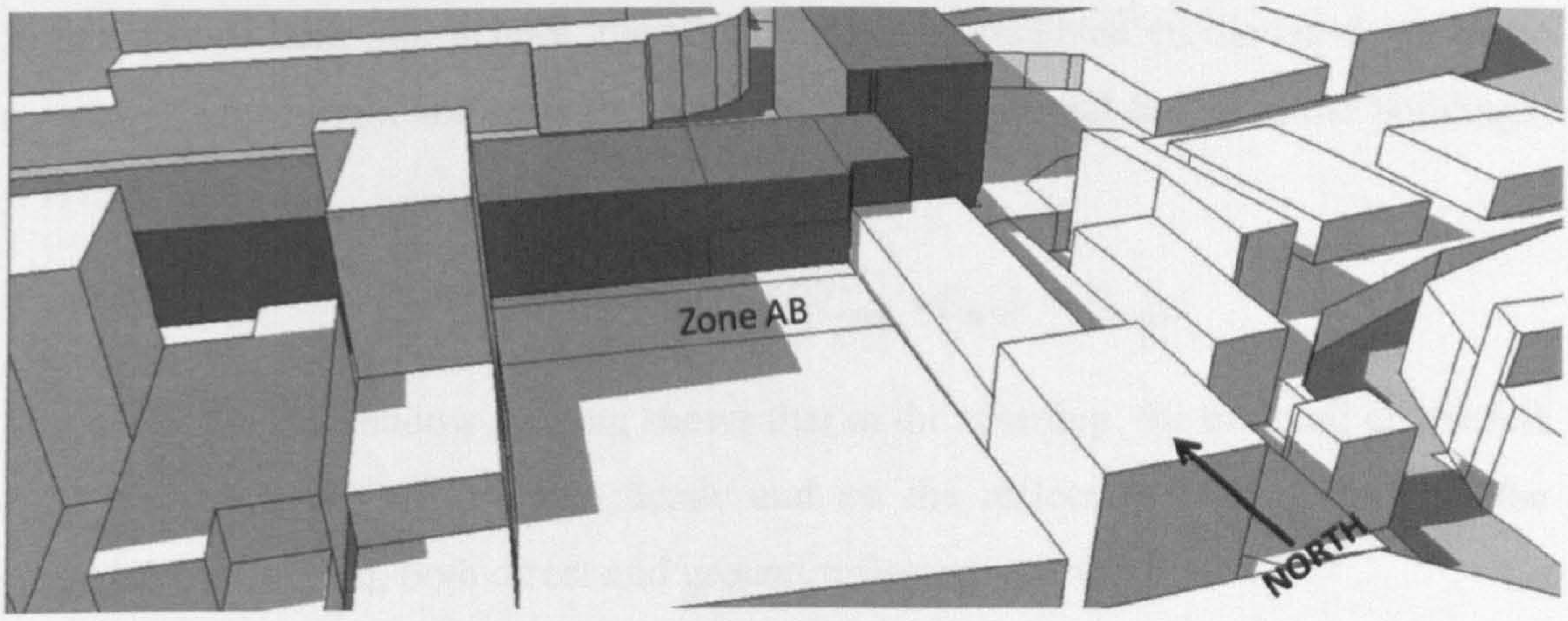


Figure 5.57 Perspective of the site at 15h00 on 15th February, from South looking toward North.

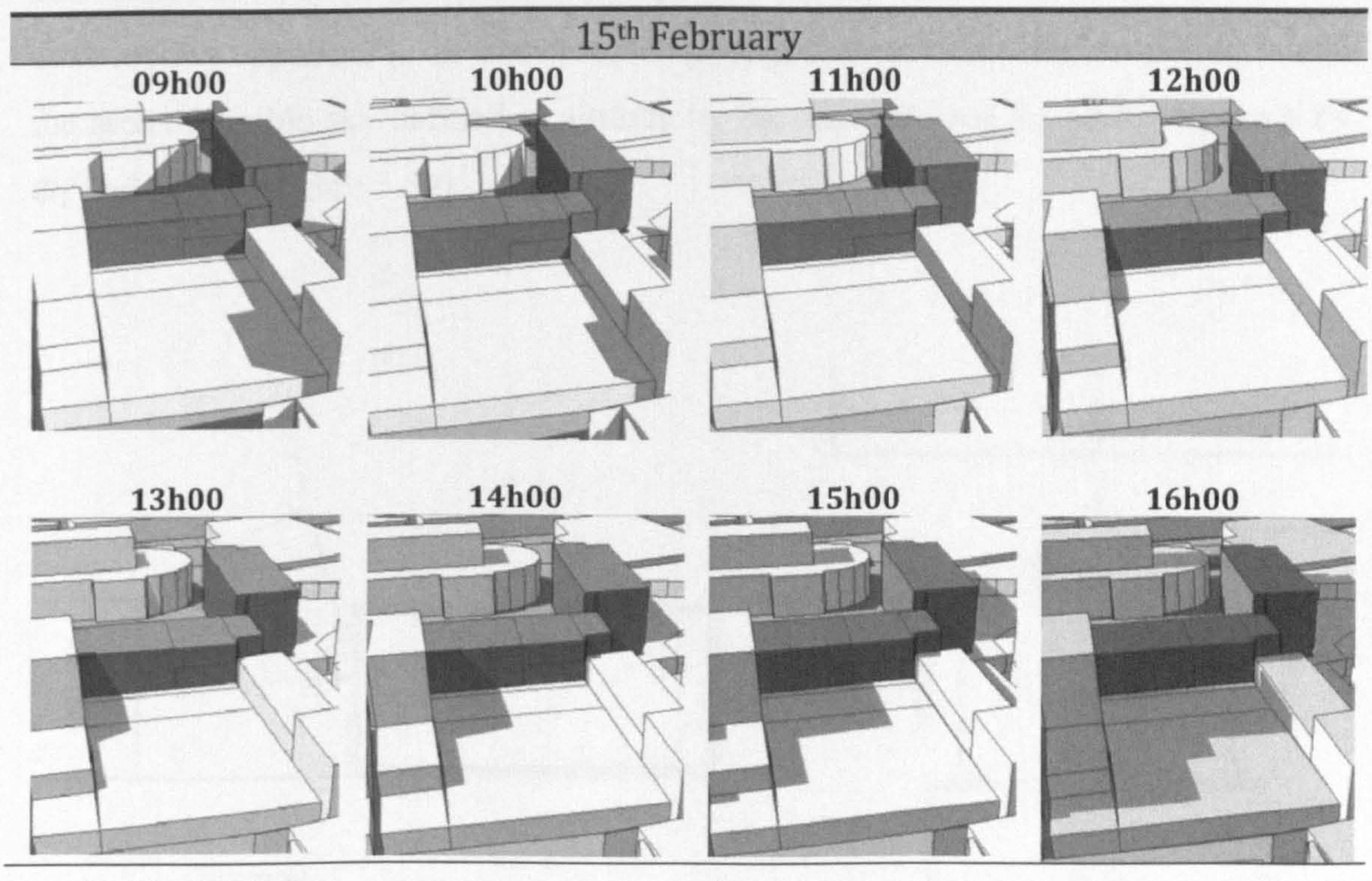


Figure 5.58 Site external shadow plotting.

In the case of Lam Son School, the vertical daylight received on the windows is the sum of direct sunlight and reflected sunlight from the ground and from the buildings. It is expressed as:

$$C = C_{sky} + C_{wr}b + C_{wr}g + C_{sun} + C_{sun}b + C_{sun}g$$

Moreover, the site shadow plotting shows that in the morning, the building on the left casts a shadow directly on the facade and on the reflecting zone A-B; thus the sunlight contribution, both direct and ground reflected, are small.

During the afternoon time, the building on the right starts casting shadow. It partly shades both the facade and the ground. From 15h00 onward the reflecting zone A-B is completed shaded and during this time the reflected sunlight is minimal. The sunlight contribution is at its peak around 11h00, because there is no shade or shadow being casted on either the facade or the ground.

To estimate the daylight contribution in this kind of urban context with large obstructions, P. R.Tregenza (1989) suggests using a modified formula which is described in appendix L. In this case, the daylight contribution for the sky relates to the area of visible sky defined in altitude by the angle θ_L *and* θ_H, and in azimuth by Φ_L and Φ_R (see figure 5.59).

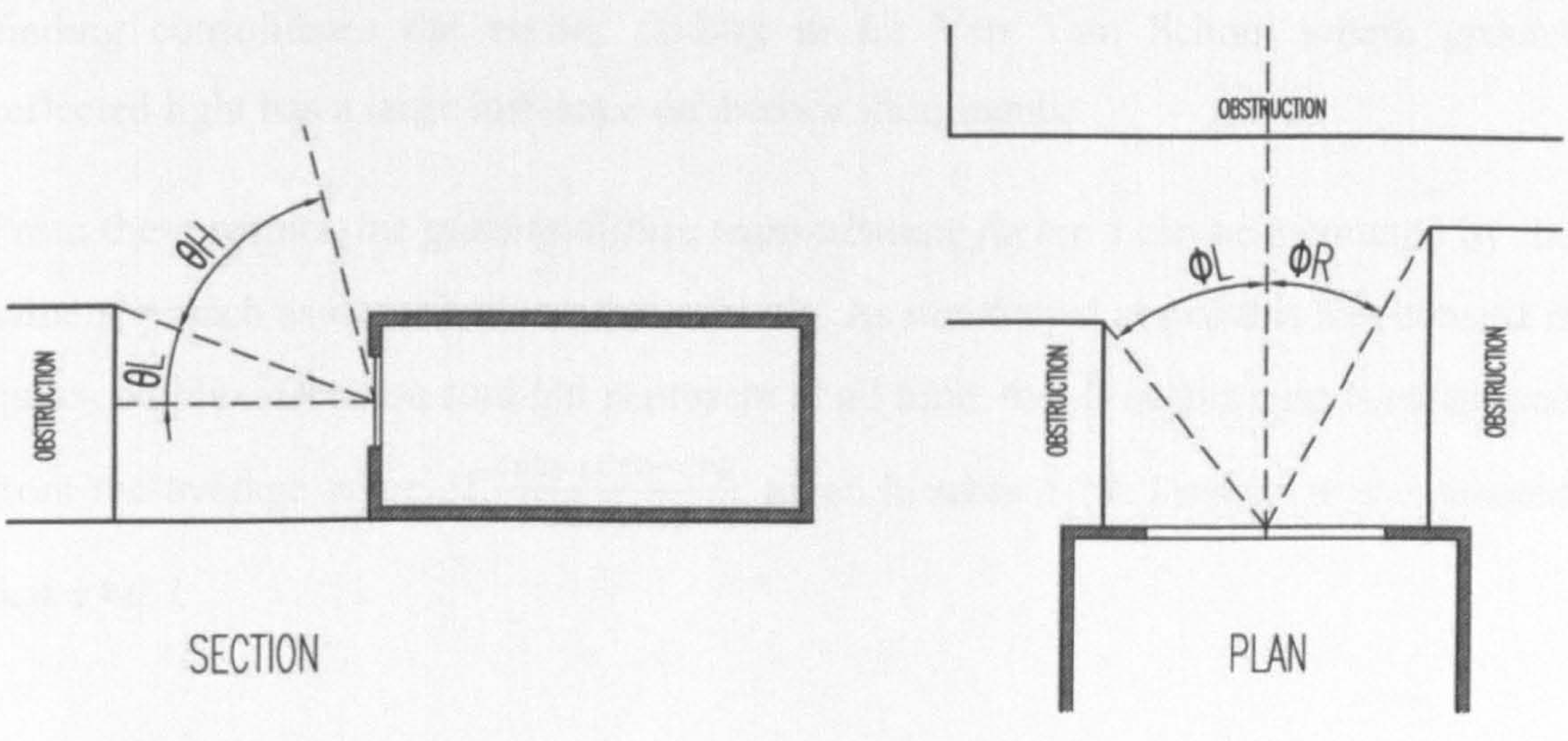


Figure 5.59 Defining the area of visible sky.

From the site documentation, the visible area is defined by θ_L=10, θ_H=70° and Φ_L=10°, Φ_R=36°. If these values are substituted into the table L.1 of appendix L then it is estimated that the light received from the sky (sum of D_{ws}, $D_{wr}b$ and $D_{wr}g$) is approximately 13.1%.

Comparing this value to the data presented in table 5.19 suggests that there is sunlight contribution in the morning during the Wet season. Furthermore, in the Dry season, $C_{diffuse}$ remains quite stable throughout the day. The site shadow plotting shows that at 16h00, the ground reflecting zone A-B is completely shaded by neighbouring buildings (see figure 5.58). In figure 5.55, a small drop is seen in the $C_{diffuse}$ reading at that time. This suggests that this drop is due to the ground reflected sunlight being taken out. This drop of $C_{diffuse}$ reading at that time is approximately 0.06. Therefore it is estimated that $C_{sun}g \approx 0.06$ (or $D_{sun}g \approx 6\%$).

Because the sun directly falls on the South facade all the time, there is always a considerable contribution of sunlight received in different forms, either direct or reflected, on the window surfaces. As the sun moves, these contributions also vary. This means that at some time direct sunlight is the main contributor, at another time reflected sunlight becomes the main contributor.

Data presented in table 5.19 shows that reflected sunlight from ground can account for up to 50% of the total light reaching the window surface at peak time. This finding consolidates the earlier finding in Le Van Tam School where ground reflected light has a large influence on interior illuminance.

From these results, the *glazing diffuse transmittance factor* τ can be estimated by the same approach as described in other schools. As mentioned above this site context is quite complex. Because sunlight is present at all time, the $\overline{D}$ in this case is calculated from the average value of $\frac{Csky+Crb+Crg}{Cdiffuse}$ given in table 5.19. Finally, it is estimated that $\tau \approx 0.3$.

5.6 Establishing effective window-to-floor ratio

5.6.1. Effective opening area

As discussed above, these four classrooms have similar architecture and daylight strategies (side lighting). Therefore, the main factor that affects daylight contribution is the window- to-floor ratio (R_o).

This ratio is often calculated as total net area of all the openings. However, the above analyses show that only certain openings provide meaningful daylight contribution. If all the actual openings are taken into consideration in the calculations, the prediction of daylight contribution is no longer accurate. Therefore, it is important that the window area used in the daylight calculating formulae should be precisely defined as the effective area that contributes meaningful daylight access rather than sum total of all window areas. However, this issue is not clearly defined in the current Vietnamese codes. This leaves space for wrong interpretation as seen in many variations of window designs. As a consequence, the daylight contribution is also not predicted accurately. Evidence can be seen in the differences of values predicted by the codes and values actually recorded on site. The analyses presented in previous sections indicate that the real situation is much more complicated.

For instance, in Truong Cong Dinh School there are several openings positioned in different parts of the walls. These may help to improve the natural ventilation, but their daylight contributions are not the same. Those openings which are located very close to the ceiling are mostly shaded by the overhang. Furthermore, daylight entering the interior through those top openings is mostly reflected and scattered by the ceiling. Therefore, any meaningful contribution from these openings to interior illuminance is little. However, the diffused light provided by these openings may help to raise the uniformity. It also illuminates the ceiling and makes the space look brighter. Additionally, the ground reflected light can be an important element in some cases, and in such cases, these openings may make critical contributions. They also help to increase the vertical illuminance. This explains why Truong Cong Dinh classroom, especially in the Dry season when there is a lot of reflected sunlight, has higher $\frac{Eiv}{Eih}$ ratio than other classrooms. Lam Son School also has similar conditions

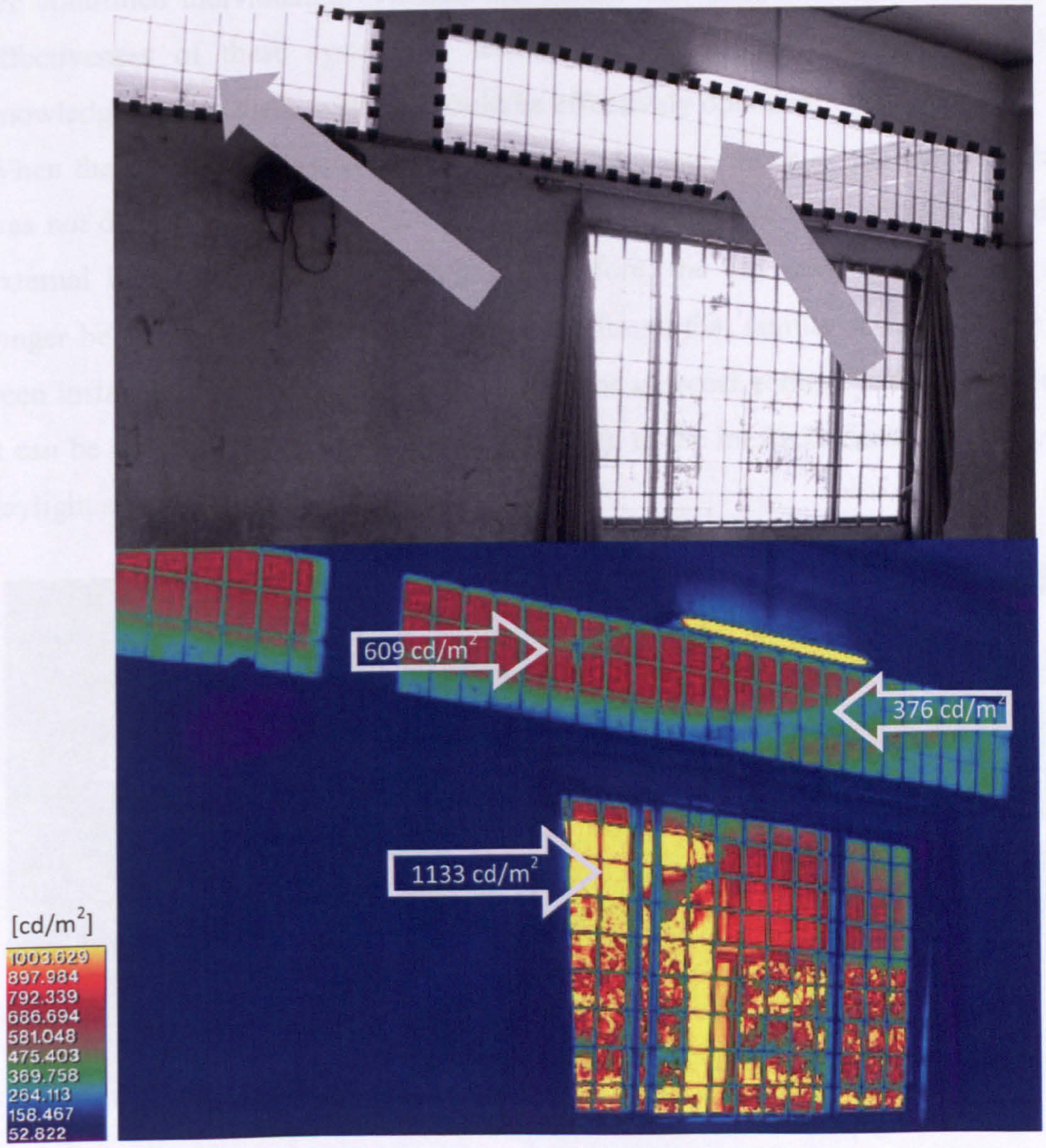


Figure 5.60 Actual opening and effective opening.
The opening areas in Truong Cong Dinh classroom, which are indicated by the arrows, are perhaps useful for natural ventilation but their meaningful daylight contribution is small because they are blocked by the corridor soffit and receive only reflected light. On that side the ground is well shaded by trees so ground reflected light, particular reflected sunlight, is minimal.

Furthermore, site studies reveal that the shading system comprises of several small components (e.g. overhangs, rolling blinds, curtains) which work independently and are controlled individually. Though this means that there is a high flexibility, the effectiveness of these systems is left to the individuals who may have little knowledge of how these systems should be effectively operated.

When these schools were designed a few decades ago, much of the neighbourhood was not densely populated. Since then many new buildings have been built and the external landscapes has also changed. Therefore, the old shading design may no longer be effective. Furthermore, it has been found that similar shading design has been installed in all the facades even though the external context is different. Hence it can be inferred that these problems contribute to the ineffectiveness of the current daylight system.

Figure 5.61 In reality, glazing, blinds, security window bars, and poor maintenance considerably reduce the actual daylight access.

5.6.2. Establishing effective window-to-floor ratio

This discussion attempts to establish an effective window-to-floor ratio (R_o) based on the data and analyses discussed above. These four schools represent some typical scenarios of the HCMC urban context. The results can be used as a meaningful tool for daylight designers. It should be noted that in reality, the site context is very complex. It is difficult to establish an absolute R_o that works equivalently in all scenarios. The designers should review the site context carefully to investigate daylight availability and choose appropriate design strategies.

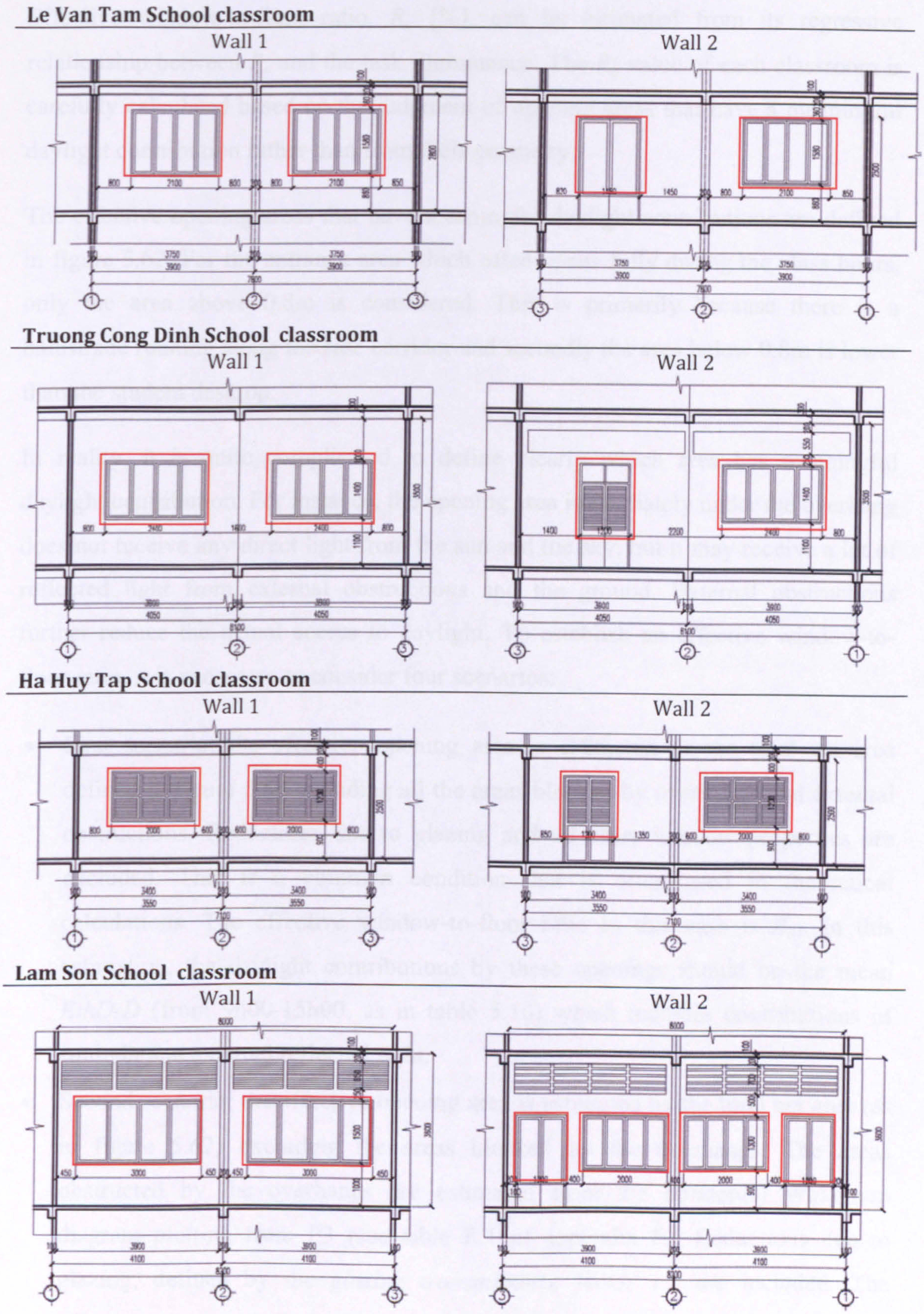


Figure 5.62 Defining the effective opening areas of each school classroom (highlighted in red)

Effective window-to-floor ratio, R_o [%], can be estimated from its regressive relationship between R_o and the task illuminance. The R_o value of each classroom is carefully calculated based on the judgment of opening areas that have a meaningful daylight contribution rather than from their geometry.

The effective opening areas that have meaningful daylight contributions are defined in figure 5.62. For the entrance area which often opens fully during the class hours, only the area above 0.8m is considered. This is primarily because there is a balustrade running along the side corridor and secondly the area below 0.8m is lower than the student desktop.

In reality, it is quite complicated to define clearly which area has meaningful daylight contribution. For instance, the opening area immediately under the overhang does not receive any direct light from the sun and the sky, but it may receive a lot of reflected light from external obstructions and the ground. External obstructions further reduce the actual access to daylight. To establish an effective window-to-floor ratio, it is necessary to consider four scenarios:

- First scenario: the effective opening area is estimated as the total net area defined in figure 5.62 including all the areas blocked by overhangs and external obstructions. Reductions due to glazing and all other window properties are excluded. This is a common condition that is often used in theoretical calculations. The effective window-to-floor ratio in this case is R_{o1}. In this estimation, the daylight contributions by these openings should be the mean *EihD-D* (from 9h00-15h00, as in table 5.16) which includes contributions of sunlight and external reflected light.
- Second scenario: the effective opening area is estimated by the total net area (as in figure 5.62) excluding the areas blocked by the overhangs. The areas obstructed by the overhangs are estimated from the horizontal Waldgram diagram plotting from P3 (see table E.1 of appendix E). Reductions due to glazing, defined by the *glazing transmittance factor* τ , are included. The effective window-to-floor ratio in this case is R_{o2}. In this estimation, the daylight contributions by these openings is the mean *EihD-D* (from 9h00-15h00, as in table 5.16, page 224).

- Third scenario: the effective opening area is the net of only the area which has direct access to sky; it excludes any area which obstructed by either the overhangs or external obstructions. These obstructed areas are estimated from the Waldgram diagram plotting from P3. Reduction due to glazing is also included. The effective window-to-floor ratio in this case is R_{o3}. In this estimation, the daylight contributions by these openings is the mean *EihD-D* (from 9h00-15h00, as in table 5.16).

- Fourth scenario: the effective opening area is R_{o3}, which is similar to scenario 3. In this estimation, contribution from direct sunlight is excluded. If it is assumed that sunlight contribution is minimal in the Wet season then the daylight contributions by these openings used in this plotting should be the mean *EihD-W* (from 9h00-15h00) which perhaps represents the diffuse sky condition.

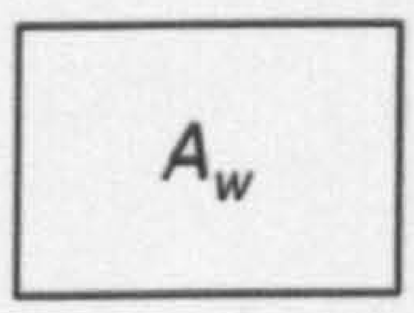
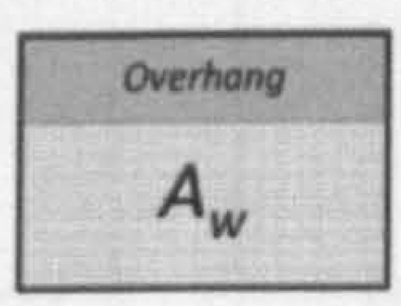
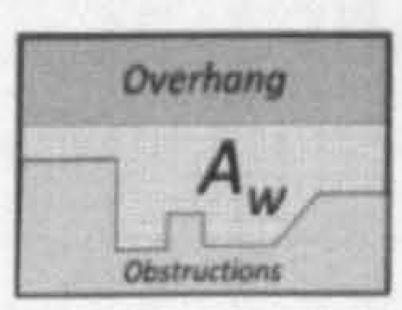
The *glazing diffuse transmittance factor* τ of each school classroom which is used in the second, third and fourth scenario is the value found in previous discussions (i.e. presented in section 5.5.2-5.5.5)

In case of Ha Huy Tap classroom, the total opening area is multiplied by 0.406 to represent the reduction due to the wooden louvers.

Taking into consideration all of these factors, the effective window-to-floor ratio of each school classroom in each scenario is estimated and presented in table 5.20.

The regressive plotting of each scenario is presented in figure 5.63. It should be noted that these graphs present average conditions. As the external environments of each site are different and they change during the day, the specific conditions at any given time vary.

Table 5.20. Estimates of the effective window-to-floor ratio [%].

		School			
Description		Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
Total floor area A_{floor} [m²]		54.60	48.00	42.00	64.00
Total effective opening area [m²]		11.69	11.87	3.56*	17.56
Total area of opening which is not obstructed by overhang [%]		53.57	50.66	76.89	96.74
Total area of opening which is not obstructed by overhang [m²]		6.26	6.01	2.74	16.99
Total unobstructed opening area which has direct sky access [m²]		6.26	1.65	2.04	9.98
Glazing diffuse transmittance factor τ		0.42	0.49	0.47	0.30
R_{o1} [%]		21.41	24.73	8.47	27.44
R_{o2}[%]		4.82	6.14	3.06	7.96
R_{o3}[%]		4.82	1.68	2.29	4.68
Mean *Eih-D-D (09h-15h)* [lx]		242	113	99	405
Mean *Eih-D-W (09h-15h)* [lx]		157	39	97	178

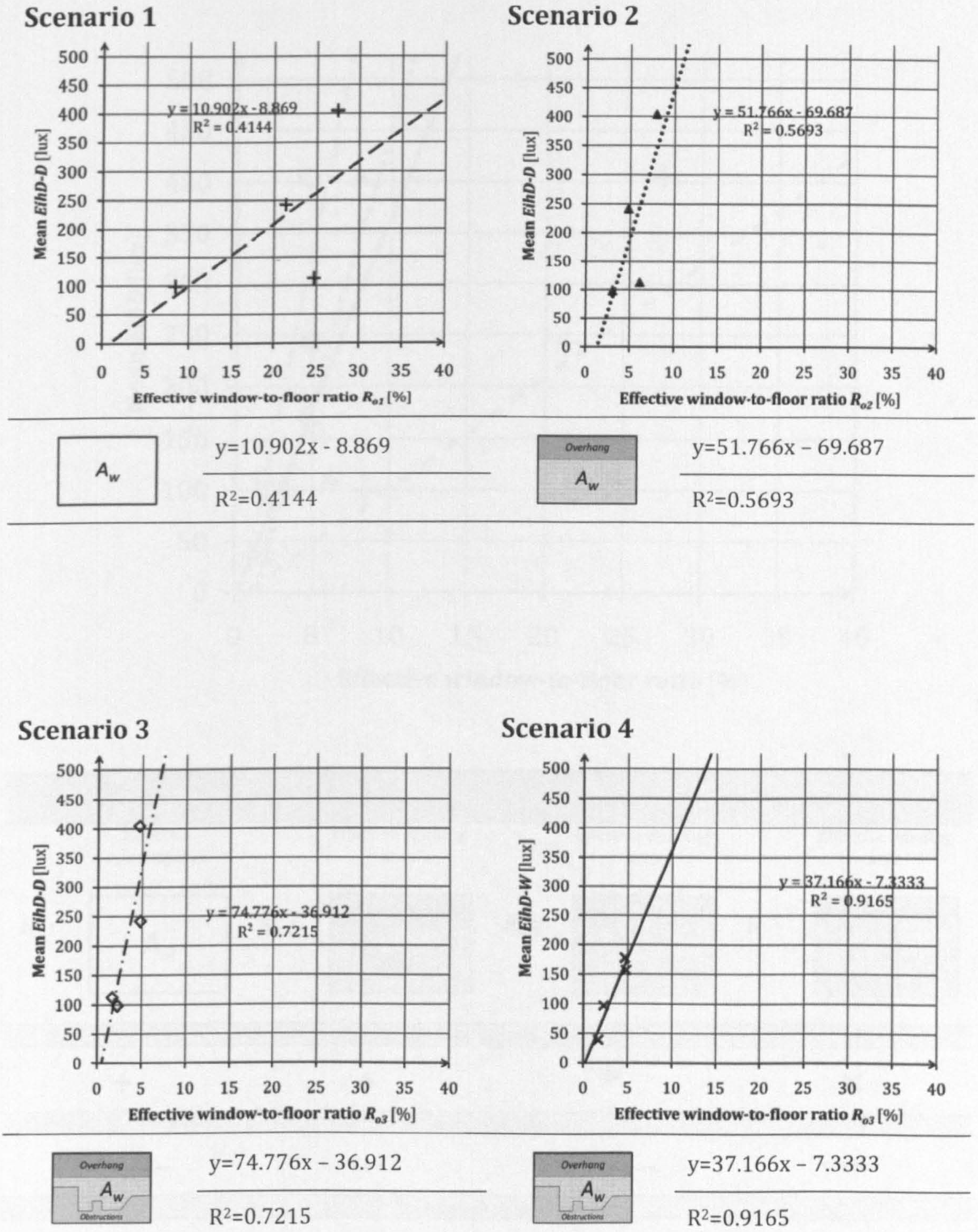
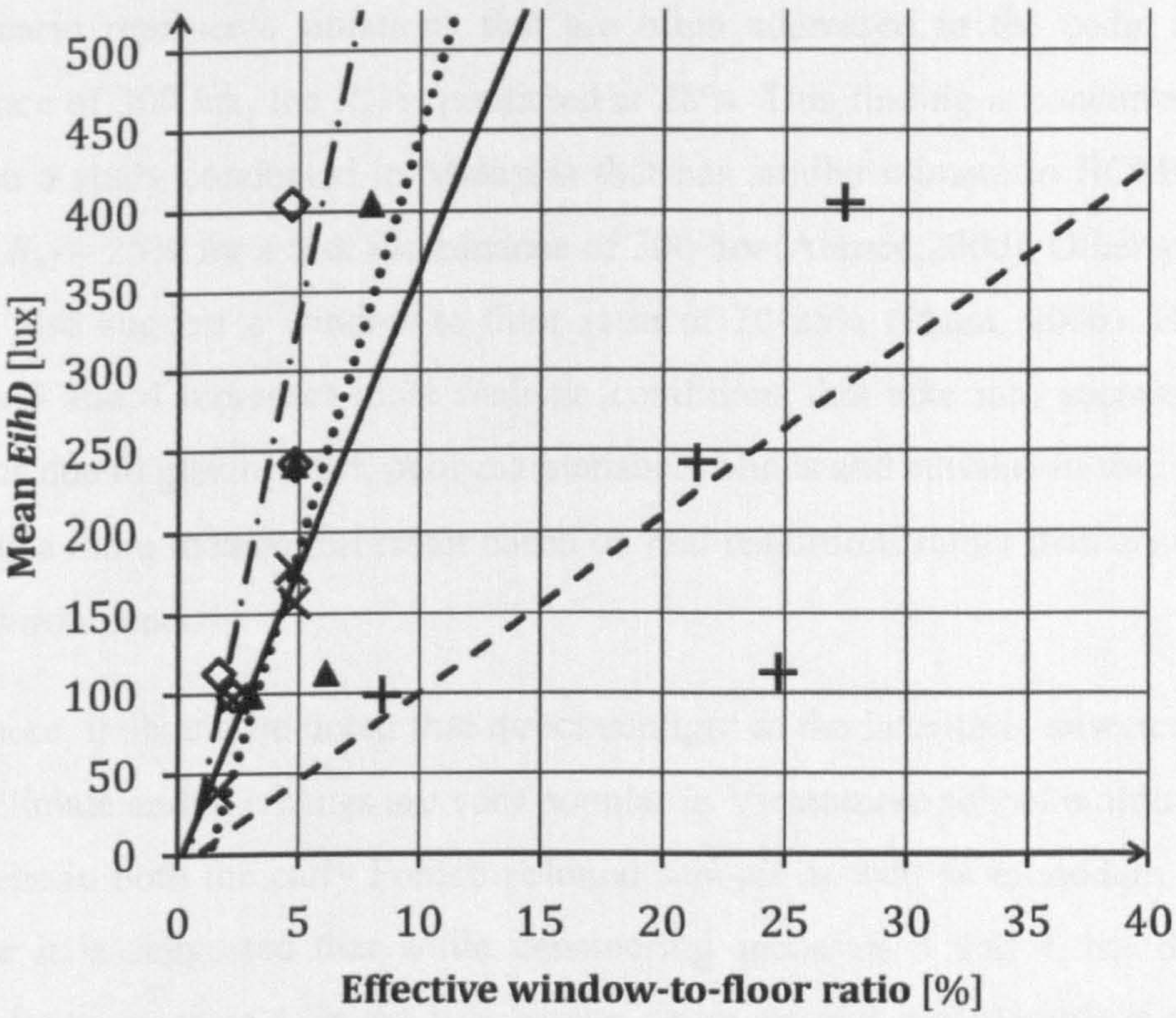
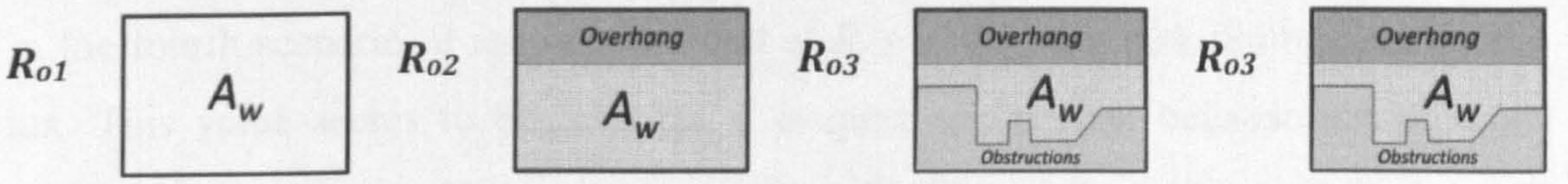


Figure 5.63 Regressive plotting of effective window-to-floor ratio R_{o1}, R_{o2} and R_{o3} and mean *EihD-D* (in scenario 1, 2, and 3) or *EihD-W* (in scenario 4), from 9h00-15h00.



Scenario 1	Scenario 2	Scenario 3	Scenario 4
Effective opening area	Effective opening area	Effective opening area	Effective opening area



Data symbol			
+	▲	◆	×
Regressive line			
– – – –	• • • • •	– · – · –	——
Regressive relationship			
y=10.902x - 8.869	y = 51.766x – 69.687	y=74.776x – 36.912	y = 37.166x – 7.3333
Coefficient of determination, R^2			
R^2=0.4144	R^2 = 0.5693	R^2=0.7215	R^2 = 0.9165
Predicted effective window-to-floor ratio for *EihD* from 300-500 lux			
28-47%	7-11%	5-7%	8-14%

Figure 5.64 Regressive plotting of all scenarios plotted in same graph.

As is evident from figure 5.64, there are significant differences in each scenario. The first scenario represents situations that are often addressed in the code. For task illuminance of 300 lux, the R_{o1} is predicted at 28%. This finding is concurrent to the finding in a study conducted in Malaysia that has similar climate to HCMC which suggests $R_{o1} = 25\%$ for a task illuminance of 300 lux (Ahmed,2000). Other studies in Vietnam also suggest a window-to-floor ratio of 20-25% (Pham, 2006). However, scenarios 3 and 4 represent more realistic conditions that take into account all the reductions due to glazing, dirt, poor maintenance, blinds and curtains in use; and thus it presents a more meaningful result based on real conditions rather than absolute lab based environments.

Furthermore, it should be noted that direct sunlight in the interior is unwelcome in a tropical climate and overhangs are very popular in Vietnamese school buildings. This can be seen in both the early French colonial schools as well as in modern schools. Therefore it is suggested that while considering scenarios 3 and 4, the designers should refer to scenario 4. In the Wet season, there are still considerable numbers of hours of sunny intervals, particularly in the morning. Therefore the mean *EiD-W* used in the fourth scenario is perhaps more appropriate to represent the standard conditions.

In the fourth scenario, it is predicted that at $R_{o4} = 10\%$, the task illuminance is 364 lux. This value seems to be low, but it is quite appropriate because the previous analyses indicates that the overhangs obstruct 20-40% of the main windows on wall 1 and the secondary windows on wall 2 are heavily obstructed by the side corridors and external blinds. This means that the final total effective window area that has direct sky access is small.

Therefore, it seems appropriate to suggest that an effective window-to-floor ratio for school classrooms in HCMC should be 10%. However, it is necessary to look at its thermal comfort consequences which are discussed in chapter 7.

5.7. Conclusions

It is found that the methods introduced by the Vietnamese codes are not effective enough to predict daylight in the complex urban context of HCMC. Firstly, the *ĐRASTN* equation underestimates the impact of external obstructions. Secondly, the *Danhiluc* chart proves to be very complicated, since it correlates a long list of utilizing factors which can only be obtained from an existing table of values. In reality, the daylight context is much more complicated, so that in many cases it is sometimes not possible to find the appropriate values from these tables. The current Vietnamese codes either do not provide reliable and simple methods or provide insufficient information to designers. The existing international codes were developed from different climatic database, thus their validity is uncertain. Hence, there is a need to develop appropriate daylight design guidance specifically for HCMC.

This study reveals that using daylight can be potentially useful as well as be a threat in HCMC. Daylight availability is quite good. Although the mean availability in both seasons is not much different, the distribution varies in a wide range both daily and seasonally. It is found that sunlight penetration plays an important role in interior illuminance. Thus, to maximize the daylight advantage, a good daylight control system should be installed. There is a potential to save a lot of energy if a daylight linked control system is installed.

Furthermore, this study reveals that the impact of sunlight, especially ground reflected light, plays a significant role in room illumination. Ground reflected light may contribute up to 30-50% of the total light reaching the outer window surface. However, both the methods introduced by the Vietnamese codes and the popular Daylight Factor method underestimate this component. The Vietnamese codes employ the overcast sky model which is perhaps more appropriate for the Northern climate. The site measurements show that most of the time the classroom is under a sunlit condition hence using this sky model for daylight calculation in HCMC buildings may lead to a compromise of thermal comfort due to excessive solar gain.

It is discovered that the ineffectiveness sometime comes from minor design faults. This could be attributed to the lack of details in the current Vietnamese guidance which leads to inappropriate interpretation. For instance, the role of overhangs, the definition of effective opening areas, the significance of the ground area near the facade, these issues should be defined better in the codes.

It is also recommended that the code should provide better and clearer definitions of the effective opening areas that have meaningful daylight contributions. This study reveals that the effective opening area is much smaller than the actual opening area defined by window geometry. Based on the data collected on site, this study attempts to establish an effective window- to- floor ratio for a classroom in HCMC. To have adequate daylight access, it is suggested that a *Ro* ratio of 10% is recommended.

Chapter 6

Visual quality

6.1. Introduction

The task of classroom lighting scheme is not limited to providing enough light to see things correctly, it should also foster desirable interaction and communication, health benefits and improve the aesthetic appreciation of the space (CLEAR, 2004). Because light and vision are perceptions, the visual quality of a classroom lighting scheme depends upon both physical and psychological parameters. It cannot be measured, but visual quality is often quantified by visual performance, comfort and ambience (as in figure 6.1).

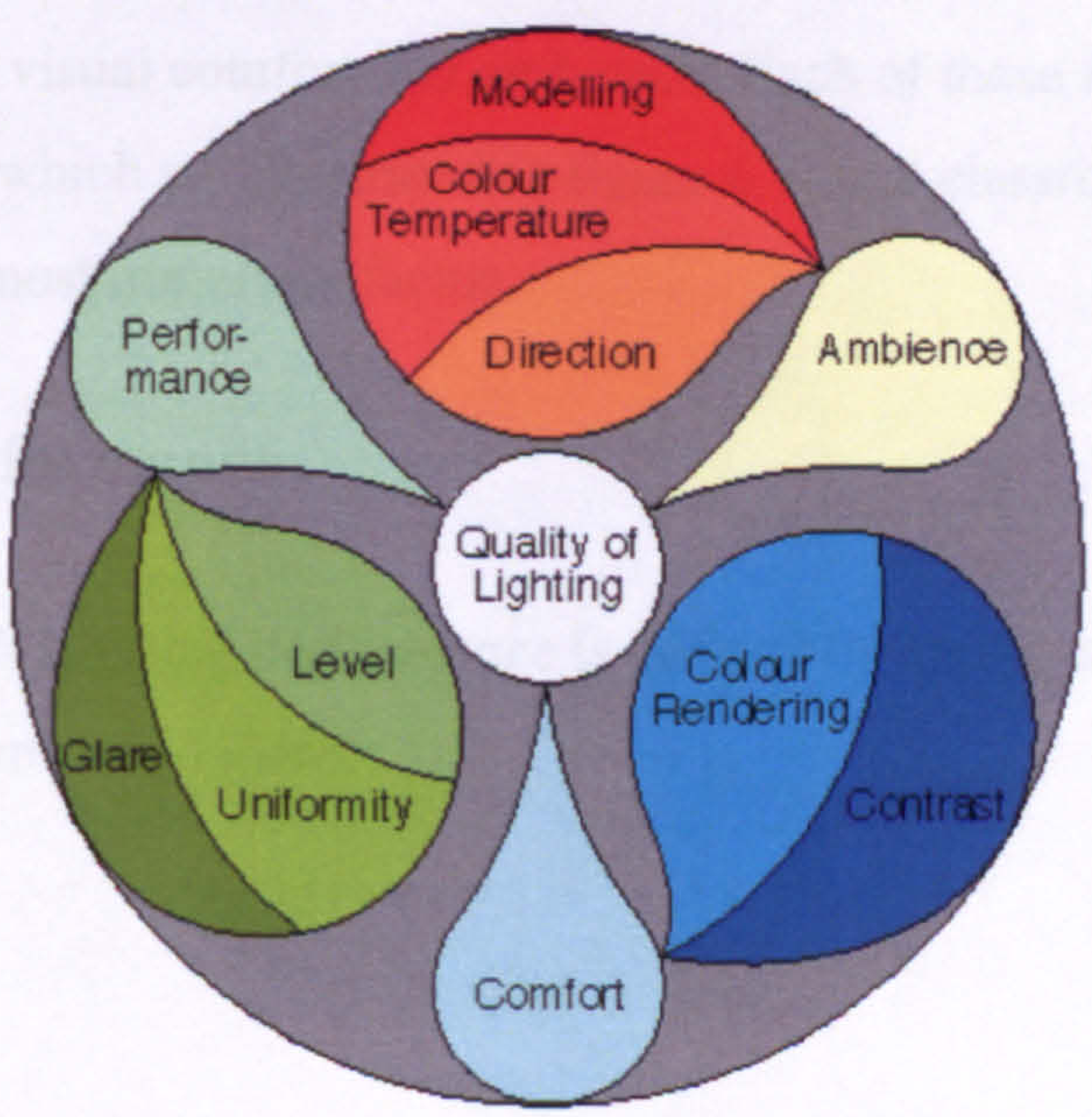


Figure 6.1 The quality of the lighting depends on a number of factors (CLEAR, 2004)

Most of the issues related to task illuminance have been discussed in chapter 5. This chapter provides further discussions on the visual quality of the four surveyed classroom. It is structured into three parts:

- The first part of this chapter discusses about the quality of the visual environment in the surveyed classrooms, focusing on the important factors that illustrated in figure 6.1. It should be noted that among these factors, some are more important than others; and since they also interact with each other a lot, there is no clear boundary between them.
- The second part of this chapter provides further evaluation on other relevant issues such as architectural integration, controlling strategies and energy efficiency of the lighting systems.
- The third part of this chapter presents the results and analysis of the users' visual comfort survey to establish the preferred visual comfort parameters for classrooms in HCMC schools.

6.2 Evaluating visual quality

The main factors that play an important role in the quality of visual environments are visual performance, visual comfort and ambience. Each of these factors is defined by several parameters, which are illustrated in figure 6.1. In a classroom, visual performance is the most important factor.

6.2.1. Visual performance

As shown in figure 6.1, visual performance is defined by the light level (task illuminance), uniformity and glare.

6.2.1.1. Light level

As discussed in chapter 3, the Vietnamese codes give conflicting recommendations on task illuminance. Therefore, it is difficult to verify whether the light level complies with the codes. The latest code TCVN: 09 (2005), which perhaps can be used as a good reference, requires that there be 300 lux at the student's desktop. This value is also often recommended in other codes such as in the European and US codes (e.g. BB: 90, ANSI/IESNA:RP3).

Table 6.1 presents the mean values of the task illuminance (*Eih,* in lux) of the surveyed classrooms. Because of daylight changes, the light level also varies. Data presented in table 6.1 indicates that only two school classrooms, i.e. at Le Van Tam and Lam Son, have *Eih* > 300 lux in both seasons. The other two classrooms have very low light level. It was found that the *Eih* in these classrooms is only 40-50% of what is recommended.

At a given point of time, daylight contribution may be low, but artificial light should be switched on to maintain an adequate light level at all times. The best lighting strategy should be a daylight-artificial linking scheme where artificial light is switched on and dimmed according to the daylight availability. It is noted that artificial light was asked to be switched on at all times during the surveys. Artificial light level *(EihA)* is often designed to be able to provide full illuminance (300 lux) in a worst case scenario or in case of a classroom is to be used during night time.

In this site survey, *EihA* was measured on site by portable handheld lux-meter during night visits. The results are presented in table 6.1, which indicates that all of the surveyed classrooms have very low *EihA*. The mean *EihA* of all school is only 165 lux, which is only 55% of what commonly is recommended. The best classroom is in Le Van Tam School, in which *EihA* is at 82% of the recommended level (248 lux).

It should be noted that all of the classrooms are lit by same type of lamp (i.e. T8 40W fluorescent tube) and the number of the lamps in each classroom are quite similar, but the *EihA* in each case, as presented in table 6.1, is very different. Therefore it can be inferred that layout, the mounting position and the optical control system can give different results.

Table 6.1 Classroom's task illuminance contributed by artificial light *(EihA)*

Task illuminance [lx]											
Measurements	Field survey					Recommendations					
						Vietnam codes			International codes		
	Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son	All Schools	TCXD 3978 (1984)	TCVN: 29 (1986)	TCVN: 09 (2005)	DIN 5035 & BB:90 (Europe)	IESNA RP-3 (The U.S)	METP (Malaysia.)
Eih	377.16	130.66	166.57	409.77	270.92	100	200	300	300	300 - 500	350
Eih-D	393.23	115.12	150.42	451.78	277.64						
Eih-W	361.10	146.20	182.73	366.77	264.20						
EihA	248.00	91.16	148.84	172.29	165.07						

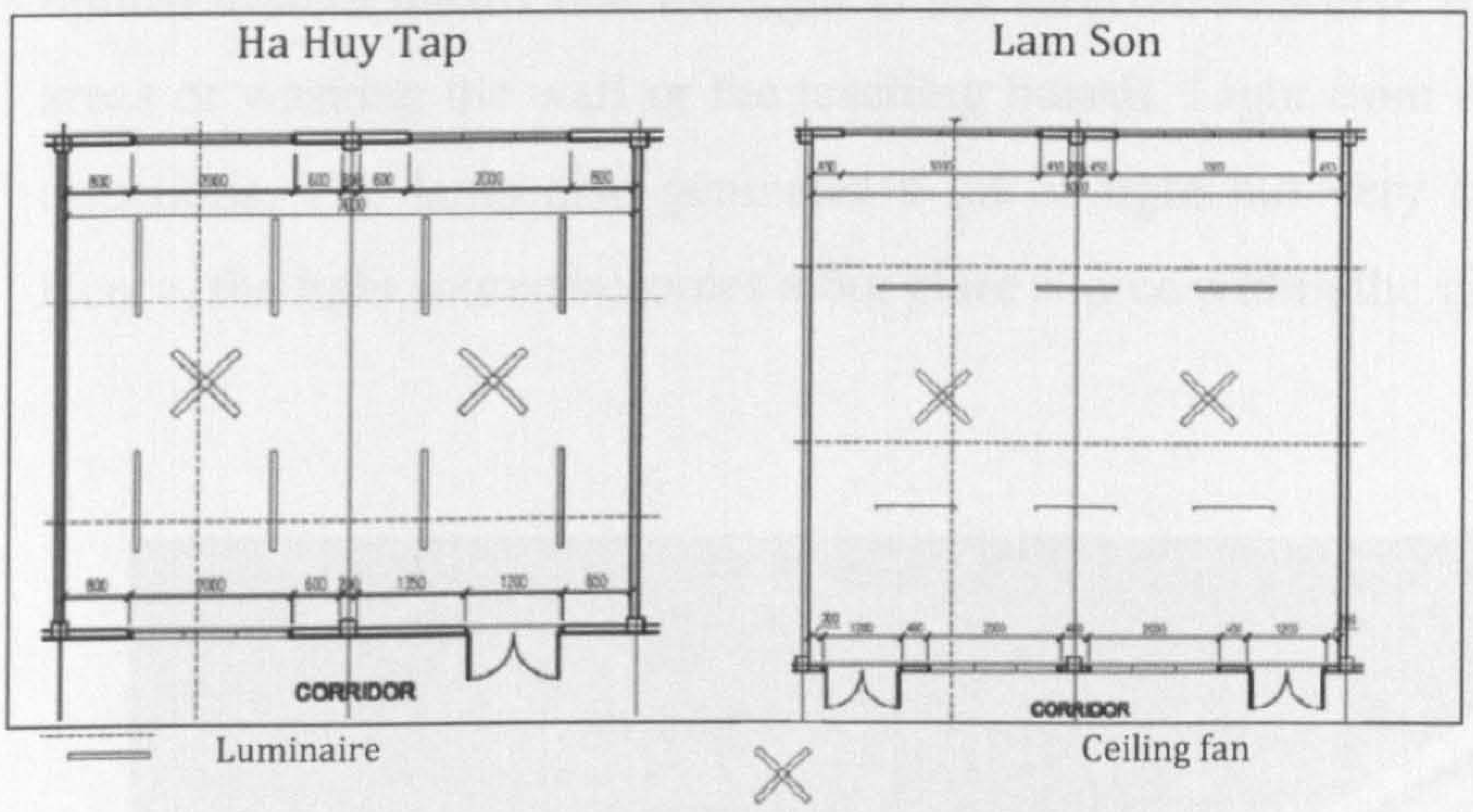


Figure 6.2

The luminaire layout and mounting positions do not associate well with the classroom layout to work well functionally. There is also very little switching and controlling flexibility provided.

It is found that the layout of light fixtures does not seem to have been coordinated well with the classroom layout (e.g. the layout of the student desks, window positions). As illustrated in figure 6.2, light fixtures are often arranged in a symmetrical grid, rather than on the basis of how they would light the space.

It is recommended in the TCVN: 3978 (1984) that fluorescent battens should be mounted downward and arranged in rows parallel to the side wall where the main windows are located. In three of the surveyed classrooms, they are all mounted perpendicularly to the side wall. In Truong Cong Dinh School the fluorescent battens are mounted vertically on the walls and very little light falls on the students desks. In the Ha Huy Tap classroom, some of the battens are mounted directly onto the ceiling surfaces and some of them are mounted onto the underside of the structural beams. Thus the distance between the light fixtures and the students' desks varies. The situation seems to be better in the Le Van Tam School and the Lam Son School classrooms. In these two classrooms, the fluorescent batten is suspended from the ceiling by steel rods and hence they are closer to the student's desk top. However, as observed on site, these suspended rods are not arranged properly making the ceiling appear very busy and can distract both the students and the teachers' view (see figure 6.3).

There is no optical control installed for these light fixtures. Only Le Van Tam classroom's light fixtures have simple reflectors and they make a significant improvement on the effectiveness, as seen in table 6.1. In other classrooms, bare T8 tube lamps are mounted either vertically or horizontally on surfaces. The lack of an optical system means that the light is not directed to where it is required (e.g. task areas or washing the wall or the teaching board). Light from the fixture emits in all directions. The lamp also generates a lot of light but very little of this is useful. Hence, the light source becomes a big glare source within the visual field.

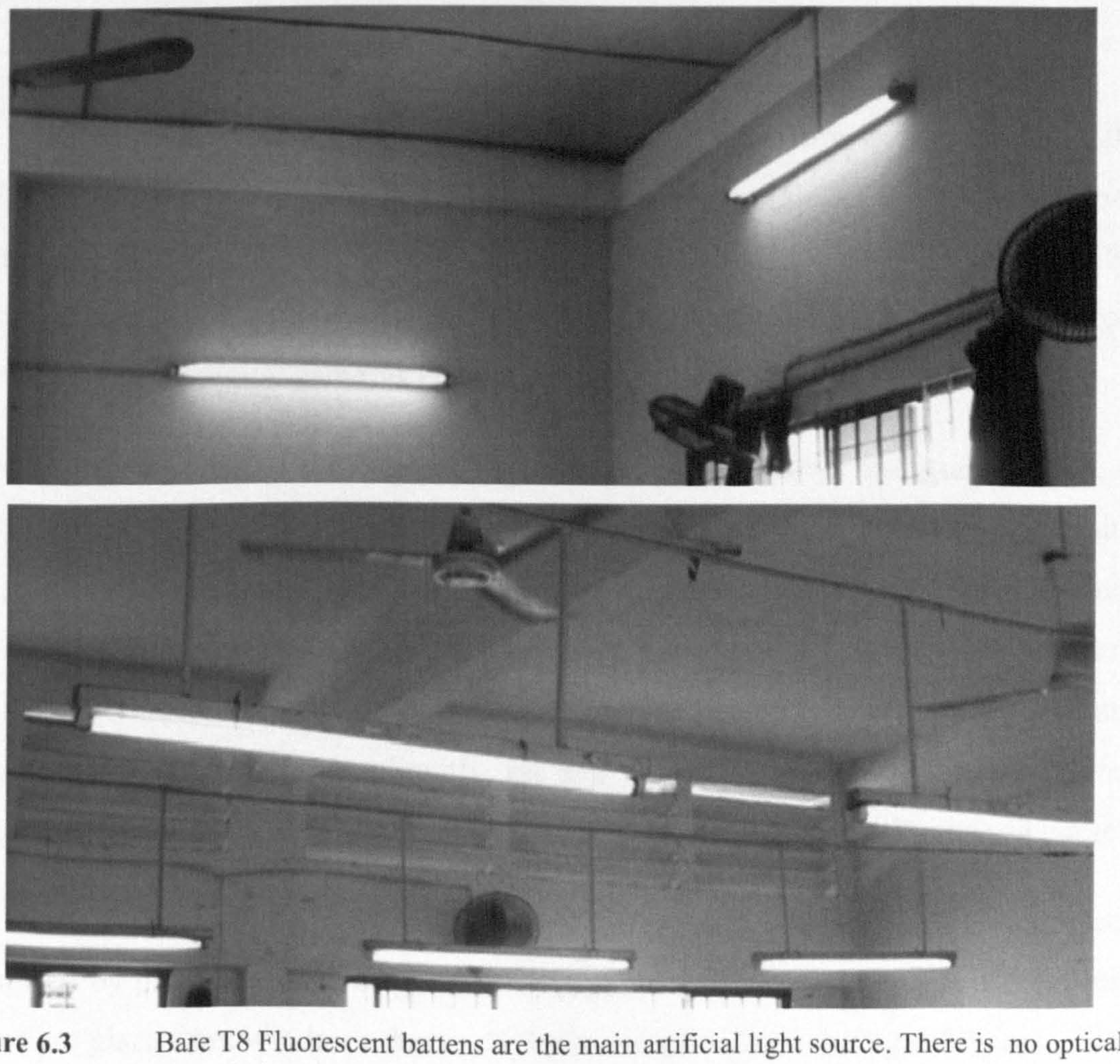


Figure 6.3 Bare T8 Fluorescent battens are the main artificial light source. There is no optical control, thus they produce glare and are ineffective.

6.2.1.2. Uniformity

Only one light meter is used to measure the task illuminance in the middle of the classrooms. However, site documentation shows that the uniformity is quite good.

Because the classrooms are all side lit and the size of opening in both side walls are quite similar, the daylight contribution is quite fair from both sides (see table 5.16, chapter 5). Furthermore, because the artificial light fixtures are arranged in a symmetrical grid and the size of the classrooms are not too big, it seems that there is high uniformity in these classrooms. This issue is further discussed in section 6.2.2.1 and section 6.2.3.2.

6.2.1.3. Glare

Low glare is an important requirement for good visual comfort. Glare is caused by excessive brightness contrast in the visual field. Theoretically, glare can be evaluated by glare indices. The theory behind the glare indices has been introduced in section 3.3.2.3, chapter 3, page 106-108.

To identify glare sources, the spatial luminance maps are constructed by the *WebHDR* software. *WebHDR* is a *High Dynamic Range* (HDR) image composition engine developed by Axel Jacobs of the London Metropolitan University. This software is capable of generating false colour luminance images of any space from pictures taken by digital cameras (Jacobs, 2007).

The luminance maps of the four survey classrooms are shown in figure 6.4-6.7. In these images, specific brightness values of important positions are calculated using the *RADIANCE ImageViewer,* which is a simple software developed by Dr. Andrew J. Marsh of Square One Research (now Autodesk-Ecotect) . It is capable of reading luminance values of the HDR Radiance images (generated by *WebHDR*) and providing accurate readings directly on the computer screen. In these figures, potential glare sources, defined by excess brightness, are identified by the red circles.

As seen in figure 6.4-6.7, there are two main glare sources which have been identified by their excessive brightness differences to the surrounding environments. These are glare from windows due to daylight and glare from the light fixtures.

Le Van Tam classroom

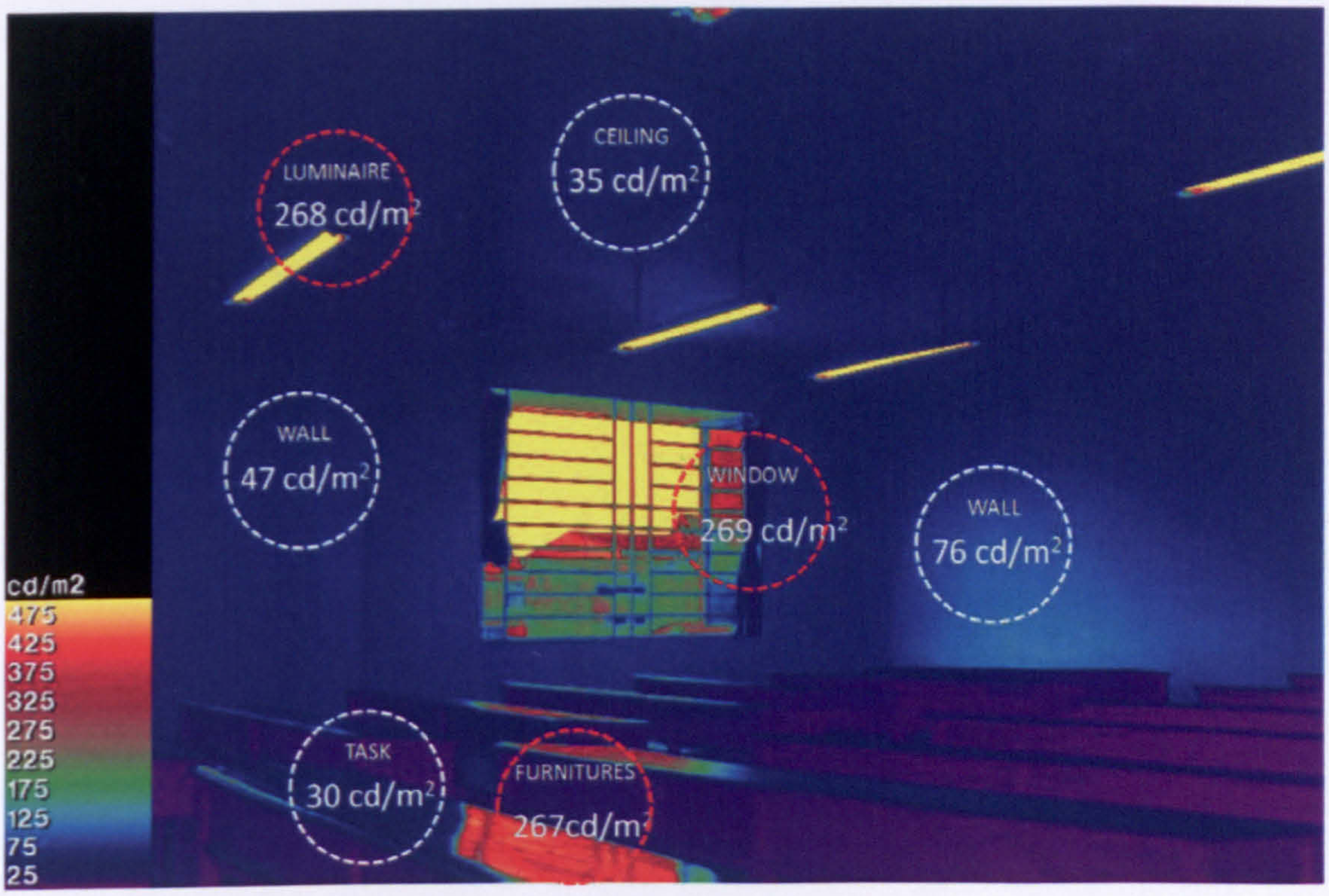


Figure 6.4 WebHDR Luminance map of Le Van Tam classroom.

Truong Cong Dinh classroom

Figure 6.5 WebHDR Luminance map of Truong Cong Dinh classroom.

Ha Huy Tap classroom

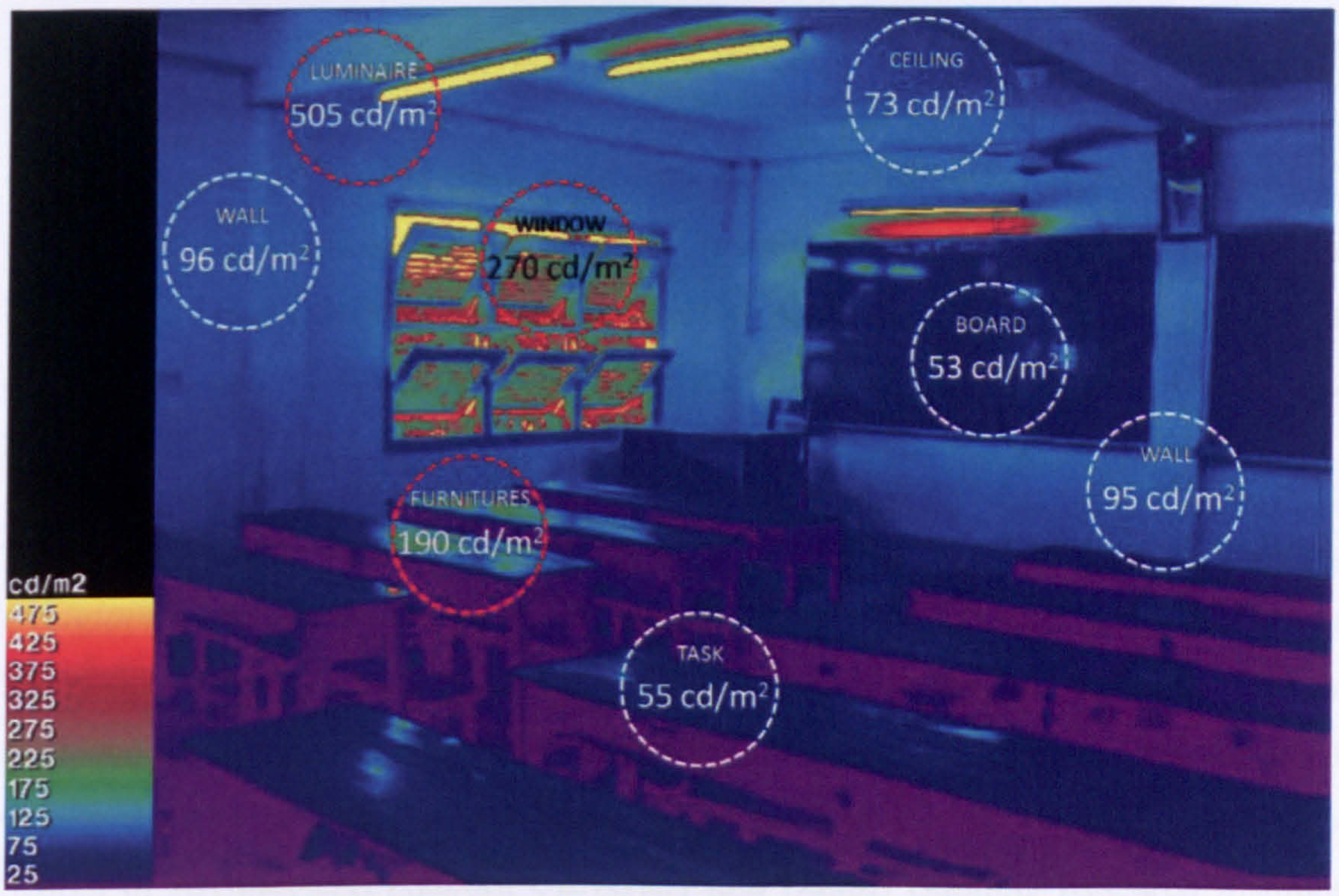


Figure 6.6 WebHDR Luminance map of Ha Huy Tap classroom.

Lam Son classroom

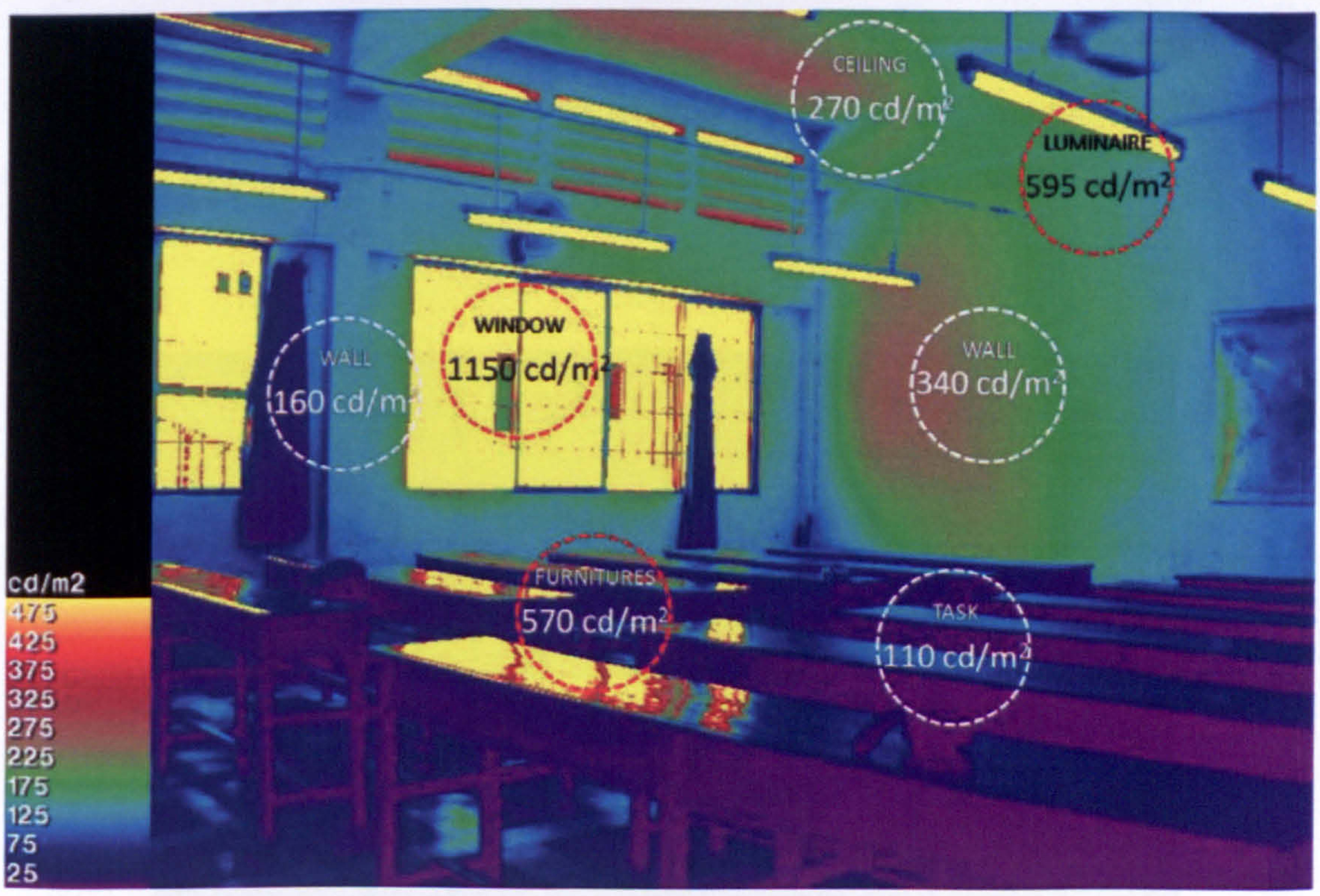


Figure 6.7 WebHDR Luminance map of Lam Son classroom.

To quantify glare, the Vietnamese and European codes use the *UGR* index (i.e. *Unified Glare Rating*, is an international glare index presented by CIE). It is recommended that classroom lighting should have UGR>19 (equivalent to *Daylight Glare Index*, DGI>22). The US code uses the *Visual Comfort Percentage* (VCP) index and for classroom lighting it is recommended that there should be a VCP>70%. These indices can be calculated manually, although the process is complicated and is often done using computer software (e.g. Radiance, Dialux and Relux).

In this discussion, the *Evalglare* software is employed to calculate glare indices. *Evalglare* is a simple Radiance-based software using MS-DOS interface (as shown in figure 6.8). It was developed by the German Fraunhofer Institute for Solar Energy Systems, Europe's largest application-oriented research organization, and has been widely used in several daylight research institutions, e.g. in Harvard University-School of Architecture, Aalborg University and Danish Building Research Institute (Wienold & Christoffersen, 2006). This software analyzes glare from the HDR images taken by digital cameras or produced by computer simulations. It is able to detect glare sources and calculate glare indices. The HDR image used in this analysis were taken by digital camera and generated by *WebHDR* software, and they are compatible to *Evalglare* software. The results are presented in table 6.2.

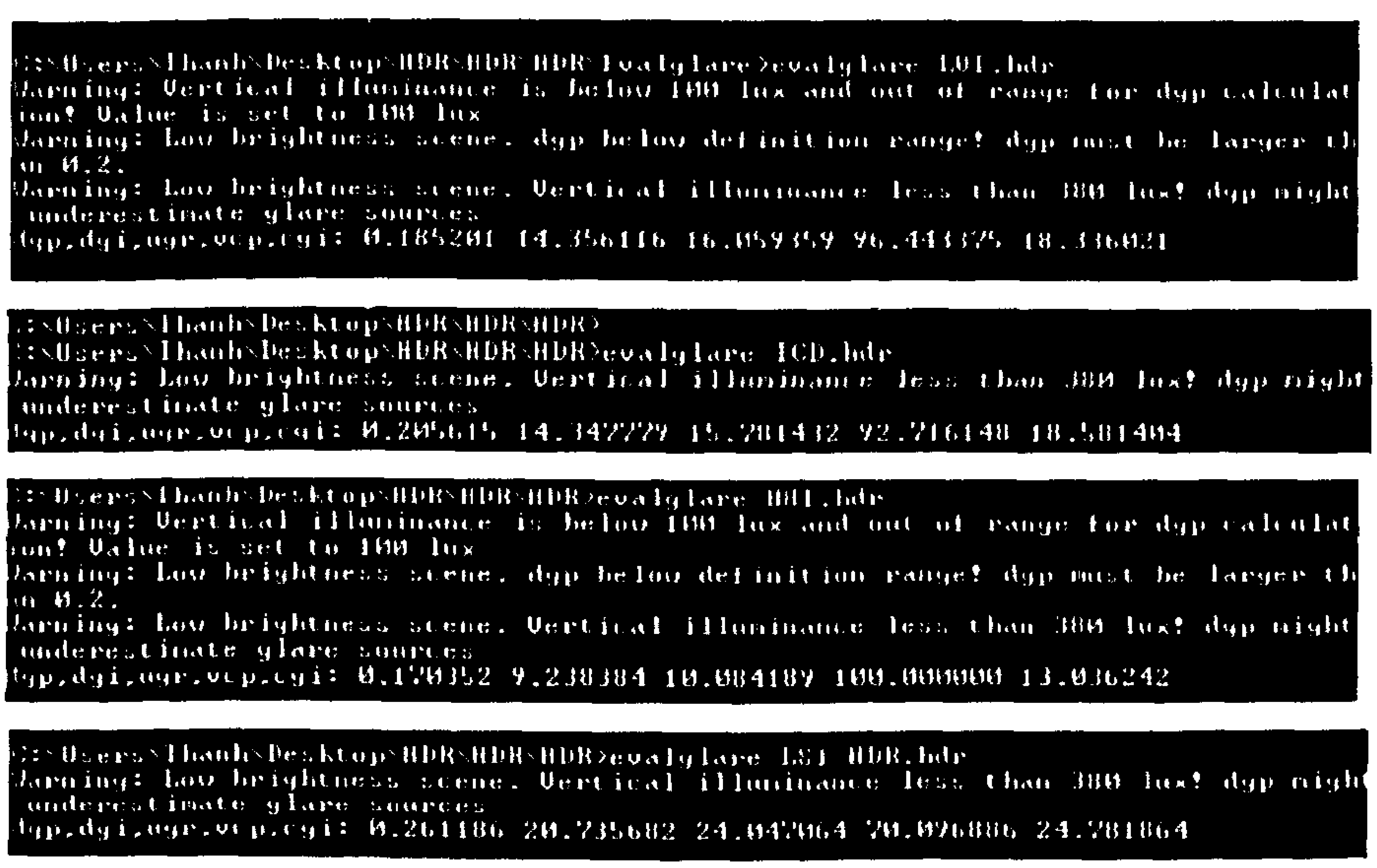


Figure 6.8 Glare analyses using *Evalglare* software.

Table 6.2 Glare indices generated by *Evalglare* software.

School	Daylight Glare Probability	Daylight Glare Index	Unified Glare Rating	Visual Comfort Probability [%]	CIE Glare Index
	DGP	***DGI***	***UGR***	***VCP***	***CGI***
LE VAN TAM	0.185	14.356	16.059	96.4433	18
TRUONG CONG DINH	0.205	14.347	15.781	92.716	18.581
HA HUY TAP	0.1703	9.238384	10.08	100	13.0362
LAM SON	0.2789	22.121	27.282	57.01	28

As shown in table 6.2, it is quite surprising that the glare indices (UGR, DGI, and VCP) are actually within the acceptable range (see section 3.3.2.3 of chapter 3, page 106-108). Only Lam Son School was found to be out of the comfort zone. These calculations are done when both daylight and artificial light are present. However, it should be noted that these glare indices were originally developed for evaluating artificial lighting conditions and therefore they may not be applicable for conditions where daylight is present. The main reason is the size of daylight openings which typically exceed solid angles of 0.01 steradians. Daylight also lights up the surrounding, it reduces the brightness contrast and thus, as per the glare prediction, is less accurate (Osterhaus W. K., 2005).

Furthermore, glare from windows due to daylight is difficult to quantify. Several researches suggest that glare from window is actually much more tolerable and is comfortably accepted by users (Tuaycharoen & Tregenza, 2007). Chauvel et al. (1982) discovered that discomfort glare from a window is practically independent of the window size and its distance from the observer, but is critically dependent on the luminance of the sky portion seen through the window. Therefore, it is difficult to quantify glare from daylight using available literature. Additionally, it has been noted that if there is pleasant view from the window causing the glare, the discomfort from daylight appears to be tolerated to a much higher degree than predicted by the available theoretical assessment methods (Chauvel et al., 1982; Osterhaus, 2001; Tuaycharoen, Tregenza, 2007).

Glare from light reflected off glossy furniture surfaces is dependent on the viewing angle. Although such glare is visible only at certain views it is still noticeable.

Further provisions should be made in the current codes on this issue to improve visual comfort.

From the site documentation it is quite obvious that there is glare from the artificial light source since these light fixtures are bare T8 tubes and they have no optical control. Although in this case there is scepticism about the reliability of the glare indices. It should be noted that the UGR system is mostly used as a glare standard for electric lighting rather than daylight applications and the glare analysis generated by *Evalglare* software is also associated with lighting measurements and corresponding subjective evaluations (Osterhaus W. , 2009). Furthermore, Inoue and Itoh (1989) also critique that the DGI system is not reliable. Perhaps the glare problem is not critical in such reading-writing environments, but it will be problematic in classrooms equipped with computer screens (visual display unit, VDU).

6.2.2. Visual comfort

In general, visual comfort is often expressed as the satisfaction with the visual environment. In this discussion, visual comfort is specifically defined by the spatial brightness contrast and the colour rendering (as illustrated in figure 6.1).

6.2.2.1. Spatial brightness contrast

The overall visual perception of the appearance of the interior is given by the spatial brightness contrast. It has been noted that high brightness contrast can also cause glare.

Field surveys indicate that the spatial brightness contrast has a large influence on a user's visual comfort. In a classroom, appropriate brightness ratio between the task area and the surrounding environment makes the visual quality of the environment better and thus would improve the students' academic performance (Govén, 2009).

Technically, the Vietnamese code TCVN:7114-1(2008) recommends a ratio of 3:2 between the task area and the surrounding area for best visual comfort. Other lighting codes such as BB:90 (1999) and the IESNA Handbook (2000) provide more specific requirements for the ratio between task, ceiling and walls (see section 3.3.2.2.2 of chapter 3, page 101-104). These recomendations are summarized in table 6.3.

Because there is no available data on ceiling illuminance, in this section the assessment focuses on analyzing the spatial luminance distribution and the ratio between the interior vertical illuminance and horizontal illuminance (*Eiv* and *Eih)*.

Table 6.4 presents the brightness values of the task area and the surrounding environment. These values are generated by the *RADIANCE Images Viewer* software. Figure 6.4 - 6.7 also provide further information on the spatial brightness distribution. From these values, the brightness ratio between important surfaces is estimated in table 6.5.

Table 6.3 Recommended brightness contrast ratio for best visual comfort.

Descriptions	TCVN: 7114-1	BB:90	IESNA	Reiman, 2008	Govén et al, 2002
Between task and adjacent surroundings	3:2 *(1.5)*	2:1 *(2)*	3:1 *(3)*	3:1 *(3)*	2:1 *(2)*
Between task and more remote areas	3:2 *(1.5)*	-	-	1:10 (0.1)	-
Between task and ceiling	3:2 *(1.5)*	3:1 *(3)*	-	-	-
Between task and window	-	-	1:10 *(0.1)*	-	-
Between window and adjacent surfaces	-	-	-	1:20 *(0.05)*	-
Anywhere in the field of view	-	-	1:5 *(0.2)*	1:40 *(0.025)*	-

Table 6.4 Spatial brightness distributions.

	BRIGHTNESS (luminance, cd/m2)				
School	TASK	WALL	CEILING	WINDOW	LUMINAIRE
LE VAN TAM	30	47	35	269	268
TRUONG CONG DINH	145	105	110	1100	1005
HA HUY TAP	55	96	73	270	550
LAM SON	110	160	270	1150	595

Table 6.5 Spatial luminance contrast ratio between surfaces.

	BRIGHTNESS CONTRAST RATIO				
School	*Task / Wall*	*Task / Ceiling*	*Ceiling / Wall*	*Wall / Window*	*Luminaire / Wall*
LE VAN TAM	0.64	0.86	0.74	5.72	5.70
TRUONG CONG DINH	1.38	1.32	1.05	10.48	9.57
HA HUY TAP	0.57	0.75	0.76	2.81	5.73
LAM SON	0.69	0.41	1.69	7.19	3.72

As seen from these tables, the brightness ratio in the surveyed classrooms is quite low. In Le Van Tam and Ha Huy Tap classrooms, the light scheme is quite diffused. Le Van Tam classroom has a contrast ratio of 0.64 (approximately $\frac{2}{3}$) between the task area and walls. This means the walls are perceived as brighter than the task area. There is also no accentuation and the lighting scheme looks quite boring. Students studying under such conditions for long periods of time may feel fatigue.

In Ha Huy Tap School, the light scheme is also quite diffused (task to wall luminance ratio is 0.57). This is due to low overall brightness and low task illuminance. This ratio means that the walls are perceived to be nearly twice brighter than the desk top. Hence the students may find it difficult to focus on their note books under such a scheme.

In Truong Cong Dinh, the luminance ratio between task and surroundings is 1.3 (approximately $\frac{4}{3}$). This means vertical and horizontal brightness is nearly the same. High vertical brightness is due to the diffused daylight scheme (as discussed in chapter 5) and the inappropriate mounting of the artificial light system. Although the overall perception of the space is brighter, the space is quite flat and not inspiring.

In Lam Son School, although the luminance ratios are not better than those of the Le Van Tam School, generally the light level is higher and hence the space is perceived as brighter. Perhaps some improvements in creating an appropriate spatial brightness gradient will helps to make the space look more comfortable and interesting.

6.2.2.2. Colour Rendering Index (CRI)

Lighting codes recommend that *Colour Rendering Index* (CRI) should be between 60 and 80. Classroom lighting can be found in group II of the *CIE* colour rendering classification which requires *"moderate colour rendering"*.

It has not been possible to measure exact colour rendering index onsite, because this task requires specific professional equipements.

Because the classrooms are mainly day lit, they have good colour rendering properties. Furthermore, the main light sources are the T8 fluoresecent tubes, which have adequate *CRI*. However, the quality of the lamp depends on the manufacturer, hence the *CRI* would vary (73-98). It is further noted that these light fixtures are also poorly maintained, thus the quality may be reduced. However, it is approptiate to assume that the the colour rendering in these classrooms is fairly acceptable.

6.2.3. Visual ambience

Luminous ambience perception has a large impact on people's light perception. Theoretically, it is found that colour temperatures, colour, rendering, luminance repartition, uniformity and luminaire types, all contribute to the luminous ambience in a room (CLEAR, 2004). Some of these factors are discussed in previous sections. This section provides further evaluation on colour temperature as well as modelling and directionality of light.

6.2.3.1. Correlated Colour Temperature (CCT)

According to the *Kruithof effect* chart, a classroom *CCT* should be within the range of 2700°K to 7500°K. This range is quite wide and includes both warm white and cold white light sources. The Vietnamese codes recommend cool white (CCT = 4200°K) for classrooms. For a day-lit space, European codes also recommend CCT>4000°K.

It is not possible to measure *CCT* onsite due to lack of equipment, but documentation shows that the surveyed classrooms are illuminated by cool white T8 fluorescent tubes. It is observed that these lamps have *CCT* around 4000°K-4500°K (from the specification label printed on the lamp). Overall, the perception of the space is quite cold, but the choice of colour temperature of the lamps, in this case, is quite appropriate.

6.2.3.2. Spatial modelling and directionality of light

In a classroom, task illuminance should have good uniformity. However, spatially, a brightness gradient is preferable. If the light is too diffused, the spatial rendering of the object can be poor and so the object may look blurred. If the light is too direct and casts a strong shadow, the extreme contrasts can be cause optical illusions.

An appropriate choice of brightness gradient and directionality of light helps to improve the three-dimensional perception of the space, and thus improve the architectural aesthetical value of the space.

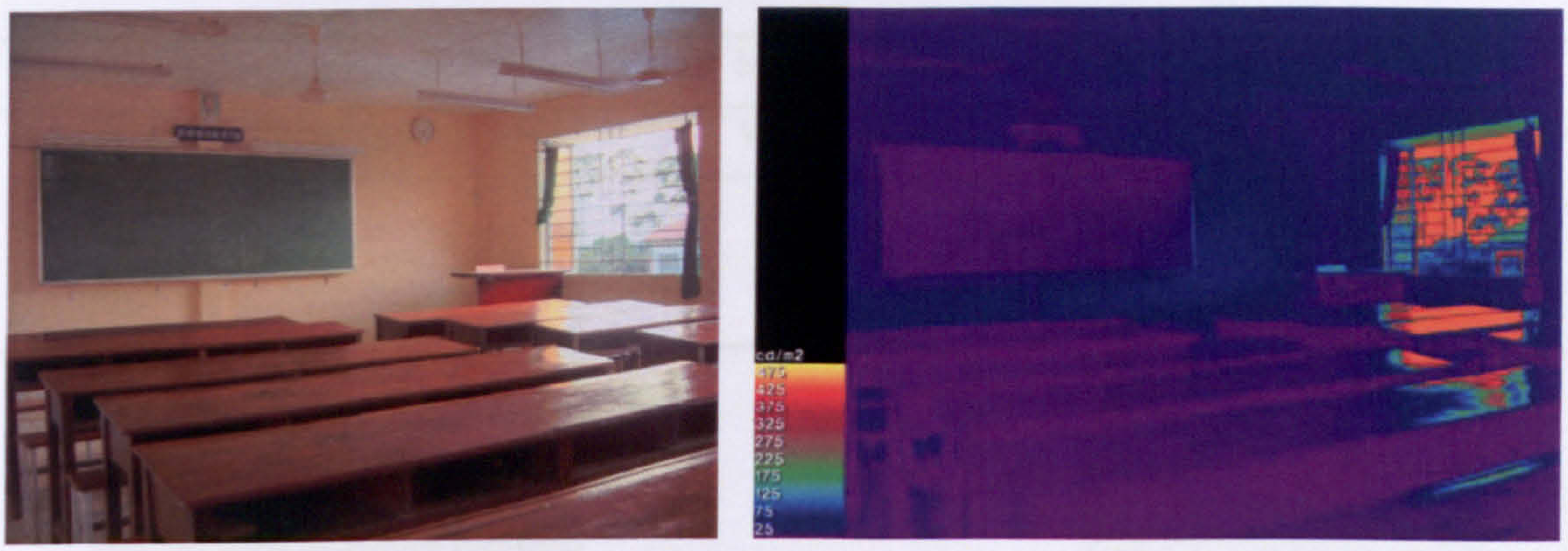
Furthermore, in a lighting scheme where the rendering of faces is important, the ratio of direct light and ambient light is important. This ratio is expressed as *Display Illuminance Ratio* (DIR). For good facial rendering, it is recommended that DIR should be 1.2 to 1.8 (CLEAR, 2004).

The spatial rendering of the surveyed classrooms is illustrated in figure 6.8, and the illuminance ratio of relevant surfaces is presented in table 6.7.

Table 6.6 Illuminance ratios and their effect (CLEAR, 2004)

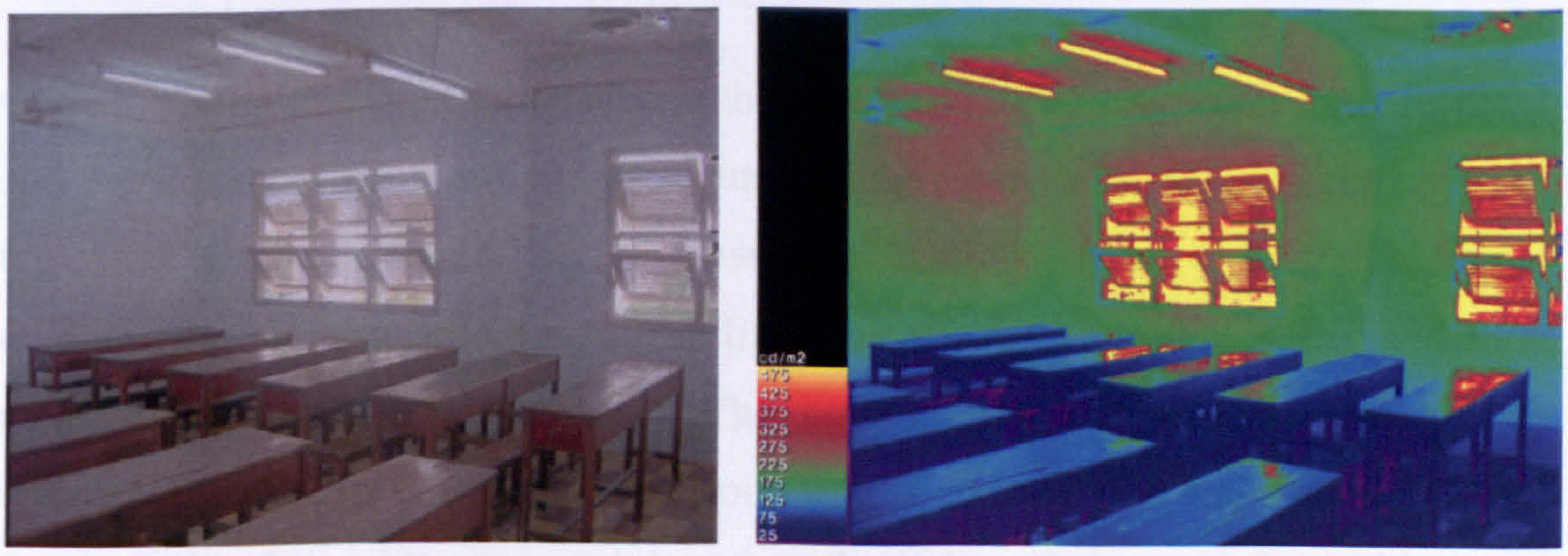
Display effect	Objective DIR	Subjective brightness ratio
Subtle	5:1	2.5:1
Moderate	15:1	5:1
Strong	30:1	7:1
Dramatic	50:1	10:1

LE VAN TAM



TRUONG CONG DINH

HA HUY TAP



LAM SON

Figure 6.9 Spatial luminous rendering of the surveyed classrooms by *WebHDR*.

Table 6.7 Illuminance ratio between interior surfaces; estimated from site measurements.

Schools	Dry season			Wet season			Both seasons		
	$\frac{Wall}{Task}$	$\frac{Wall}{Window}$	$\frac{Task}{Window}$	$\frac{Wall}{Task}$	$\frac{Wall}{Window}$	$\frac{Task}{Window}$	$\frac{Wall}{Task}$	$\frac{Wall}{Window}$	$\frac{Task}{Window}$
LE VAN TAM	1.24	270.27	29.84	0.93	310.76	38.50	1.08	290.52	34.17
TRUONG CONG DINH	0.77	259.30	36.44	1.13	220.94	20.55	0.95	240.12	28.49
HA HUY TAP	0.93	268.94	32.90	1.86	319.21	19.18	1.41	293.22	26.04
LAM SON	1.51	324.04	21.44	1.59	298.96	26.95	1.55	311.50	24.20

SPATIAL RATIO OF SURFACE ILLUMINANCE

Overall, the interior lighting scheme in the surveyed classrooms seems quite diffused and there is a lack of focus and accentuation (see figure 6.9). All surfaces are lit in the same way. It is found that the classroom lighting scheme is very simple and uninteresting. It is mostly functional lighting. The light pattern is flat and little contrast is found between surfaces. The light fixtures are arranged in a simple symmetrical grid layout. A better layout would consider the integration of light fixtures with the architecture and associate the light effect to aid the architectural design of the space.

Furthermore, there is not much difference between the vertical and the horizontal illuminance. In some cases, the vertical illuminance is eventually higher than the task illuminance (see table 6.7).

It seems that the external context has some influence on the interior illuminance spatial distribution. In three schools (i.e. Truong Cong Dinh, Ha Huy Tap and Lam Son) where there are large external obstructions, the $\frac{wall}{task}$ illuminance ratio is higher in the Wet season. In Le Van Tam School, where ground reflected light contribution is considerable, the $\frac{wall}{task}$ ratio in the Dry season is higher. This finding consolidates the important role of reflected daylight light in a tropical urban space.

Artificial light also has significant impact on vertical illuminance. In Le Van Tam School where a reflector is installed, the artificial light is controlled better and thus the spatial brightness ratio seems to be better. In Truong Cong Dinh School where light fixtures are mounted vertically on the wall, the vertical illuminance is higher than the task illuminance (see table 6.8).

Table 6.8 Interior Vertical Illuminance contributed by artificial light.

***EivA* [lx]**			
Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
84	80	110	132

There are some decorative features in the classrooms (e.g. posters, maps and flower pots) that are mounted on the walls, but they are all lit in the same way. The overall appearance is very flat. There should be some focal point and accentuations in the lighting scheme to make the space look more interesting (example given in figure 6.10 and figure 6.11).

There is also very little design coordination between light and either surface finishes or surface colours. The furniture has a dark finish providing high contrast. In Le Van Tam school classroom it has a very glossy finish that reflects a lot of light. Luminaire is often found within the students' views, which may cause glare.

It can also be seen that the lighting scheme does not provide an environment that encourages interactive activities which are important in the learning process. This includes good facial rendering of students and teacher, interesting views and focal points. Overall, it can be concluded that the visual amenity is poor and not inspiring. Same lighting scheme is used for both the students' areas and the teaching station.

Recent researches suggest that teaching –learning is an interaction process and facial recognition is very important. Improving facial recognition is not simply raising vertical illuminance but better facial rendering should be taken into consideration (BB:90, 1999). It is reported that the forthcoming British code for classroom LG5 is going to address these issues. As seen from the site documentation, down lighting is the only scheme in all classrooms, and thus people's faces are not rendered properly. As there is very little effective optical control provided, the light scheme is quite patchy. A lot of unwanted light falls unintentionally on the walls making the space look messy.

Figure 6.10 Focal points and accentuation should be added to the lighting scheme. In the left and the middle picture, the map and the shelf are not accentuated. In the right picture, luminaires are mounted at inappropriate positions and thus leave the wall features poorly visible.

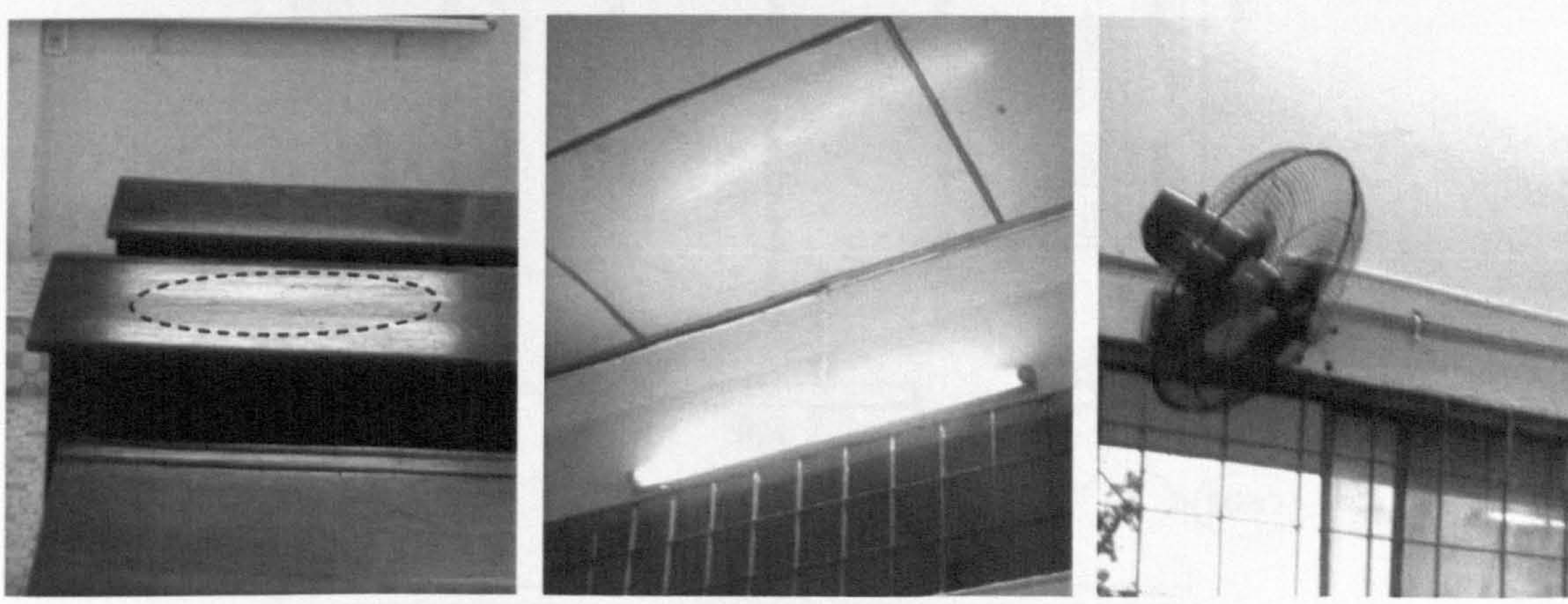


Figure 6.11 There is little awareness of integrating lighting and architecture. Problems spotted are inappropriate finishes (as seen in the left and middle picture). In the right picture, the luminaire is mounted above the escalating fan and thus the light is flickered.

6.3. Controlling Strategies

It is found that daylight contribution provides a large percentage of the total *Eih*. As discussed in previous sections, there is the provision of switching off the artificial light during the class hours when daylight can provide enough required task illuminance. Although it may seem that controlling artificial light would be easier, it has been found in all the schools that the switching strategy is very basic (i.e. simple on/off mode); all the artificial light is non dimmable and they are grouped together in the same circuit controlled by single on-off switcher located at the entrance. There are two switches: one for those mounted above the teaching board and one for the remainder. Light fixtures are often grouped in the same circuit for their proximity rather than the task that they perform. There is very little flexibility in controlling these fixtures individually and they are neither centrally controlled nor linked to any automatic sensors.

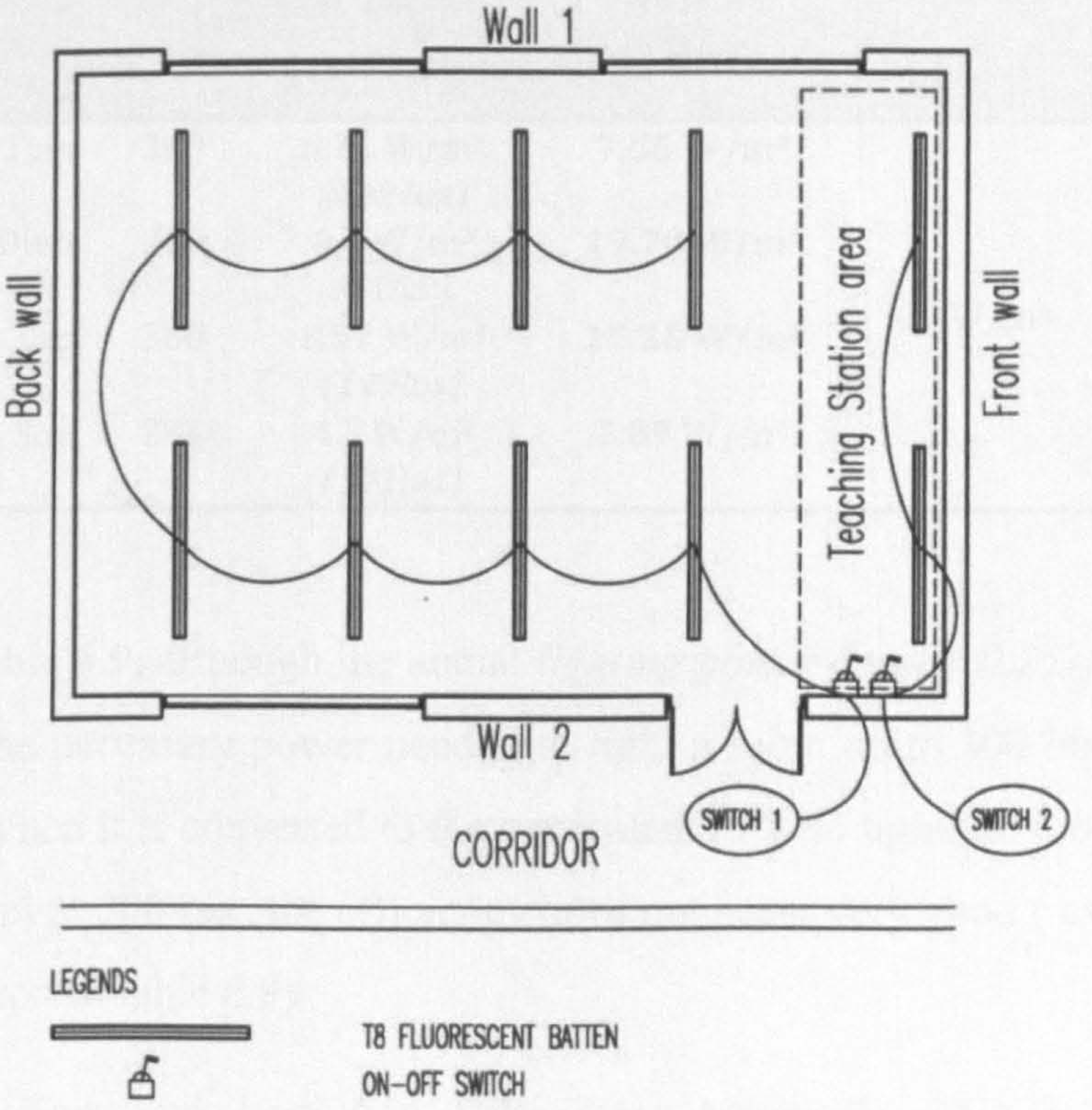


Figure 6.12 Typical controlling strategies of artificial lighting of the surveyed classrooms. Luminaires are grouped in two circuits. One circuit links all the light fixtures in the students' areas. Another one links the two fixtures mounted above the teaching board. The switches are only on-off mode type.

6.4. Energy efficiency

Site documentation shows that all the surveyed classrooms are equipped with T8 fluorescent battens, which are quite energy efficient (as seen in table I.2 of in appendix I, the luminous efficacy is 88lm/W). The energy efficiency of a lighting scheme is often evaluated by the *Lighting Power Density (LPD)*, which is the lighting power required per square meter to light the space as per requirements. There are several factors that affect the effectiveness of the lighting scheme (e.g. the optical control of the light fixtures, the mounting position and ballast). The *LPD* of the surveyed classrooms are estimated in table 6.9.

Table 6.9 Estimates of the Lighting Power Density of the surveyed classrooms.

School	Total power [W]	Lighting Power Density (LPD)			
		Site survey		Recommendations	
		Actual LPD *(Actual lux)*	**Equivalent LPD** *(to lit at 300 lux)*	TCXDVN: 09 (2005)	CIBSE Guide F (UK)
Le Van Tam	360	6.25 W/m^2 *(248 lux)*	**7.56 W/m^2**	13 W/m^2	7 W/m^2 *(lowest among International codes)*
Truong Cong Dinh	288	6.0 W/m^2 *(91lux)*	**19.70 W/m^2**		
Ha Huy Tap	360	8.57 W/m^2 *(149lux)*	**17.25 W/m^2**		
Lam Son	288	4.5 W/m^2 *(171lux)*	**7.89 W/m^2**		

As shown in table 6.9, although the actual *lighting power density (LPD)* is quite low, these are not the necessary power needed to light a room up to 300 lux, required as per the code. When it is converted to the equivalent *LPD* to light the room at 300 lux, to light the room at 300 lux, the efficiency does not seem very good (as presented in the fourth column of table 6.9).

Only Le Van Tam and Lam Son School are below the TCXDVN:09 (2005) requirement, and slightly miss the British code CIBSE Guide F (CIBSE, 2004). Moreover, these light fixtures are the inexpensive type powered by budget T8 lamp and conventional magnetic ballast which has a low rate of efficiency. Site study also shows that they are also not well maintained.

To evaluate lighting efficiency, particularly for estimating energy saving of the daylight-artificial linked lighting scheme, the European code EN:15193 (2007) *Energy performance of buildings — Energy requirements for lighting* provides a specific method for estimating energy consumption for interior lighting. This method takes into account the building's latitude as well as the prediction of energy saving due to daylight contribution defined by the *Daylight dependency factor (FD)*. It also provides estimates on the *Lighting Energy Numeric Indicator* (LENI). Further information about this issue can be obtained in EN: 15193 (2007).

In this research, there have been efforts to estimate the *LENI* index by using this code. However, this method seems to be valid only for buildings located within 60°N to 35°N. When this method is applied for estimating *FD* in the surveyed classroom, errors are found in the results for Le Van Tam and Truong Cong Dinh School, where *FD* is smaller than zero. This result is caused by a combination of large *depth indices* I_{De} and small *transparency indices* I_T. *DC* then should be set to $DC_{adj}=0$. This means that there is little daylight penetration for Le Van Tam and Truong Cong Dinh School, although the site measurements show evidence of daylight penetration. Therefore, this method is not appropriate for HCMC cases (10°N). There is a need to develop an appropriate method to predict energy saving of lighting in HCMC classrooms.

In summary, the artificial light system in all classrooms does not meet the expectation in all criteria, e.g. visual comfort, effectiveness and energy efficiency. There is a lot of room for improvement in this system, such as adding better optic control, introducing more flexible controlling strategy and using more energy efficient lamps and ballasts (e.g. T5 fluorescent lamp with dimmable high frequency electronic ballast).

6.5. Architectural integration

It is found that there is little awareness of the integration of the lighting system, both daylight and artificial light, into the architectural design. As discussed in previous part, the site layout is not coordinated with the solar geometry. Shading devices are also not properly designed to work within the surrounding context. Similar shading types are found in all schools (simple solid concrete overhangs in most cases), despite the external daylight context being different. Same shading and window types are installed in all facades; although they are they face different orientations. They are also not concealed well into the building architecture. It has also been found that there is very little integration between the building and the classroom layout. All windows have the same design, size, glazing type and positions. The windows and openings design are often compromised by architectural amenity rather than by functional effectiveness. For example, same design of windows is installed in both side walls despite the fact that they open to different landscapes. Classrooms have similar layouts despite the position of the windows. There is also very little integration of artificial light system into the architecture. Light fixtures are often found mounted directly on the walls or the ceiling.

Figure 6.13 Same shading and window designs installed in all facades despite the difference in orientation and the external context.

6.6. Predicting students' visual comfort preferences

The following factors will be discussed in this section:

Table 6.10 Symbols and definitions of the visual comfort preferences.

	Symbols		*Descriptions*
Students	*psEih*	*lux*	Students' preferred interior horizontal illuminance in both seasons
	psEih-D	*lux*	Students' preferred interior horizontal illuminance in the Dry season
	psEih-W	*lux*	Students' preferred interior horizontal illuminance in the Wet season
	psEihD	*lux*	Students' preferred on daylight contribution on interior horizontal illuminance in both seasons
	psEihD-D	*lux*	Students' preferred on daylight contribution on interior horizontal illuminance in the Dry season
	psEihD-W	*lux*	Students' preferred on daylight contribution on interior horizontal illuminance in the Wet season.
	psEiv	*lux*	Students' preferred interior vertical illuminance in both seasons
	psEiv-D	*lux*	Students' preferred interior vertical illuminance in the Dry season
	psEiv-W	*lux*	Students' preferred interior vertical illuminance in the Wet season
	Symbols		*Descriptions*
Teachers	*ptEih*	*lux*	Teachers' preferred interior horizontal illuminance in both seasons
	ptEih-D	*lux*	Teachers' preferred interior horizontal illuminance in the Dry season
	ptEih-W	*lux*	Teachers' preferred interior horizontal illuminance in Wet season
	ptEihD	*lux*	Teachers' preferred on daylight contribution on interior horizontal illuminance in both seasons
	ptEihD-D	*lux*	Teachers' preferred on daylight contribution on interior horizontal illuminance in the Dry season
	ptEihD-W	*lux*	Teachers' preferred on daylight contribution on interior horizontal illuminance in the Wet season.
	ptEiv	*lux*	Teachers' preferred interior vertical illuminance in both seasons
	ptEiv-D	*lux*	Teachers' preferred interior vertical illuminance in the Dry season
	ptEiv-W	*lux*	Teachers' preferred interior vertical illuminance in the Wet season

In previous discussions, the evaluation of the classrooms' lighting performance was mainly based on recommendations from the current codes and established studies. In this section, classroom lighting performance is examined from the users' perspective. The evaluation is based on the review of students' responses collected from field questionnaires to provide an overview of the current situation and to predict the users' visual comfort preferences.

Further details of the comfort survey are given in appendix A.

The students' mean visual comfort votes are presented in table 6.11. The overall students' responses on visual comfort are quite moderate. Majority of the mean votes are within the comfort range (between *slightly low and slightly high*). Although site measurements show that there are significant differences in lighting conditions in the Dry and in the Wet season, these differences are not clearly shown in the users' responses. In all schools, visual comfort is seen as slightly better in the Wet season. This indicates that the students are quite adaptive to their circumstances. However, the distribution of the votes of each school on the comfort scale varies.

Ha Huy Tap School has the largest percentage of votes on *"very low visual comfort"*, where 27% of the students selected the worst choice. Truong Cong Dinh School seems to have fair distribution of votes on the comfort scale. Le Van Tam School has the highest percentage of votes on *"very high visual comfort"*. Overall, Lam Son School has the largest percentage of votes falling within the neutral comfort zone (see table 6.12). These mixed results suggest that there are differences in levels of visual comfort adaptation of each group of students.

Table 6.11 Students' visual comfort mean votes.

STUDENTS' VISUAL COMFORT MEAN VOTES					
SEASON	LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON	ALL SCHOOLS
DRY SEASON	**4.6**	**4.3**	**4.1**	**3.8**	**4.2**
WET SEASON	**4.8**	**4.6**	**4.2**	**4.0**	**4.3**
BOTH SEASONS	**4.7**	**4.4**	**4.2**	**3.9**	**4.3**

Comfort Scale	1	2	3	4	5	6	7
Sensation	Very low	Low	Slightly low	Neutral	Slightly high	High	Very high

Table 6.12 Percentage of students' visual comfort mean votes falling within the neutral zone.

Comfort sensation scale	Very low	Low	Slightly low	Neutral	Slightly high	High	Very high
LE VAN TAM SCHOOL							
Percentage of visual comfort votes in the Dry season	17%	10%	**8%**	**16%**	**11%**	17%	21%
Percentage of votes in the neutral zone in the Dry season				**35%**			
Percentage of visual comfort votes in the Wet season	16%	10%	**9%**	**14%**	**11%**	20%	20%
Percentage of votes in the neutral zone in the Wet season				**34%**			
Percentage of visual comfort votes in both seasons	16.5%	10%	**8.5%**	**15%**	**11%**	18.5%	20.5%
Percentage of votes in the neutral zone in both seasons				**34%**			
TRUONG CONG DINH SCHOOL							
Percentage of visual comfort votes in the Dry season	17%	13%	**12%**	**20%**	**10%**	12%	16%
Percentage of votes in the neutral zone in the Dry season				**42%**			
Percentage of visual comfort votes in the Wet season	16%	14%	**13%**	**16%**	**10%**	9%	22%
Percentage of votes in the neutral zone in the Wet season				**39%**			
Percentage of visual comfort votes in both seasons	16.5%	13.5%	**12.5%**	**18%**	**10%**	10.5%	19%
Percentage of votes in the neutral zone in both seasons				**40.5%**			
HA HUY TAP SCHOOL							
Percentage of visual comfort votes in the Dry season	25%	12%	**16%**	**15%**	**17%**	12%	3%
Percentage of votes in the neutral zone in the Dry season				**48%**			
Percentage of visual comfort votes in the Wet season	29%	10%	**15%**	**20%**	**15%**	7%	4%
Percentage of votes in the neutral zone in the Wet season				**50%**			
Percentage of visual comfort votes in both seasons	27%	11%	**15.5%**	**17.5%**	**16%**	9.5	3.5
Percentage of votes in the neutral zone in both seasons				**49%**			
LAM SON SCHOOL							
Percentage of visual comfort votes in the Dry season	5%	24%	**18%**	**21%**	**20%**	8%	4%
Percentage of votes in the neutral zone in the Dry season				**59%**			
Percentage of visual comfort votes in the Wet season	8%	18%	**17%**	**27%**	**18%**	6%	6%
Percentage of votes in the neutral zone in the Wet season				**62%**			
Percentage of visual comfort votes in both seasons	6.5%	21%	**17.5%**	**24%**	**19%**	7%	5%
Percentage of votes in the neutral zone in both seasons				**60.5%**			
ALL SCHOOLS							
Percentage of visual comfort votes in the Dry season	13%	13%	**11%**	**19%**	**13%**	14%	17%
Percentage of votes in the neutral zone in the Dry season				**43%**			
Percentage of visual comfort votes in the Wet season	11%	10%	**13%**	**20%**	**13%**	15%	18%
Percentage of votes in the neutral zone in the Wet season				**46%**			
Percentage of visual comfort votes in both seasons	12%	11.5%	**12%**	**19.5%**	**13%**	14.5%	17.5%
Percentage of votes in the neutral zone in both seasons				**44.5%**			

← Neutral zone →

Although the codes have set up some recommendations for ensuring the quality of visual environment in the classroom, it should be noted that these recommendations are appropriate for average conditions. In reality, the conditions are much more complex and individual comfort preferences are different and are affected by many other immeasurable factors.

This section presents the analysis of the results collected from the site survey for predicting the visual comfort preferences of the group of users participating in the survey. The analysis employs the regressive plotting method: this means the users' comfort votes are plotted against the physical conditions of the site to predict the neutral comfort preferences from the regressive line.

Four schools participated in the survey. This means the size of samples, if based on mean vote values from each school, will be limited only to four variables representing four schools. Furthermore, there are different numbers of students participated in the survey from each school; this means that the single mean vote of each school cannot represent the weight of the total population accurately. Moreover, because all the measurements are taken within one to two months of each season, the daily climate variation is quite small and thus the range of data is not large enough to provide meaningful results. Therefore, in the regressive plotting of site measurements and user's comfort vote, it is more appropriate to plot all individual comfort votes of 477 students, which represents the weight of the population better, in the graph rather than as the single mean comfort vote of each school as done in other sections.

There is another difficulty. Although the 477 comfort votes from individuals are different, all of the students study in one of the four classrooms. This means that all of these responses actually evaluate the four physical conditions. To extend the data range and thus predict results more accurately, the students are split into smaller group according to their study shifts. For instance, students of the same classroom but studying in different shifts (i.e. morning and afternoon) are treated as two student groups and votes from individuals from each of these groups are plotted against the mean measurement of the shift accordingly. For example, in a classroom used by 100 students in two shifts, 40 study in the morning and 60 study in the afternoon; the 40 votes of the morning shift students are plotted against the single value of the same mean task illuminance of the classroom measured during the morning shift. Therefore, in the graph, all the votes from the 40 students would overlap and thus they are seen as a single vote but the weight of the votes is still considered.

6.6.1. Predicting the students' preferred task illuminance

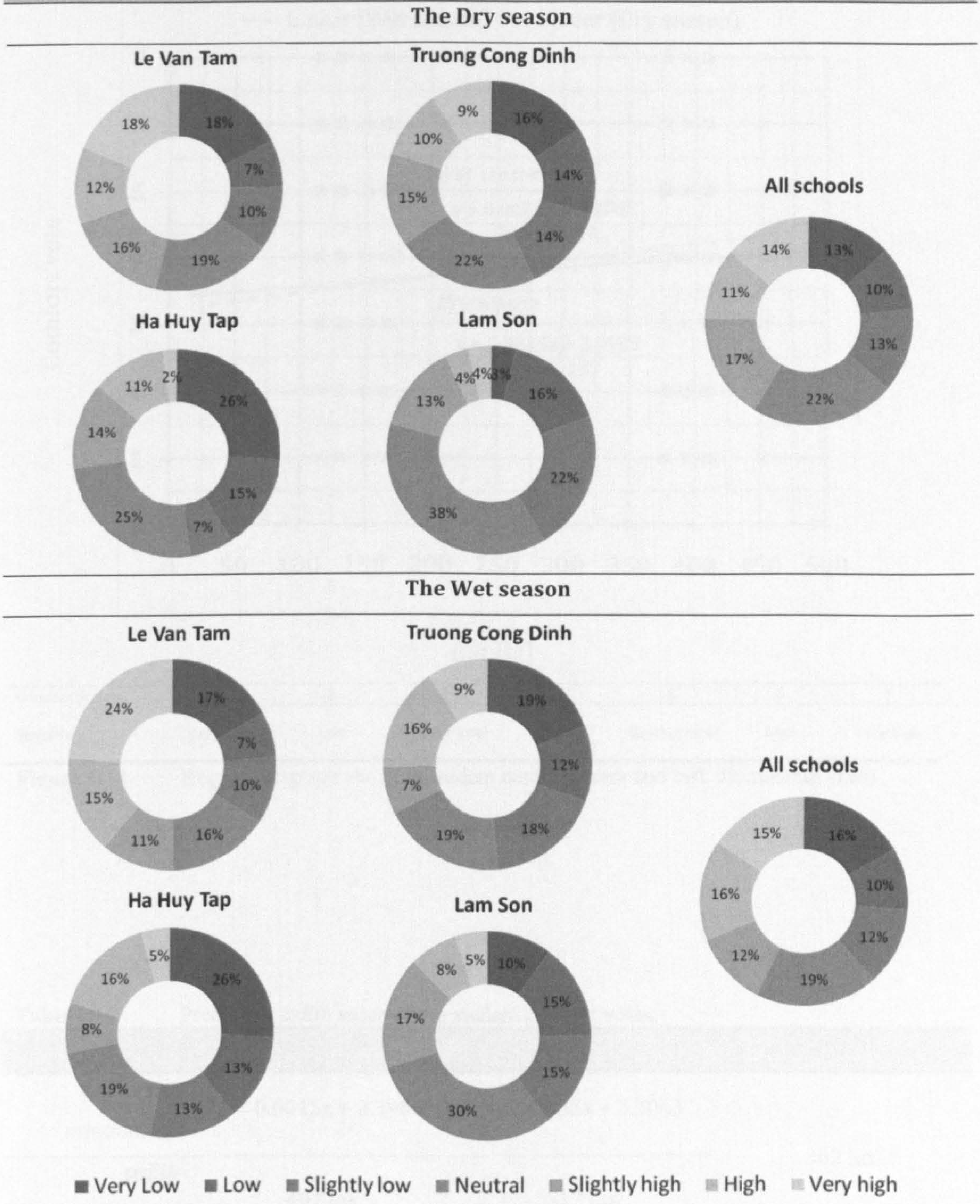
The first concern is the task illuminance. Table 6.13 presents further details of the students' responses on task illuminance (*Eih*). Although the mean task illuminances recorded on site of each school vary, no significant difference has been found on the comfort means votes of each school. Majority of the mean votes of all four schools fall within the neutral zone, i.e. between "*slightly low to slightly high*". This suggests that either the students are quite adaptive or the task illuminance is adequate.

Figure 6.14 show the regressive graph of mean task illuminance (*Eih*) and the students' comfort votes. The regressive lines suggest that students feel their classrooms are under lit and that their neutral comfort illuminance should be higher. The regressive line predicts that the preferred task illuminance, *psEih* (both seasons), is approximately 362 lux, which is slightly higher than what is recommended by current codes (300 lux). Specifically, the *psEih-D* is slightly higher than *psEih-W* (see table 6.14).

In the Wet season when the daylight context is more diffused, the *psEih-W* is predicted at 317 lux, which is very close to the codes' recommendations that have been developed for overcast sky conditions. Therefore, it can be concluded that this prediction is quite reliable. In the Dry season, when the external illuminance is higher, it is understood that the students prefer higher task illuminance (at 407 lux).

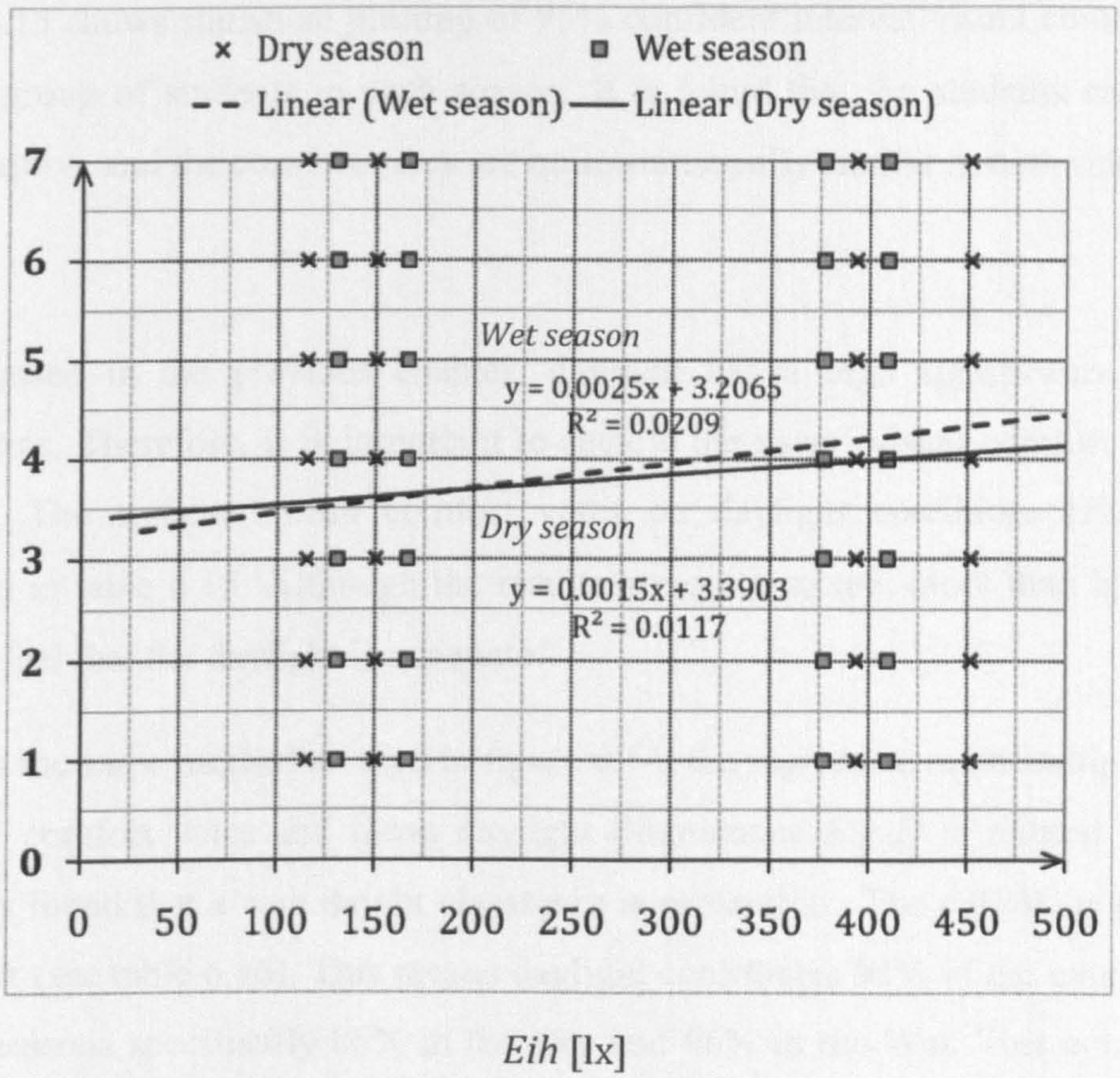
Table 6.13 Students' visual comfort votes on task illuminance.

STUDENTS' VISUAL COMFORT VOTES ON TASK ILLUMINANCE OF EACH SCHOOL



STUDENTS' VISUAL COMFORT MEAN VOTES ON TASK ILLUMINANCE					
SEASON	LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON	ALL SCHOOLS
DRY SEASON	4.6	3.9	3.9	3.7	4.1
WET SEASON	4.6	3.7	4.2	3.5	4.1

Comfort Scale	1	2	3	4	5	6	7
Sensation	Very low	Low	Slightly low	Neutral	Slightly high	High	Very high



Comfort Scale	1	2	3	4	5	6	7
Sensation	Very Low	Low	Slightly Low	Neutral	Slightly high	High	Very high

Figure 6.14 Regressive graph showing student comfort votes and task illuminance (*Eih*) .

Table 6.14 Predicting *psEih* values from student comfort votes.

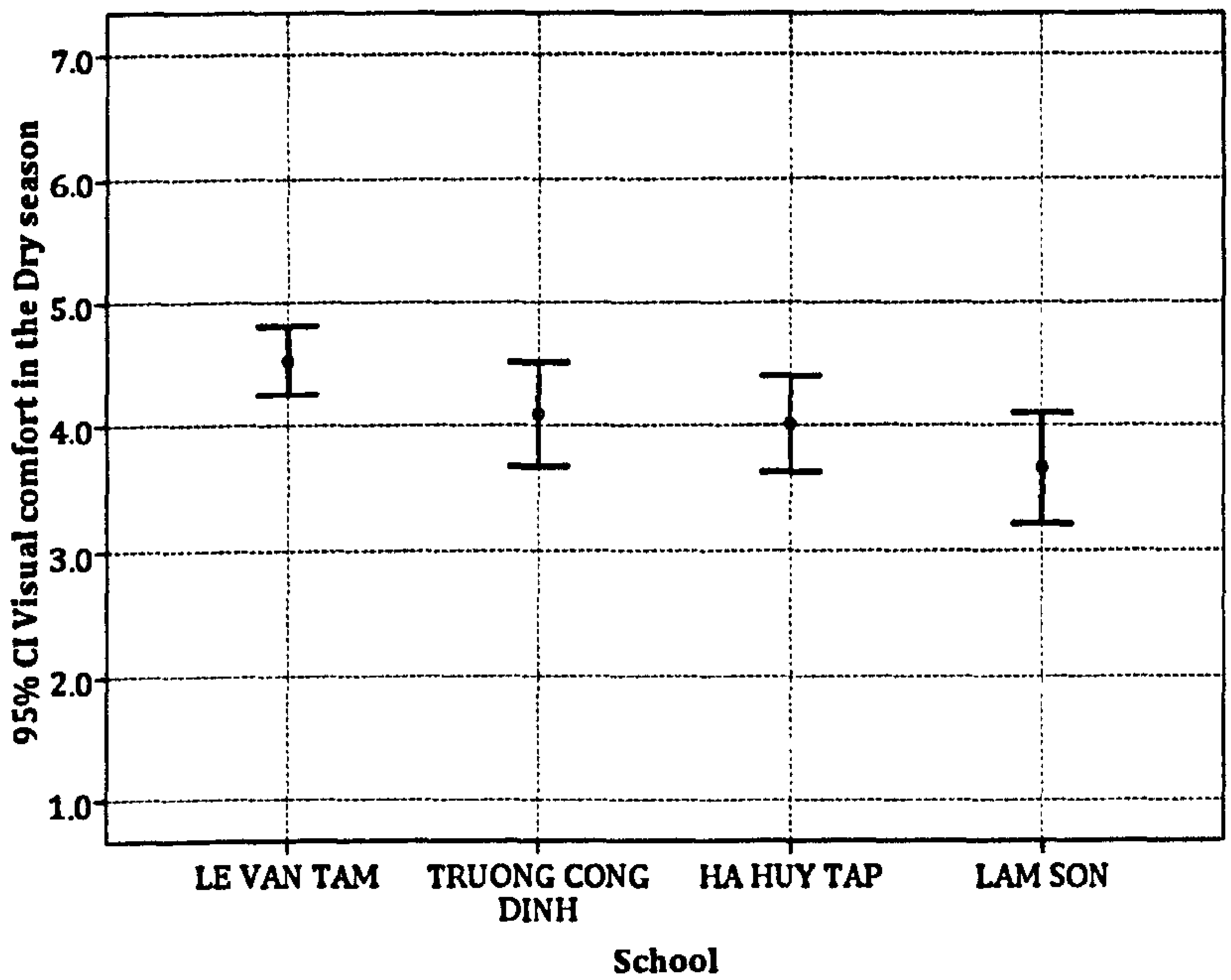
Descriptions	***psEih-D***	***psEih-W***	Mean ***psEih***
Regressive relationship	y = 0.0015x + 3.3903	y = 0.0025x + 3.2065	362 lux
psEih *(at neutral comfort vote =4)*	407 lux	317 lux	

Figure 6.15 shows statistical plotting of 95% confident interval visual comfort votes of each group of students in each season. It is found that the students seem to be quite adaptive and the comfort votes are quite statistically similar in both seasons.

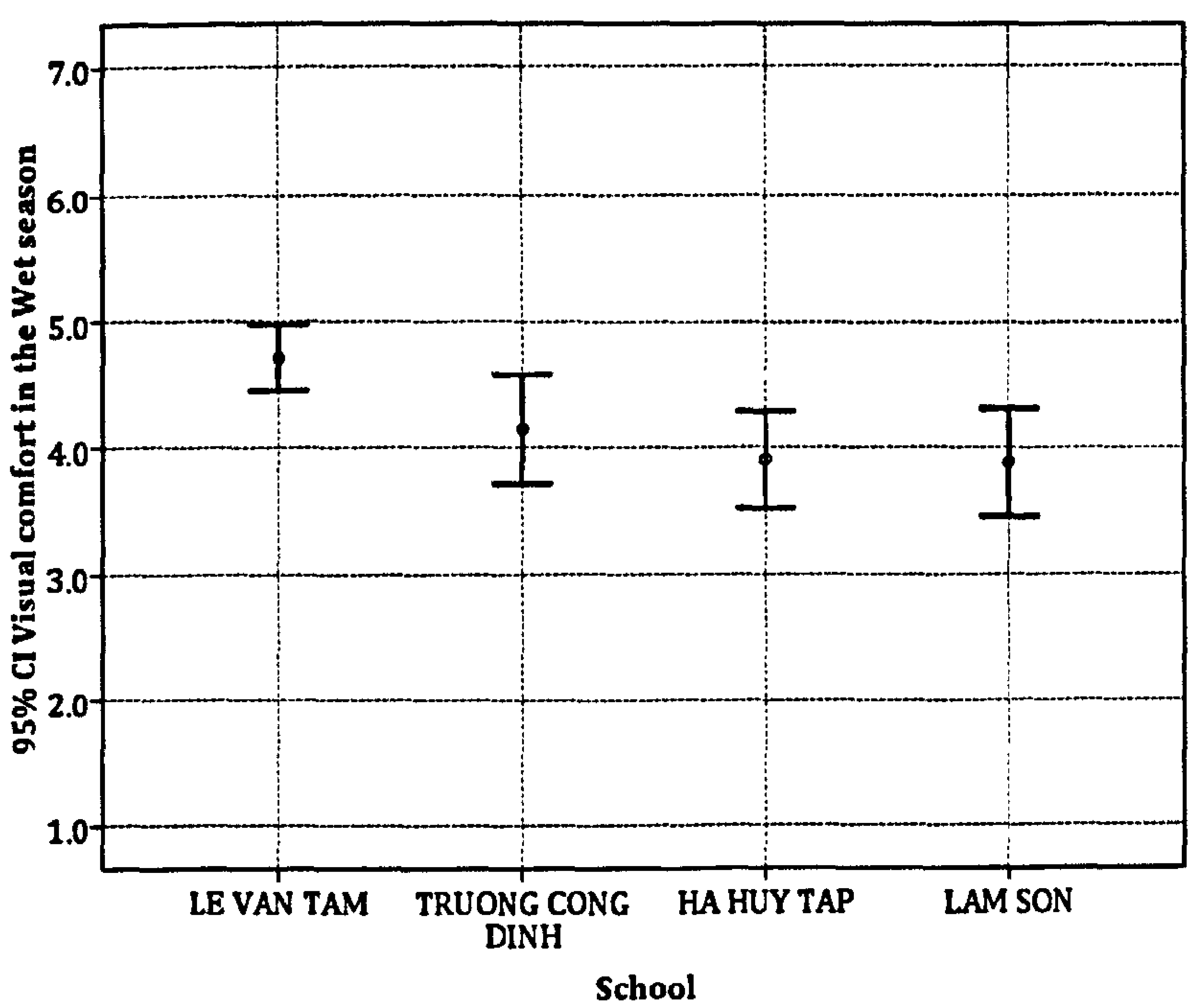
As discussed in the previous chapter, daylight has a high significance on task illuminance. Therefore, it is important to review the users' visual comfort votes on daylight. The students mean comfort votes on daylight conditions (*Eih-D*) are presented in table 6.15. Although the results are quite mixed, more than half of the students feel that the daylight is adequate.

Based on the same method as used in figure 6.14, the regressive relationship between students' comfort votes and mean daylight illuminance *Eih-D* is plotted in figure 6.16. It is found that a well day lit classroom is preferable. The *psEihD* is predicted at 328 lux (see table 6.16). This means daylight contributes 91% of the overall *psEih* in both seasons specifically 86% in the Dry and 96% in the Wet. This consolidates earlier findings by other researchers that daylight is desired as the best source of classroom lighting (Heschong, 1999).

The Dry season



The Wet season



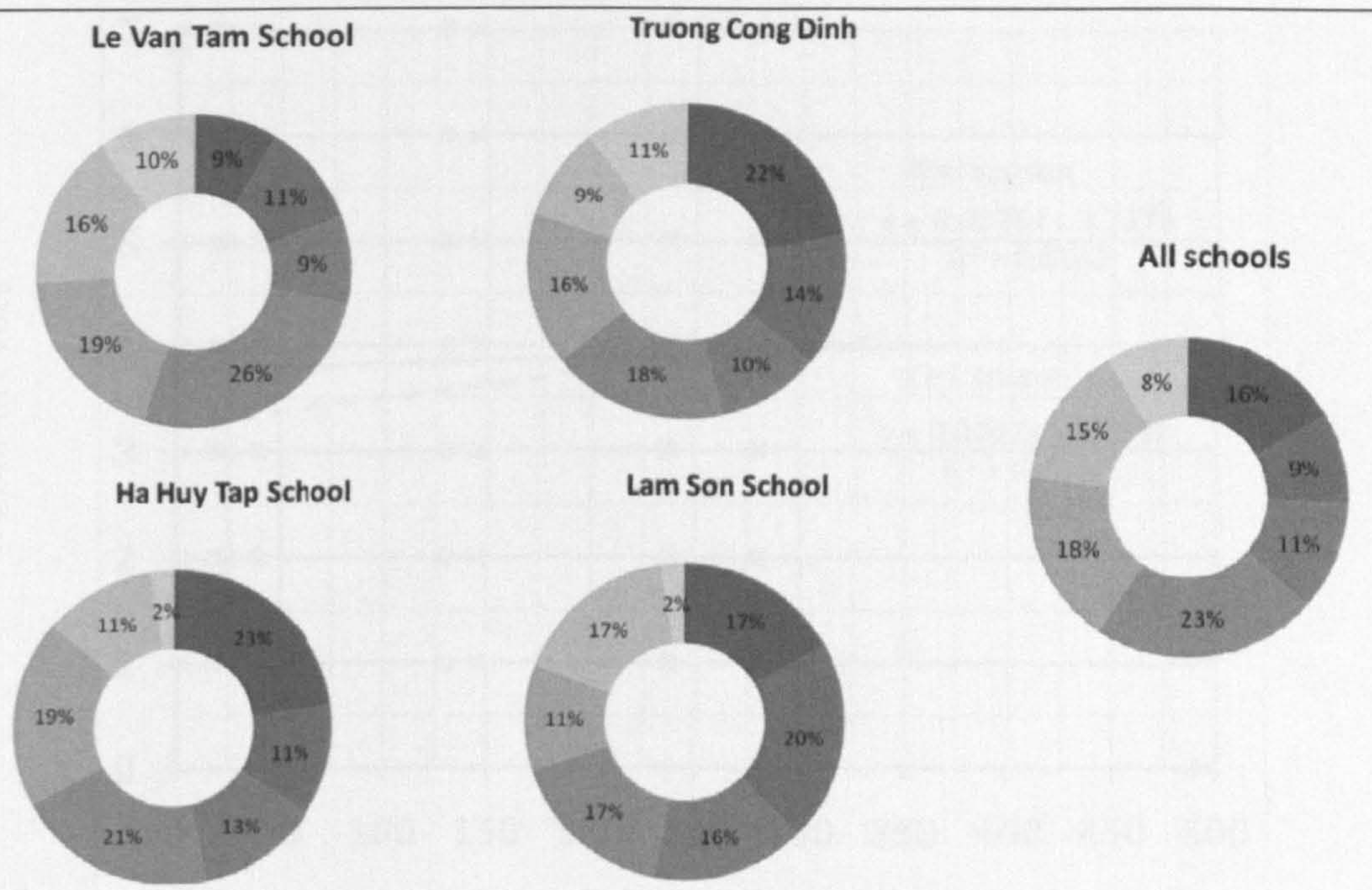
Comfort Scale	1	2	3	4	5	6	7
Sensation	Very low	Low	Slightly low	Neutral	Slightly high	High	Very high

Figure 6.15 Statistical plotting of 95% confident interval of students' visual comfort votes and the schools.

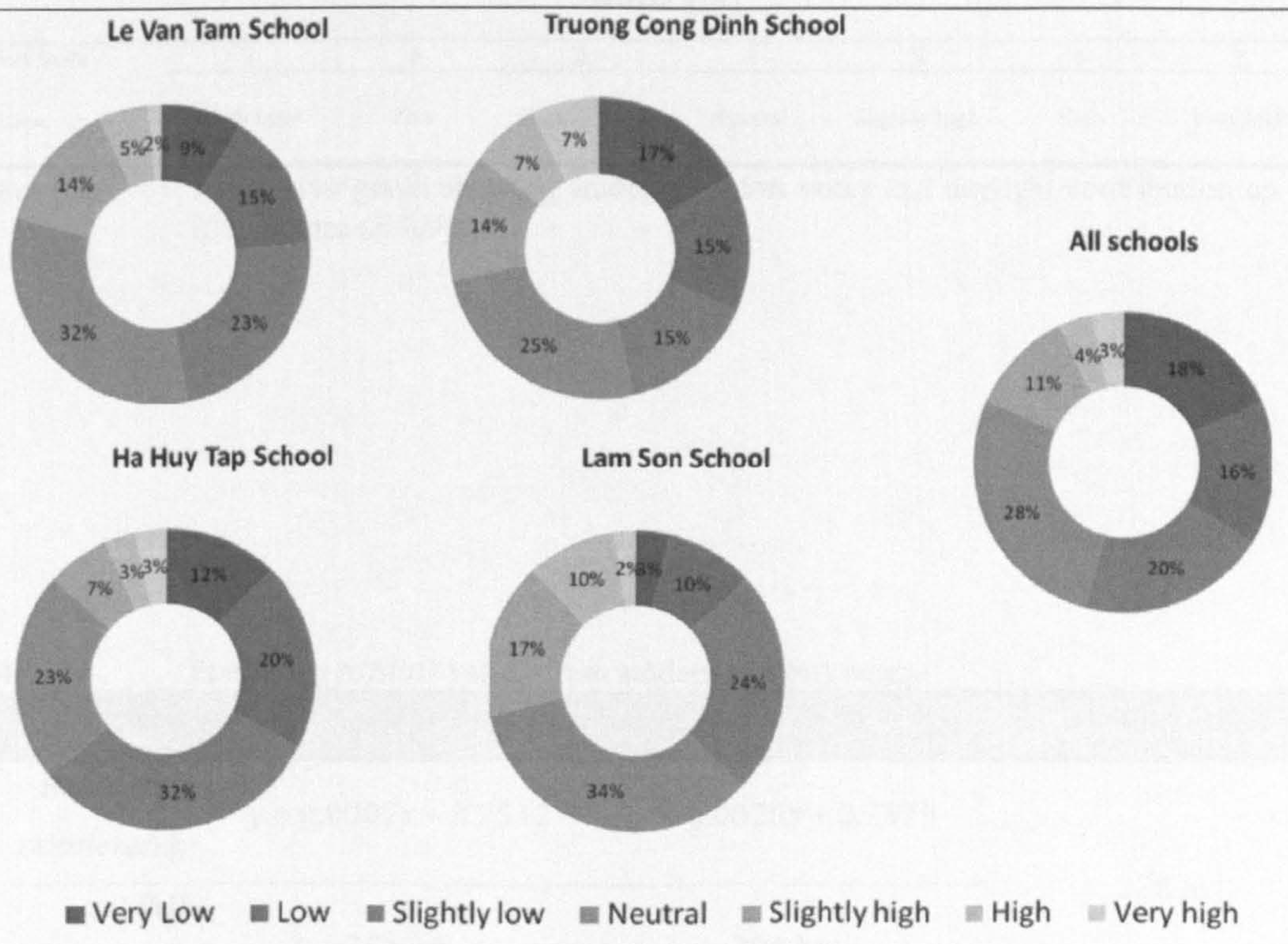
Table 6.15 Students' visual comfort votes on daylight contribution.

STUDENTS' VISUAL COMFORT VOTES ON DAYLIGHT CONTRIBUTION OF EACH SCHOOL

The Dry season



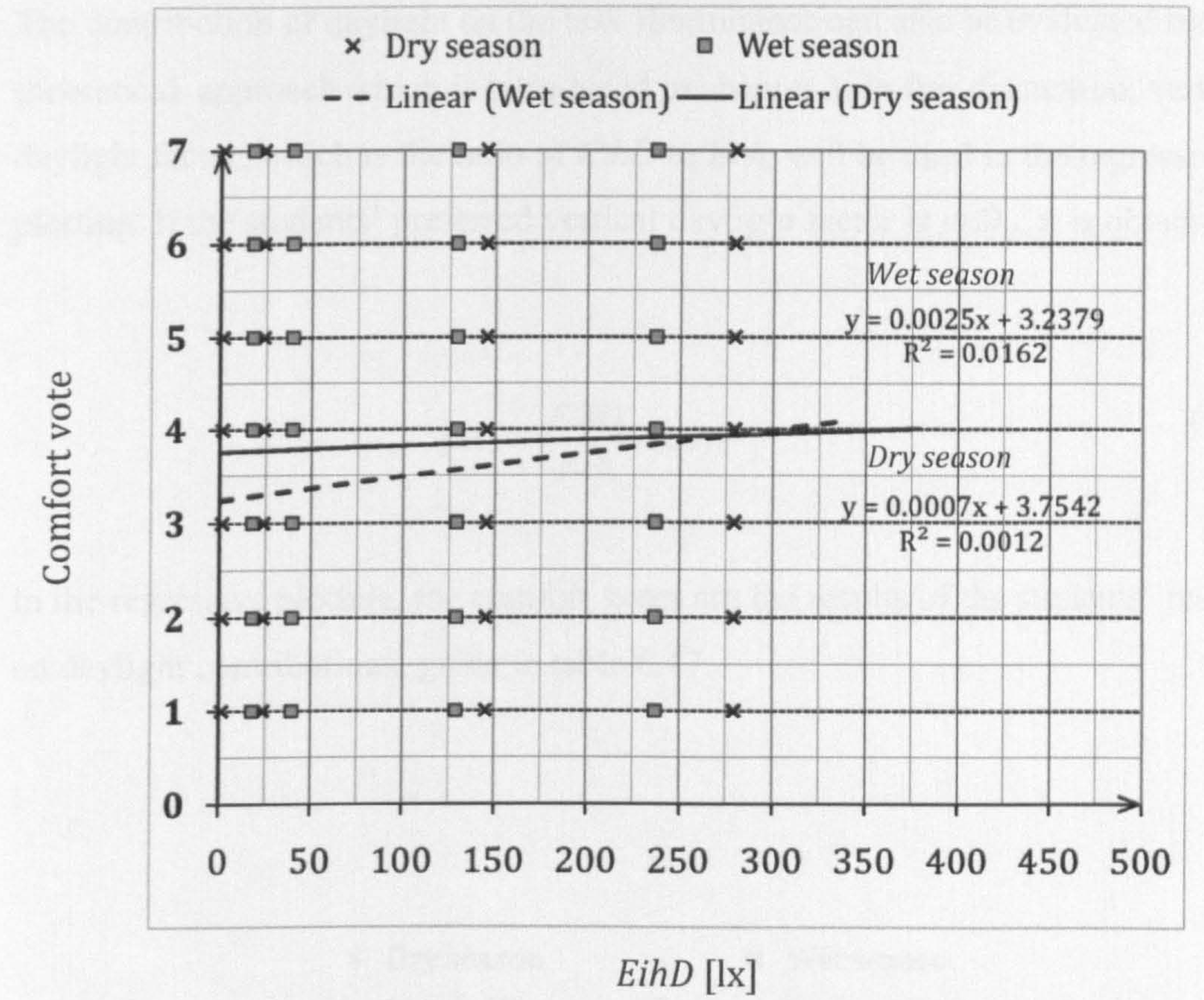
The Wet season



STUDENTS' VISUAL COMFORT MEAN VOTES ON DAYLIGHT CONTRIBUTION

SEASON	LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON	ALL SCHOOLS
DRY SEASON	4.5	3.6	4.0	3.9	3.9
WET SEASON	3.6	3.1	3.2	3.2	3.2

Comfort Scale	1	2	3	4	5	6	7
Sensation	Very low	Low	Slightly low	Neutral	Slightly high	High	Very high



Comfort Scale	1	2	3	4	5	6	7
Sensation	Very Low	Low	Slightly Low	Neutral	Slightly high	High	Very high

Figure 6.16 Regressive graph showing student comfort votes and daylight contribution on task illuminance (*EihD*).

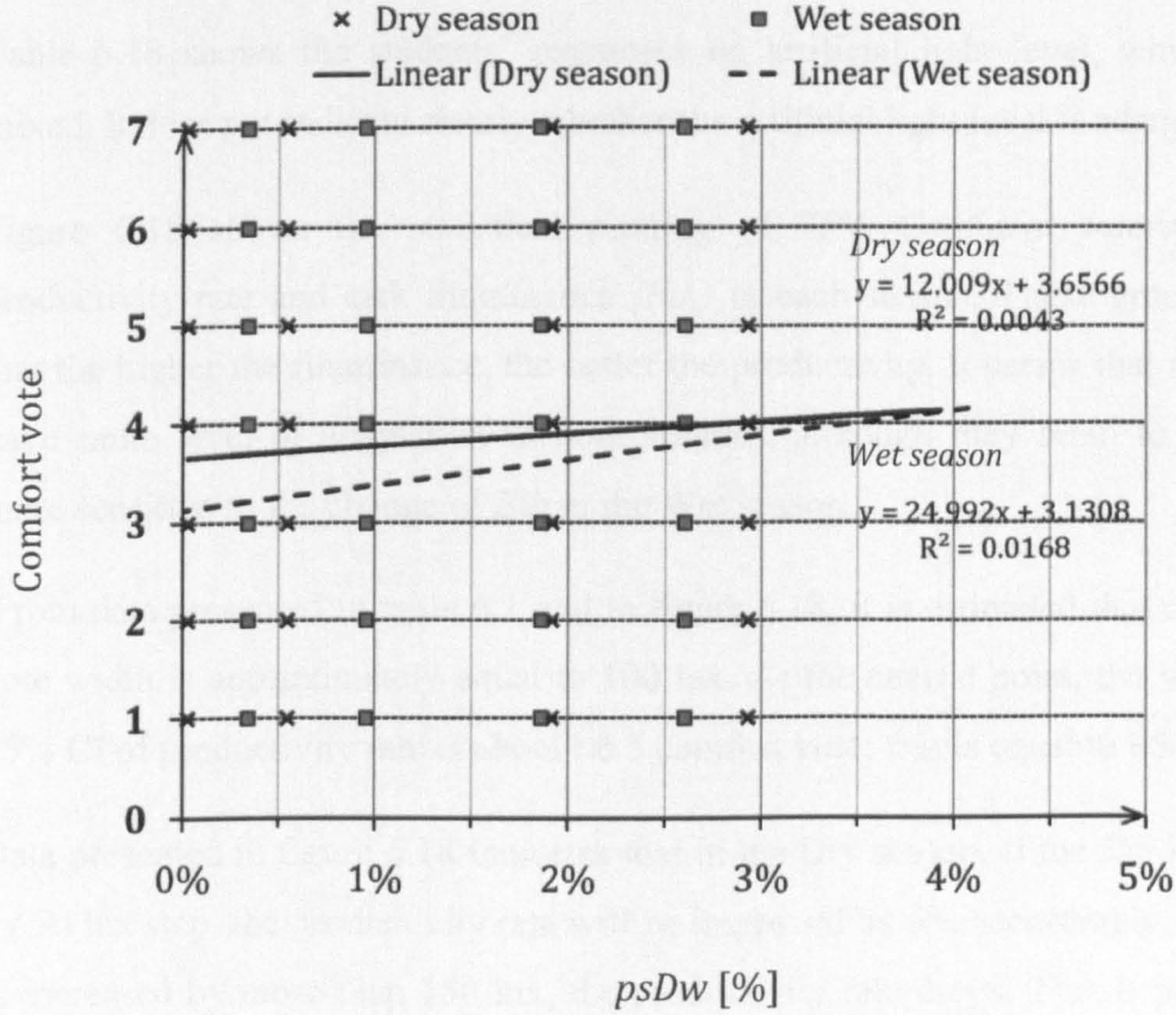
Table 6.16 Predicting *psEihD* values from student comfort votes.

Descriptions	***psEihD-D***	***psEihD-W***	Mean ***psEihD***
Regressive relationship	y = 0.0007x + 3.7542	y = 0.0025x + 3.2379	328 lux
psEihD *(at neutral comfort vote =4)*	351 lux	304 lux	

The contribution of daylight on the task illuminance can also be evaluated by the theoretical approach which is introduced in chapter 3. In this discussion, vertical daylight factor, which is the ratio of *EihD* to *Eeh,* will be used in the regressive plotting. If the students' preferred vertical daylight factor is psD_w, it is obtained by:

$$psD_w = \frac{EihD}{Eeh} x100\% \qquad (6.1)$$

In the regressive plotting, the comfort votes are the results of the students' responses on daylight contributions, given in table 6.17.



Comfort Scale	1	2	3	4	5	6	7
Sensation	Very Low	Low	Slightly Low	Neutral	Slightly high	High	Very high

Figure 6.17 Regressive graph showing student comfort votes and vertical daylight factor psD_w

Table 6.17 Predicting psD_w values from student comfort votes.

Descriptions	psD_w-D	psD_w-W	Mean psD_w
Regressive relationship	y = 12.009x + 3.6566	y = 24.992x + 3.1308	3.15 %
psD_w (*at neutral comfort vote =4*)	2.85 %	3.45 %	

Table 6.18 Students' comfort mean votes on artificial light quality.

School	LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON	ALL SCHOOLS
Students' comfort votes on artificial light level					
Both seasons	**4.1**	**3.2**	**3.9**	**3.5**	**3.6**
Students' comfort votes on glare from artificial light					
Both seasons	**5.2**	**4.9**	**4.9**	**4.9**	**5.0**

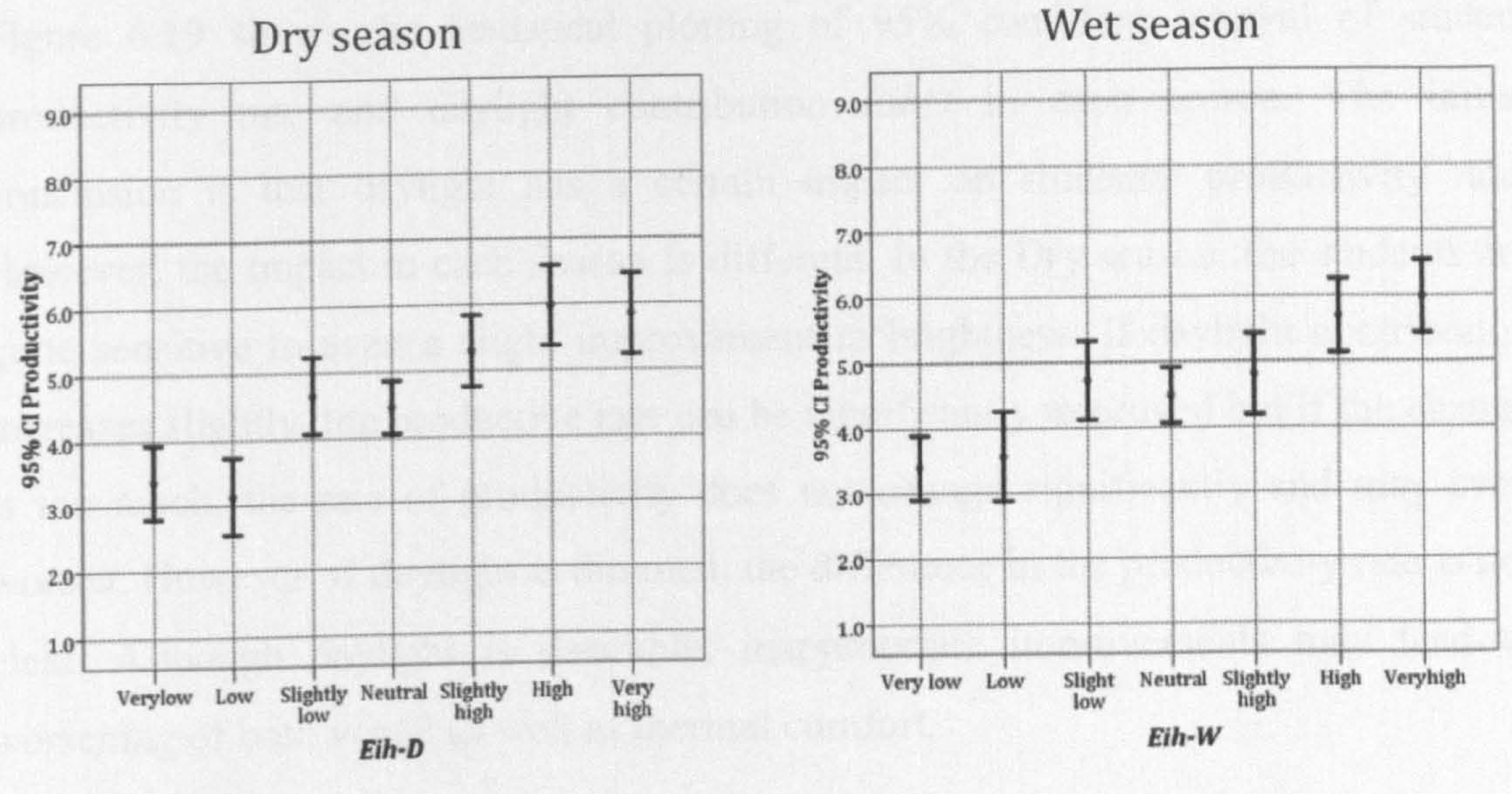
Comfort Scale	1	2	3	4	5	6	7
Sensation	Very low	Low	Slightly low	Neutral	Slightly high	High	Very high

Table 6.18 shows the students' responses on artificial light level, which is quite mixed. It does not indicate clearly whether the artificial light level is adequate or not.

Figure 6.18 shows the statistical plotting of 95% *Confident Interval (CI)* of productivity rate and task illuminance *(Eih)* in each season. These graphs indicate that the higher the illuminance, the better the productivity. It seems that the students have same level of adaptation in both seasons, although they seem to be slightly more sensitive to the change of *Eih* in the Wet season.

From data presented in table 6.1 and in figure 6.18, it is estimated that one comfort vote width is approximately equal to 100 lux. At the neutral point, the width of the 95% CI of productivity rate is about ±0.5 comfort vote; this is equal to ±50 lux.

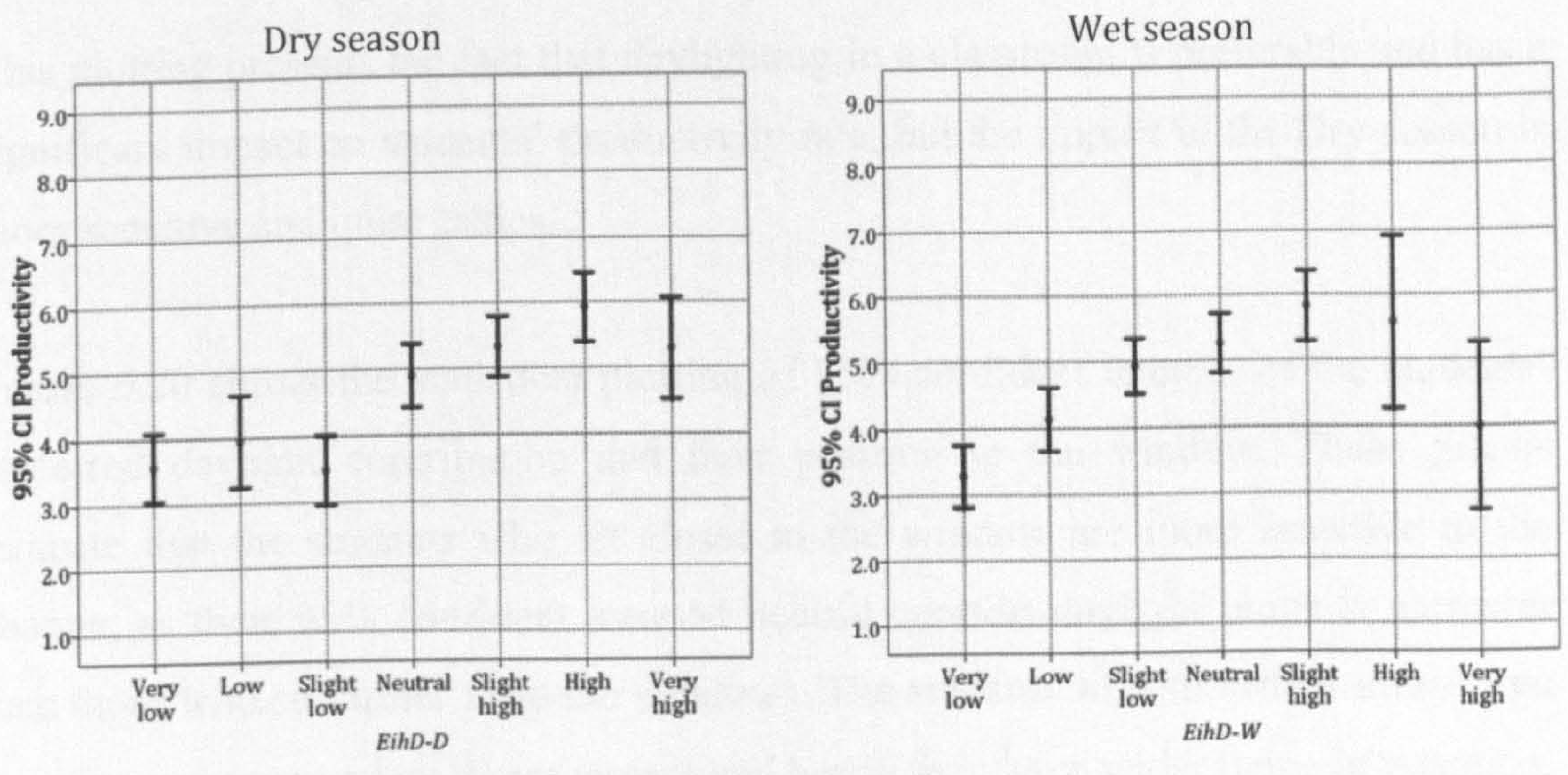
Data presented in figure 6.18 indicates that in the Dry season, if the *Eih* is improved by 50 lux step, the productivity rate will be improved by 5% accordingly. But if light is increased by more than 150 lux, the productivity rate drops. This is probably the upper comfort limit. If the *Eih* is dimmed by 100 lux, the change of productivity rate is not statistically significant. In the Wet season, the students seem to be more sensitive to any change. For every change in 30-50 lux step, the productivity rate also changes by 5-7%. However, if the *Eih* is increased 100 lux more from the neutral value, the change of productivity is no longer statistically significant.



Productivity scale:

1	2	3	4	5	6	7	8	9
-40%	-30%	-20%	-10%	±0	+10%	+20%	+30%	+40%

Figure 6.18 Statistical plotting of 95% confident interval student productivity rate and *Eih*.



Productivity scale:

1	2	3	4	5	6	7	8	9
-40%	-30%	-20%	-10%	±0	+10%	+20%	+30%	+40%

Figure 6.19 Statistical plotting of 95% confident interval student productivity rate and *EihD*.

Figure 6.19 shows the statistical plotting of 95% confident interval of student productivity rate and daylight contribution *EihD* in each season. The initial conclusion is that daylight has a certain impact on students' productivity rate. However, the impact in each season is different. In the Dry season, the students are quite sensitive to even a slight improvement in brightness. If daylight contribution increases slightly, the productive rate can be significantly improved but if the change is too much, the rate of productivity does not change significantly and may even worsen. However, if daylight is dimmed, the difference in the productivity rate is not clear. Although daylight is desirable, inappropriate improvements may lead to worsening of both visual as well as thermal comfort.

In the Wet season, the relationship between daylight and productivity rate is much clearer. When daylight contribution is improved, the rate of productivity also steadily and proportionately improves. It also shows that if daylight is too low or too high, the productivity rate drops significantly.

This plotting presents the fact that daylighting in a classroom is preferable and has a significant impact on students' productivity rate, but the impact in the Dry season is more sensitive and quite critical.

Figure 6.20 shows the statistical plotting of 95% confident interval of the students' preferred daylight contribution and their position to the window. These graphs indicate that the students who sit closer to the window are more sensitive to the change, as their 95% confident interval neutral comfort daylight range is narrower than those who sit farther from the windows. The students who sit further away from the windows receive less direct impact and hence they have wider range of adaption. However, the overall results between those sitting next to the windows and those at a farther distance are not really statistically significant, and do not have a big affect on the general outcome of the comfort survey.

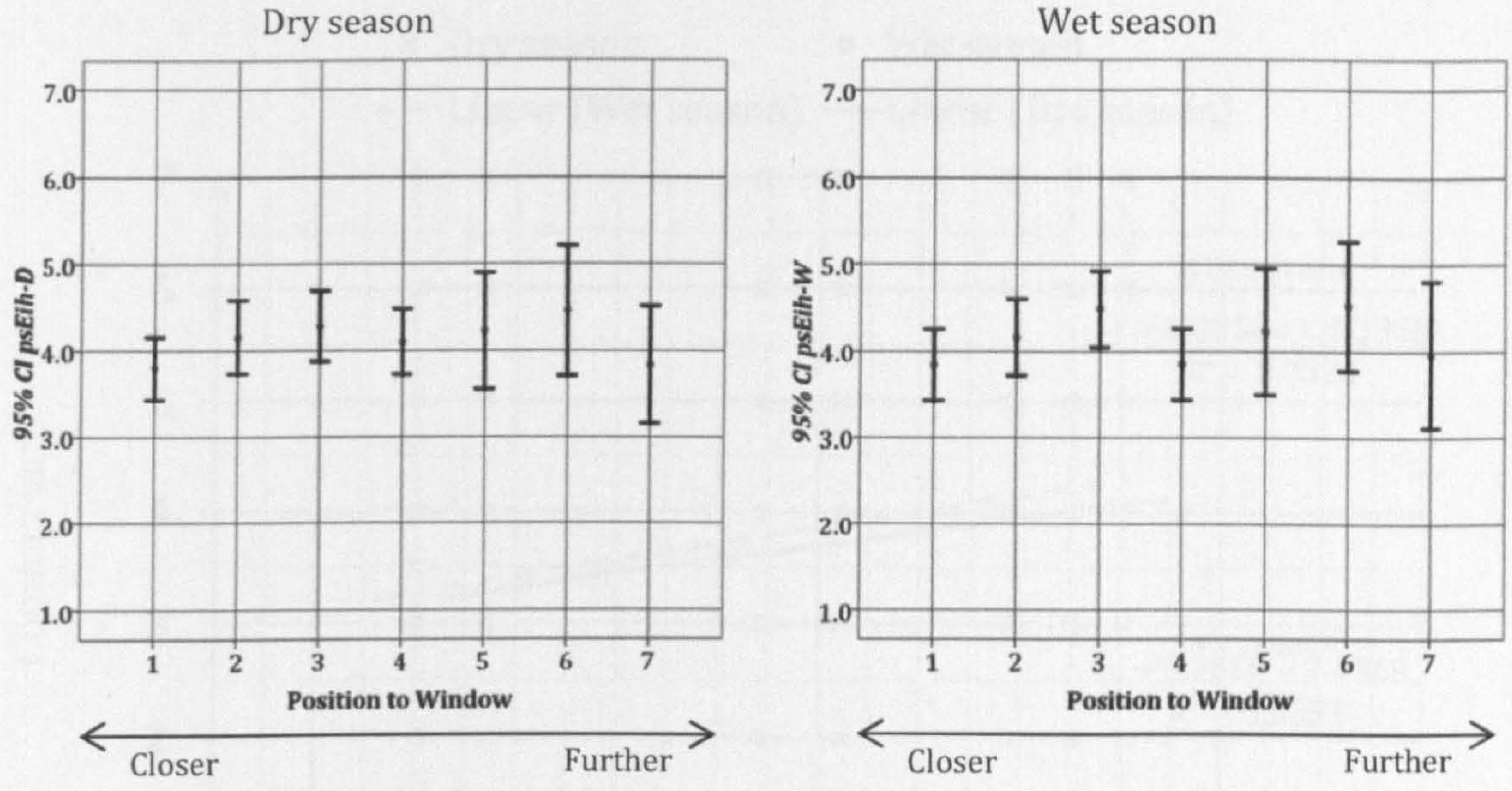


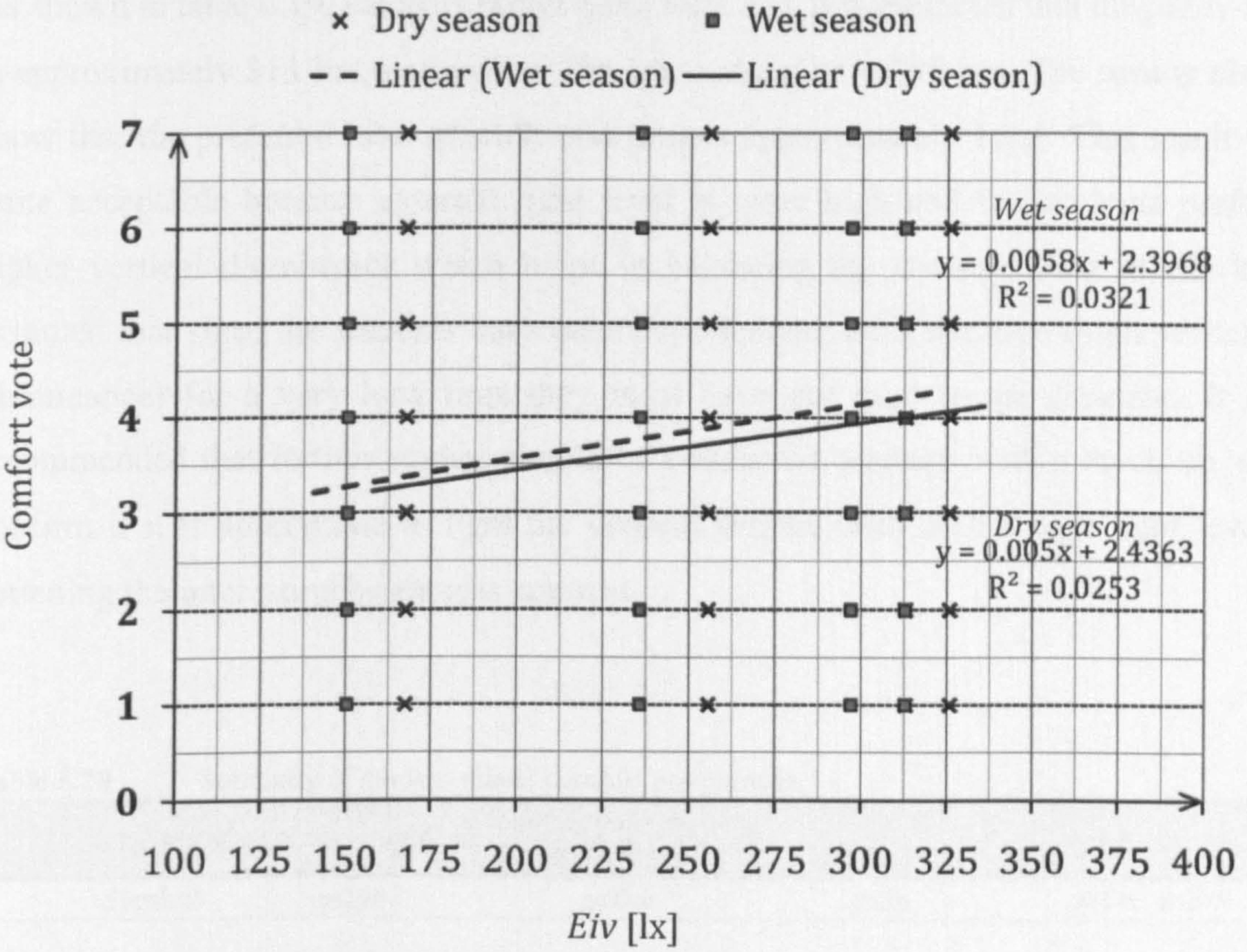
Figure 6.20 Statistical plotting of 95% confident interval student preferred daylight level and the position to the windows.

6.6.2. Predicting the students' preferred ambient illuminance

Beside task illuminance (*Eih*), the Vietnamese code does not provide specific recommendations for ambient illuminance. International codes recommend a balance illuminance ratio of 1:1:3 between wall:ceiling:desk to provide visual comfort (BB:90, 1999; ANSI/IESNA:RP3, 2000). However, site measurements and the comfort survey provide different results.

It was only possible to obtain vertical illuminance measured on the wall surface *(Eiv)*. As discussed in previous sections, the *Eiv* is quite high due to both daylight contribution and uncontrolled-artificial light sources. This scenario is very common in many schools in Ho Chi Minh City and the students get used to this situation for many years, thus this can affect their comfort sensation responses.

The regressive plotting is shown in figure 6.21, and the results are given in table 6.19



Comfort Scale	1	2	3	4	5	6	7
Sensation	Very Low	Low	Slightly Low	Neutral	Slightly high	High	Very high

Figure 6.21 Regressive graph showing the student comfort votes and vertical illuminance (*Eiv*).

Table 6.19 Predicting *psEiv* from student comfort votes.

Descriptions	***psEiv-D***	***psEiv-W***	Mean ***psEih***
Regressive relationship	y = 0.005x + 2.4363	y = 0.0058x + 2.3968	
psEiv *(at neutral comfort vote =4)*	313 lux	276 lux	295 lux
wall: task ratio $\frac{psEiv}{psEih}$	1:1.12	1:1.1	1:1.11

As shown in table 6.19, students prefer quite high *Eiv*. It is predicted that the *psEiv-D* is approximately 313 lux, *psEiv-W* is 276 lux and *psEiv* is 295 lux. The results also show that the preferred ratio of wall: task area is approximately 1:1.1. This result is quite acceptable because external light level is quite high and the students prefer higher vertical illuminance which helps in balancing the contrast. Also it can be assumed that since the students have been experiencing this condition (high vertical illuminance) for a very long time they must have got used to the situation. It is recommended that further studies should be conducted, perhaps with a mock-up, to confirm if it is appropriate to light the vertical surface with such a high light level softening the interesting brightness contrast.

Table 6.20 Summary of student visual comfort preferences.

Criteria	*Task illuminance*	*Vertical daylight factor*	*Vertical illuminance*	*Brightness ratio*
Symbol	*psEih*	*psDw*	*psEiv*	*psEiv* : *psEih*
Mean Value (both season)	**362 lux**	**3.15 %**	**295 lux**	**1:1.1**

Overall, the students seem to have adapted well to the site conditions and the results generated from the comfort surveys seem to be slightly different to what is recommended by the code. The most critical difference is seen in the high vertical illuminance. The summary of finding is presented in table 6.20.

6.7. Predicting teachers' visual comfort preferences

A separate survey was done on the teachers' comfort response. This survey used a modified version of the questionnaire used for students, but the main content remained the same. The teachers who participated in this questionnaire are those who teach in the four surveyed schools. The results were imported into *SPSS* software (i.e. Statistical Package for the Social Sciences) to generate statistical results which are discussed below. Further details of this survey are given in appendix A.

The teachers' mean visual comfort votes, as shown in table 6.21, are quite mixed. All of the mean votes are within the comfort zone (±1 off the neutral vote), but lean more toward the negative side. Particularly, artificial light level and glare have the lowest comfort votes (negative). These results concur with previous analysis on the data recorded onsite (discussed in chapter5). They are discussed in detail in next sections.

Table 6.21 Teachers' mean comfort votes on visual comfort.

Teachers' comfort response on:	Number of votes	Mean visual comfort vote
Visual comfort in the Dry season	237	**3.7**
Visual comfort in the Wet season	234	**3.8**
Visual comfort in both seasons	234	**3.8**
Task illuminance in the Dry season	234	**3.8**
Task illuminance in the Wet season	227	**3.8**
Task illuminance in both seasons		**3.8**
Artificial light level	237	**3.5**
Glare from daylight in the Dry season	237	**3.4**
Glare from daylight in the Wet season	235	**4.4**
Glare from daylight in both seasons		**3.9**
Glare from artificial light	237	**4.6**

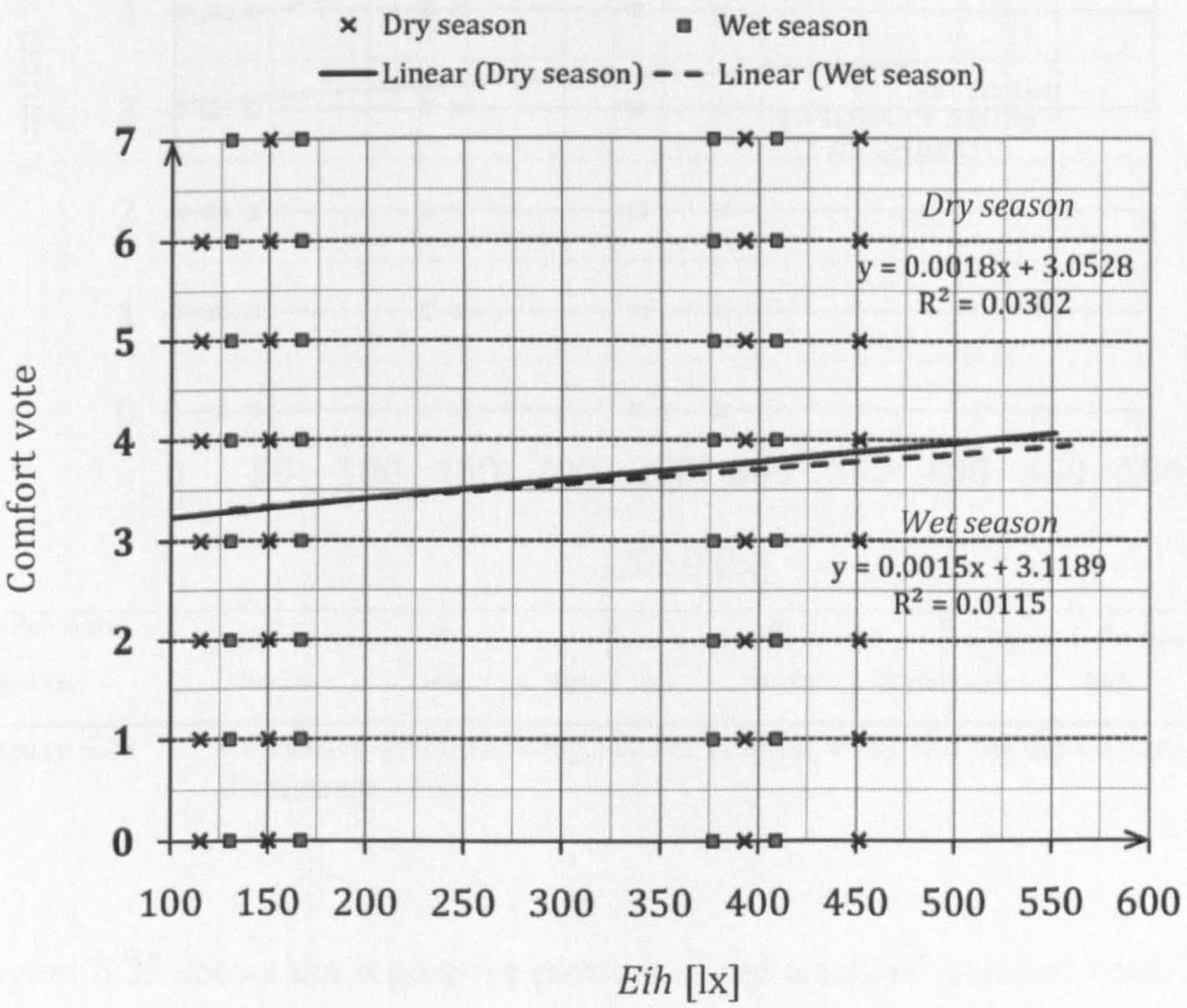
Comfort Scale	1	2	3	4	5	6	7
Sensation	Very low	Low	Slightly low	Neutral	Slightly high	High	Very high

Table 6.22 Percentage of teachers' mean visual comfort votes falling within the neutral zone.

Comfort sensation scale	Very low	Low	Slightly low	Neutral	Slightly high	High	Very high
Percentage of teachers' comfort votes in the Dry season	8%	16%	**17%**	**32%**	**16%**	6%	5%
Percentage of teachers' votes in comfort zone in the Dry season				**65%**			
Percentage of teachers' comfort votes in the Wet season	6%	18%	**16%**	**28%**	**18%**	10%	5%
Percentage of teachers' votes in comfort zone in the West season				**62%**			
Percentage of teachers' comfort votes in both seasons	7%	17%	**16%**	**30%**	**17%**	8%	5%
Percentage of teachers' votes in comfort zone in both seasons				**63%**			

6.7.1. Predicting teachers' preferred task illuminance

Figure 6.22 shows the regressive plotting of the teachers' votes on task illuminance and the site measurements of *Eih*. In comparison to the students' votes, the teachers prefer higher *Eih*. The neutral vote is predicted at 557 lux, which is similar to the task illuminance for an office space rather than a classroom desk top (500 lux). In contrast to the students' response, teachers prefer a higher light level in Wet season but overall the differences between *EihD* and *EihW* is small (approximately 10%). It should be noted that the nature of work and the task that the teachers carry out are different therefore they prefer higher task illuminance which is different to that of the students. This issue has not been yet addressed in any codes.

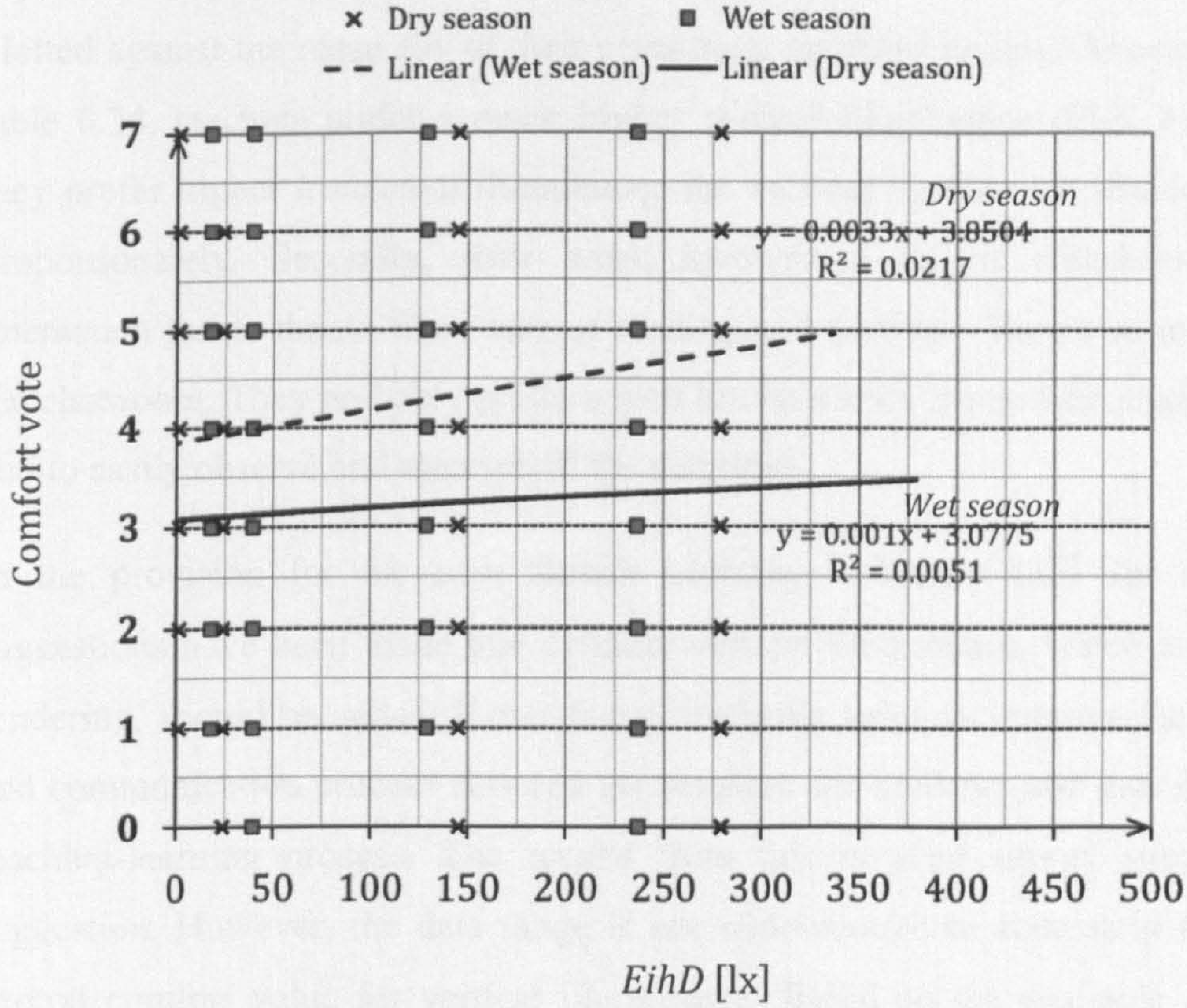


Comfort Scale	1	2	3	4	5	6	7
Sensation	Very Low	Low	Slightly Low	Neutral	Slightly high	High	Very high

Figure 6.22 Regressive graph showing teacher comfort votes and task illuminance (*Eih*)

Table 6.23 Predicting *ptEih* from teachers' comfort votes.

Descriptions	*ptEih-D*	*ptEih-W*	Mean *ptEih*
Regressive relationship	y = 0.0018x + 3.0528	y = 0.0015x + 3.1189	
ptEih *(at neutral comfort vote =4)*	526 lux	587 lux	557 lux



Comfort Scale	1	2	3	4	5	6	7
Sensation	Very Low	Low	Slightly Low	Neutral	Slightly high	High	Very high

Figure 6.23 Regressive graph showing teacher comfort votes and daylight contribution on task illuminance (*EihD*).

Figure 6.23 shows the regressive plotting of the teachers' comfort votes on daylight contribution on task illuminance and the mean *EihD* of their classrooms. However, this graph shows mixed results. Because the data range is not big enough, it is not possible to predict the neutral value. It seems that their need for daylight is not as high as that of the students. The nature of their tasks is much more reliant on artificial light and they probably prefer more stable conditions. The teachers' tasks include writing on the teaching board, lecturing and interacting with students while moving around the classroom. Thus the students are more sensitive to the illuminance and the change if daylight conditions at their seats than the teachers who move around.

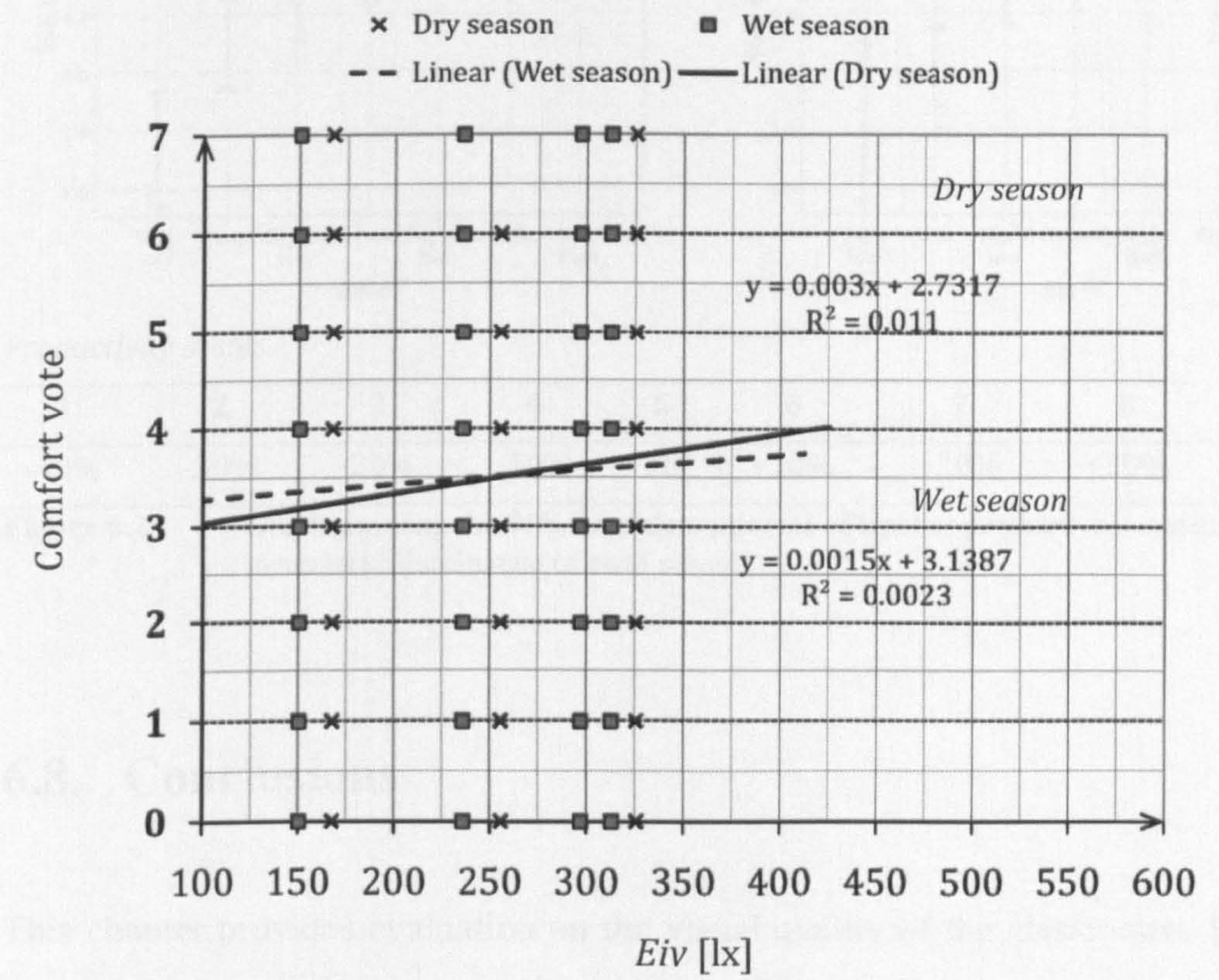
6.7.2. Predicting teachers' preferred ambient illuminance

Figure 6.24 shows the regressive graphs of the teachers' vote on vertical illuminance plotted against the mean *Eiv* of their classroom, recorded on site. As summarised in table 6.24, teachers prefer a much higher vertical illuminance *(Eiv)*. Firstly, since they prefer higher horizontal illuminance the vertical illuminance should be higher proportionately. Secondly, their work involves a lot of communication and interaction rather than a fixed task of reading and writing. They also move around the classroom. They probably prefer a well lit classroom, to see their students clearly and to easily observe and monitor all the activities.

In the provision for the new British Lighting Guidance LG5 for classrooms, suggestions have been made that cylinder vertical illuminance, which aids in facial rendering, should be added. Better facial rendering helps to improve the interactive and communication process between the teachers and students and thus improve the teaching-learning process. The results from this comfort survey strengthen this suggestion. However, the data range is not wide enough to accurately forecast the neutral comfort value for vertical illuminance. Based on the available data, it can only be predicted that *ptEiv-D* = 574 lux, *ptEiv-W*=423lux and *ptEiv* = 499 lux.

Figure 6.25 shows the plotting of 95% confident interval of teachers' perceived productivity rate and the mean task illuminance (*Eih*) in each season. These graphs indicate that higher illuminance (within a certain range) helps to raise the productivity rate. However, the adaptive range is quite wide. Teachers are quite sensitive to small change, around ±1.5 vote off the neutral point. When the light level goes beyond the range of ±1.5 comfort vote then the result is statically significant but the comfort range is also wider. The graph also shows that the teachers are more sensitive to change in the Dry season than in the Wet season. They seem to be more adaptive in the Wet season.

This study indicates that further research needs to be done on the teachers' visual comfort since this survey shows that their results are different from the students. It is found that unlike the students the teachers desire a higher task illuminance and better vertical illuminance. Teachers also prefer stably lit environments using artificial light rather than the changing day lit environment.

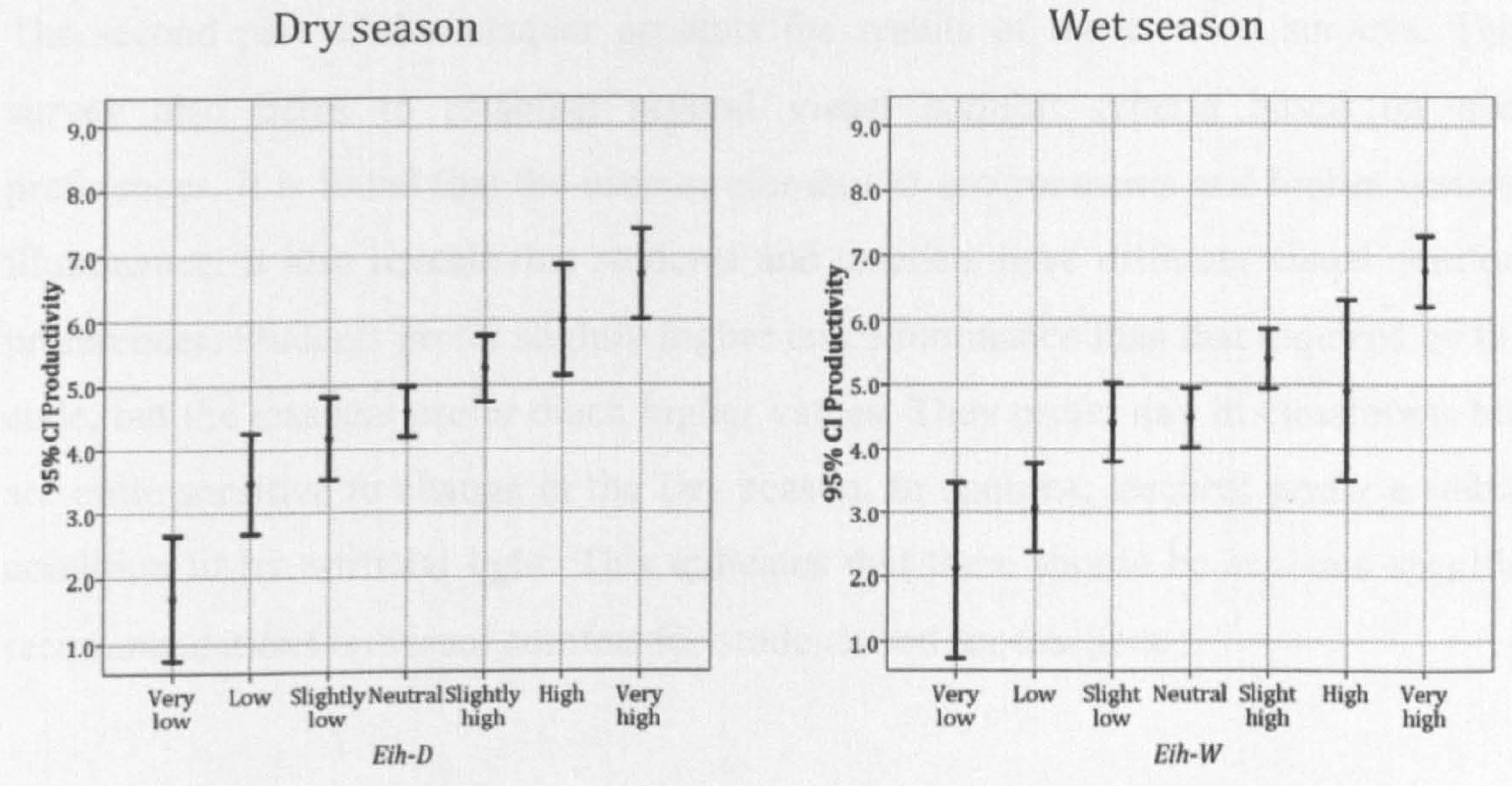


Comfort Scale	1	2	3	4	5	6	7
Sensation	Very Low	Low	Slightly Low	Neutral	Slightly high	High	Very high

Figure 6.24 Regressive graph showing teacher comfort votes and vertical illuminance *(Eiv.)*

Table 6.24 Predicting *ptEiv* from teachers' comfort votes.

Descriptions	***ptEih-D***	***ptEih-W***	Mean ***ptEih***
Regressive relationship	y = 0.003x + 2.7317	y = 0.0015x + 3.1387	
ptEih *(at neutral comfort vote =4)*	423 lux	574 lux	499 lux
wall: task ratio $\frac{ptEiv}{ptEih}$	1:1.24	1:1.02	1:1.11



Productivity scale:

1	2	3	4	5	6	7	8	9
-40%	-30%	-20%	-10%	±0	+10%	+20%	+30%	+40%

Figure 6.25 Graph showing the 95% confident interval of teacher productivity rate and the mean task illuminance of each season.

6.8. Conclusions

This chapter provides evaluation on the visual quality of the classrooms. It is found that glare is a potential problem, but it is difficult to quantify glare in a day-lit environment. This study also shows that spatial brightness distribution plays an important role in the quality of the visual environments.

The site survey reveals that the artificial lighting system in all classrooms does not meet expectations. There are many factors reducing the efficiency. Firstly, the inappropriate arrangement and layout makes the system less effective. Secondly, there is little to no optical control system. Thirdly, the controlling strategy is very basic; there is very little flexibility in controlling options for diming or switching off the light when it is not needed. Although the systems appear to be economical it does not work efficiently.

The second part of this chapter presents the results of the comfort surveys. This survey also helps to establish several visual comfort criteria based on user preferences. It is found that the users prefer day lit environments and higher vertical illuminance. It also reveals that students and teachers have different visual comfort preferences. Students prefer slightly higher task illuminance than that required by the code, but the teachers prefer much higher values. They prefer day lit classrooms but are quite sensitive to change in the Dry season. In contrast, teachers prefer a stable condition lit by artificial light. This indicates that there should be separate specific recommendations on visual comfort for students and for teachers.

Chapter 7

Thermal comfort consequences

7.1. Introduction

Solar radiation, generated by the sun, is the energy source sustaining life in the Earth. It comes to Earth as two forms of energy: natural light and solar heat (as in figure 7.1). As Ho Chi Minh City is located in an area with high availability of solar radiation, improving daylight access while balancing thermal comfort is the most important issue for developing an environmental friendly classroom design.

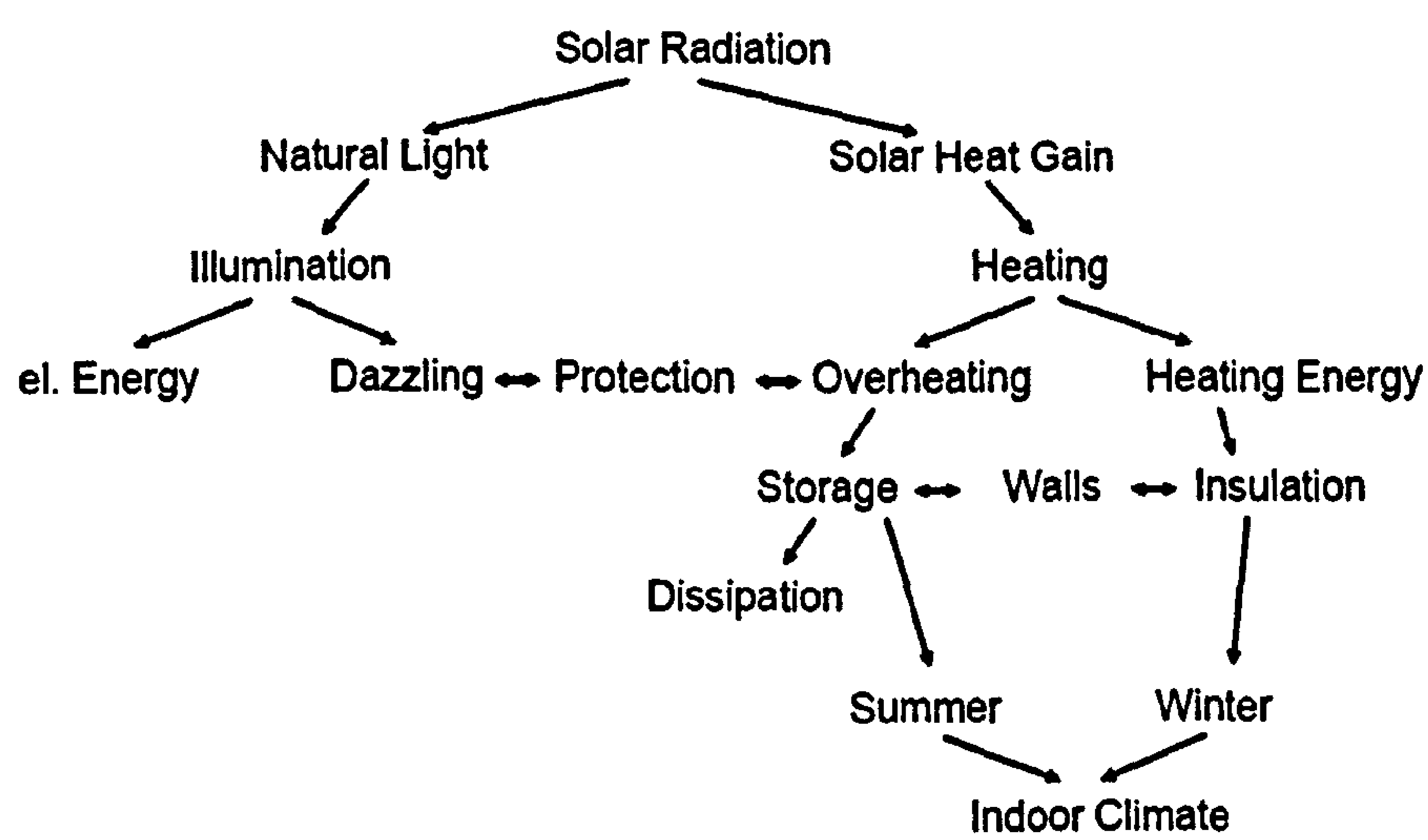


Figure 7.1.

Natural light and solar heat gain are two main concerns for improving classroom indoor environment (Hennings, 2008).

However in both theories as well as in practice, it is not easy to unite these two issues. The contributions of natural light, the visible part of solar radiation (i.e. between the wavelength ranges of 380 to 780 nm), is very much dependent of the room opening area and its sky access. However, indoor thermal comfort is a complex subject which is related to many other factors such as building envelopes, ventilation, human metabolism, clothing and users' occupation pattern.

In this chapter, the discussion focuses on providing some meaningful evaluations on the comfort performance of the surveyed classrooms using common methods introduced by different codes and the adaptive comfort approach. The final goal is to estimate the overheating potential with an attempt to connect it to the daylight discussion. The analysing process is illustrated in figure 7.2.

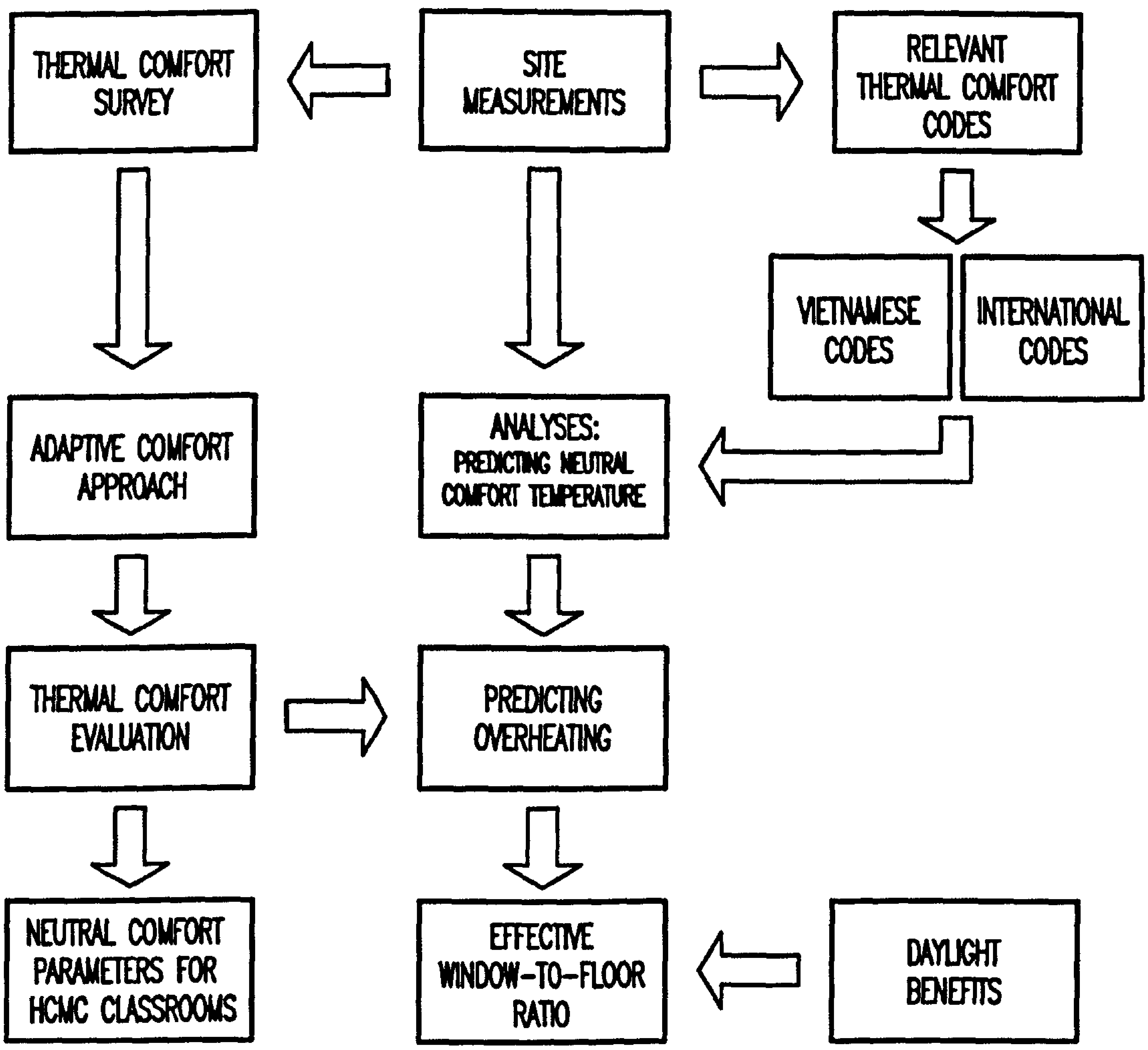


Figure 7.2 Analysing processing chart

7.2. The site measurements

Different to daylight assessments, majority of thermal comfort assessments require site measurement data such as site's temperatures (e.g. EN15251, ASHRAE: 55). Therefore, in this chapter, the data collected from the site measurements will be presented firstly.

It is important to note that each classroom is used by different groups of students, because there are not enough classrooms to accommodate all the students at the same time, the students are assigned to study in different time shifts. Some study in the morning shift, which starts from 7h00 and finish around 11h30, the others study in the afternoon shift from 13h00 to 17h30. The 6th and the 9th grade students often study in the morning shift and the 7th and 8th grade students study in the afternoon shift. This means if a student stays in the same school from 6th to 9th grade, he or she experiences the conditions of both the morning and the afternoon shift. This information is useful, because human comfort adaptation is subject to their experiences with the environment (Nicol and Humpreys, 2009).

Specifically, the surveyed classrooms in Truong Cong Dinh School and Lam Son School are used only by one group of students in the morning shift. The other two surveyed classrooms in Le Van Tam School and Lam Son School are shared by two groups of students, one in the morning shift and another in the afternoon shift. Therefore, it is more appropriate to analyze the thermal comfort of each group of students separately because they may have different comfort preferences due to their familiarity with the conditions. As defined in table 7.1, the results of the site measurements are therefore presented according to the time of the day. However, due to the data noise occurring in the early morning and late afternoon readings, it is able to show only the readings from 08h00 to 16h30. The reason is that although the class starts from 7h00, it takes sometimes for the students to enter the room, to switch on the equipments, open the windows and so on.

Table 7.1 Symbols and definitions.

Symbol	Definitions
T_{MDav}	Mean daily temperature of the morning shift in the Dry season. It is the average value of all the readings recorded by all the data loggers from 8h00 to 11h30 daily during the Dry season visit [^{0}C].
T_{ADav}	Mean daily temperature of the afternoon shift in the Dry season. It is the average value of all the readings recorded by all the data loggers from 13h00 to 16h30 daily during the Dry season visit [^{0}C].
T_{MWav}	Mean daily temperature of the morning shift in the Wet season. It is the average value of all the readings recorded by all the data loggers from 8h00 to 11h30 daily during the Wet season visit [^{0}C].
T_{AWav}	Mean daily temperature of the afternoon shift in the Wet season. It is the average value of all the readings recorded by all the data loggers from 13h00 to 16h30 daily during the Dry season visit [^{0}C].
T_M	Temperature deviation between the Dry and the Wet season [^{0}C].
T_{neu}	Predicted neutral comfort temperature [^{0}C].
RH_{MDav}	Mean daily relative humidity of the morning shift in the Dry season. It is the average value of all the readings recorded by all the data loggers from 8h00 to 11h30 daily during the Dry season visit [%].
RH_{ADav}	Mean daily relative humidity of the afternoon shift in the Dry season. It is the average value of all the readings recorded by all the data loggers from 13h00 to 16h30 daily during the Dry season visit [%].
RH_{MWav}	Mean daily relative humidity of the morning shift in the Wet season. It is the average value of all the readings recorded by all the data loggers from 8h00 to 11h30 daily during the Wet season visit [%].
RH_{AWav}	Mean daily relative humidity of the afternoon shift in the Wet season. It is the average value of all the readings recorded by all the data loggers from 13h00 to 16h30 daily during the Dry season visit [%].
RH_M	Relative humidity deviation between the Dry and the Wet season [%].

Figure 7.3 shows the plotting of daily readings of air temperature for each season, recorded by the temperature loggers mounted on site. It presents the fact that orientation plays an important role on indoor environment; depicted by the hourly solar distribution varying on each facade.

Classrooms in Le Van Tam's and Truong Cong Dinh Schools face the West direction as a consequence the highest temperature is found around 15h00. Ha Huy Tap's classrooms face East, thus the temperature is highest around 10h00-11h00. The South facing Lam Son classroom has highest temperature recorded at noon. These differences can be seen even during the seasonal changes.

The mean daily temperatures of each shift and each season are presented in table 7.2. Although the seasonal daily mean temperatures are quite similar, the distribution during the course of the day is significantly different. The hourly distribution of mean temperatures in the Dry season day is asymmetrically affected by the orientation while in the Wet season it is more evenly distributed. As a consequence, higher temperature is recorded in the Dry season, but it happens during a short period of time and people may find some ways to adjust to these changes. These adjustments could be changing their body gestures and lowering the working rate. In the Wet season the temperature is lower but remains stable during the day. This may lead to thermal discomfort if the temperature remains high for long periods of time and therefore it might be difficult for the users to adjust themselves effectively.

Table 7.2 Mean shift indoor air temperatures [^{0}C] calculated from the site measurements.

Shift temperature [^{0}C]												
Study shift	LE VAN TAM			TRUONG CONG DINH			HA HUY TAP			LAM SON		
Morning (08h00-11h30)	$T_{MD\,av}$	$T_{MW\,av}$	T_M	$T_{MD\,av}$	$T_{MW\,av}$	T_M	$T_{MD\,av}$	$T_{MW\,av}$	T_M	$T_{MD\,av}$	$T_{MW\,av}$	T_M
Day 1	28.48	29.47	-0.99	29.19	31.71	-2.51	30.47	27.62	2.85	32.80	33.68	-0.88
Day 2	28.37	29.42	-1.05	29.76	31.98	-2.23	30.87	27.84	3.03	32.93	32.78	0.15
Day 3	28.57	29.61	-1.05	30.47	30.24	0.23	30.58	27.52	3.06	32.19	34.11	-1.92
Day 4	29.20	30.45	-1.25	30.00	29.85	0.15	30.38	28.24	2.14	32.35	33.35	-1.00
Mean	**28.66**	**29.74**	**-1.08**	**29.86**	**30.94**	**-1.09**	**30.57**	**27.80**	**2.77**	**32.57**	**33.48**	**-0.91**
Afternoon (13h00-16h30)	$T_{AD\,av}$	$T_{AW\,av}$	T_M	$T_{AD\,av}$	$T_{AW\,av}$	T_M	$T_{AD\,av}$	$T_{AW\,av}$	T_M	$T_{AD\,av}$	$T_{AW\,av}$	T_M
Day 1	32.46	31.28	1.18	31.64	32.36	-0.72	33.14	28.51	4.64	36.02	32.90	3.11
Day 2	32.41	29.82	2.58	30.87	32.49	-1.61	32.96	29.04	3.91	36.14	30.10	6.04
Day 3	32.17	30.93	1.24	35.57	30.56	5.01	32.99	27.48	5.51	35.88	32.52	3.35
Day 4	32.23	29.96	2.26	34.20	31.66	2.54	34.54	29.53	5.00	33.62	31.73	1.89
Mean	**32.32**	**30.50**	**1.82**	**33.07**	**31.77**	**1.30**	**33.41**	**28.64**	**4.77**	**35.41**	**31.81**	**3.60**
Mean both shifts	**30.49**	**30.12**	**0.37**	**31.46**	**31.36**	**0.11**	**31.99**	**28.22**	**3.77**	**33.99**	**32.65**	**1.34**
Mean both seasons	**30.30**			**31.41**			**30.11**			**33.32**		

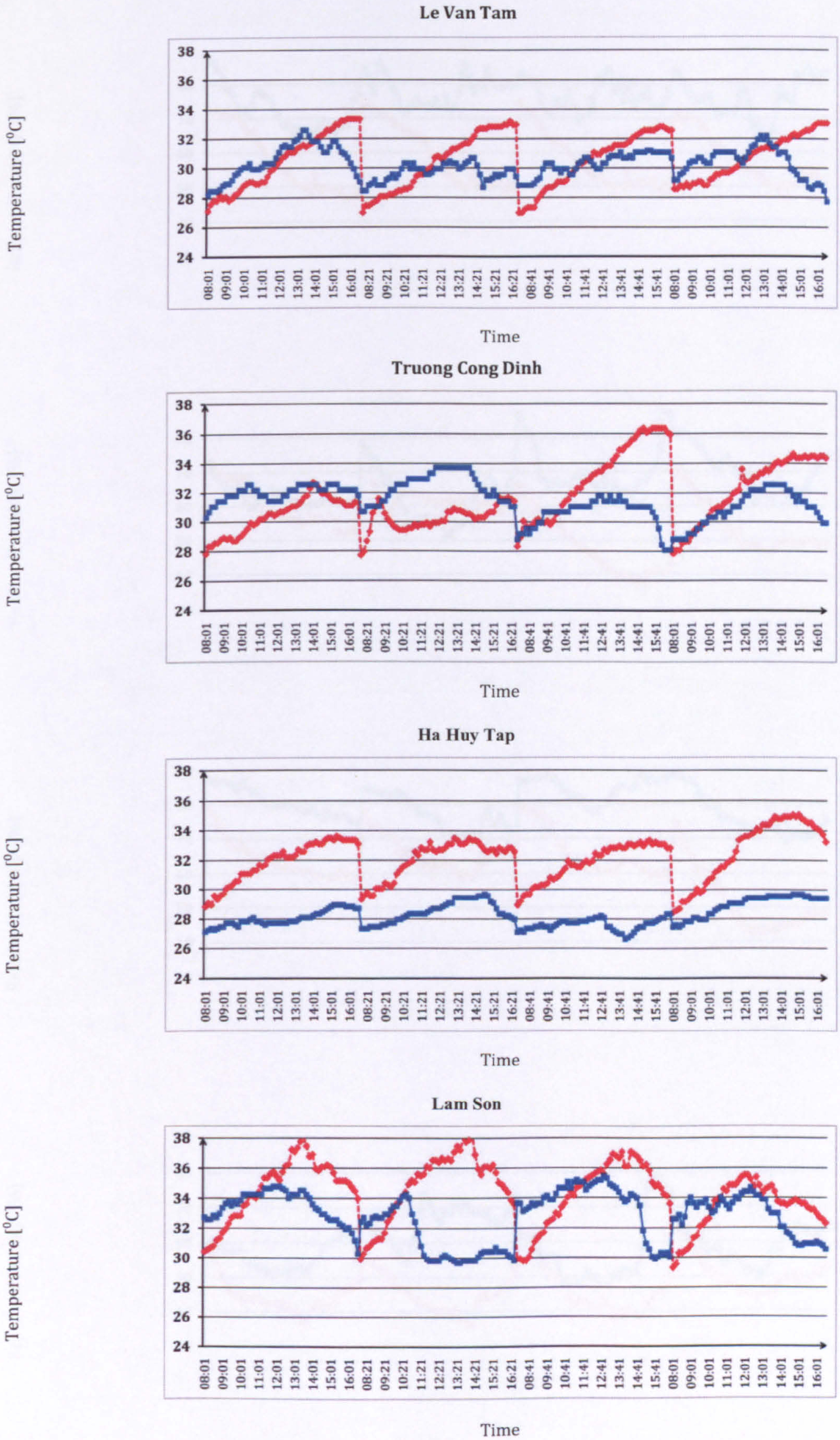


Figure 7.3 Daily indoor air temperatures [^{0}C] recorded by the data logger mounted inside the classrooms, monitoring the conditions in four continuous days in the Dry season (red colour) and the Wet season (blue colour).

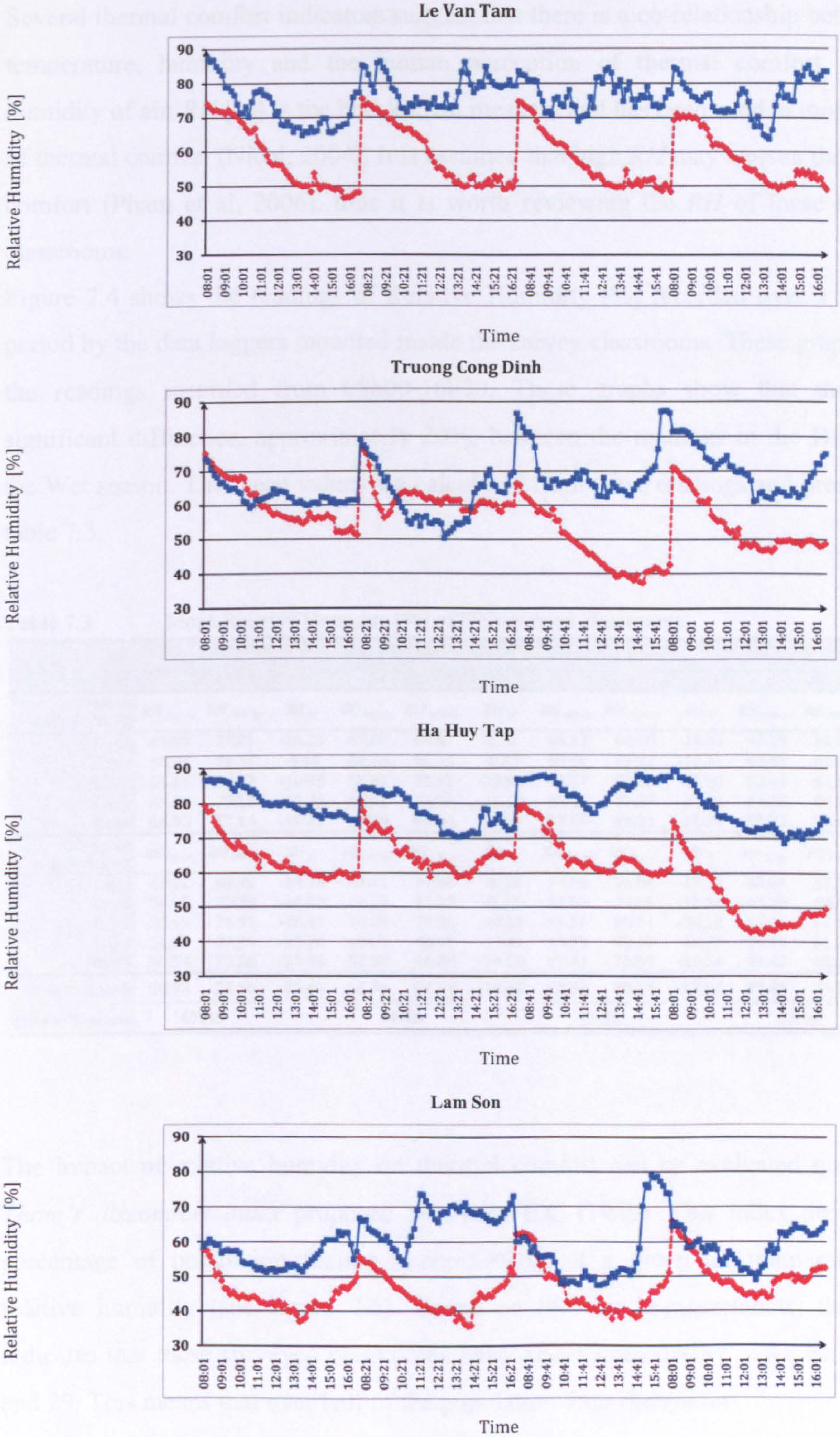


Figure 7.4 Daily Relative Humidity *RH* [%] recorded by the data logger mounted inside the classrooms, monitoring conditions in four continuous days in the Dry season (red colour) and the Wet season (blue colour).

Several thermal comfort indicators suggest that there is a co-relationship between air temperature, humidity and the human perception of thermal comfort. Relative humidity of air, *RH* [%] is the best known measure and has been used in most studies of thermal comfort (Nicol, 2004). It is assumed that high *RH* may worsen the thermal comfort (Pham et al, 2006), thus it is worth reviewing the *RH* of these surveyed classrooms.

Figure 7.4 shows the readings of Relative Humidity [%] recorded over a four day period by the data loggers mounted inside the survey classrooms. These graphs show the readings recorded from 08h00-16h30. These graphs show that there is a significant difference, approximately 20%, between the readings in the Dry and in the Wet season. The mean values are calculated from these readings and presented in table 7.3.

Table 7.3 Mean Relative Humidity [%] of the surveyed classrooms.

Shift Relative Humidity RH [%]												
Study shift	LE VAN TAM			TRUONG CONG DINH			HA HUY TAP			LAM SON		
Morning (08h00-11h30)	$RH_{MD\,av}$	$RH_{MW\,av}$	RH_M	$RH_{MD\,av}$	$RH_{MW\,av}$	RH_M	$RH_{MD\,av}$	$RH_{MW\,av}$	RH_M	$RH_{MD\,av}$	$RH_{MW\,av}$	RH_M
Day 1	67.98	78.21	-10.23	67.00	64.87	2.12	69.13	84.48	-15.34	47.19	56.06	-8.87
Day 2	68.97	78.37	-9.40	64.26	65.13	-0.87	69.50	81.92	-12.42	48.68	62.54	-13.86
Day 3	65.21	76.17	-10.96	56.86	71.92	-15.06	71.57	85.47	-13.90	52.41	54.38	-1.97
Day 4	65.52	75.82	-10.30	60.91	76.10	-15.19	60.16	81.39	-21.23	54.56	59.02	-4.46
Mean	**66.92**	**77.14**	**-10.22**	**62.26**	**69.51**	**-7.25**	**67.59**	**83.31**	**-15.72**	**50.71**	**58.00**	**-7.29**
Afternoon (13h00-16h30)	$RH_{AD\,av}$	$RH_{AW\,av}$	RH_M	$RH_{AD\,av}$	$RH_{AW\,av}$	RH_M	$RH_{AD\,av}$	$RH_{AW\,av}$	RH_M	$RH_{AD\,av}$	$RH_{AW\,av}$	RH_M
Day 1	49.22	68.38	-19.16	54.61	61.00	-6.39	59.53	76.82	-17.30	43.05	57.57	-14.52
Day 2	50.95	79.73	-28.78	59.95	62.17	-2.22	62.83	73.21	-10.38	43.20	68.66	-25.46
Day 3	50.49	76.91	-26.43	40.05	70.36	-30.31	61.56	85.74	-24.18	42.26	62.66	-20.40
Day 4	51.51	77.29	-25.78	48.66	65.97	-17.31	45.73	72.10	-26.37	49.19	61.22	-12.03
Mean	**50.54**	**75.58**	**-25.04**	**50.82**	**64.88**	**-14.06**	**57.41**	**76.97**	**-19.56**	**44.42**	**62.53**	**-18.10**
Mean both shifts	**58.73**	**76.36**	**-17.63**	**56.54**	**67.19**	**-10.65**	**62.50**	**80.14**	**-17.64**	**47.57**	**60.26**	**-12.70**
Mean both seasons	**67.55**			**61.86**			**71.32**			**53.91**		

The impact of relative humidity on thermal comfort can be evaluated quickly by *Thom's discomfort index* proposed by Thom E.C (1959). This index predicts the percentage of population feeling uncomfortable at a given air temperature and relative humidity (see figure 7.5). Based on the site measurements, this index indicates that these surveyed classrooms have *Thom's discomfort index* between 26 and 29. This means that over half of the population feels discomfort.

However, a research by J.F Nicol (2004) conducted in a hot-humid climate, indicates that the effect of relative humidity on thermal comfort is generally small. In conditions where relative humidity is high, neutral comfort temperature may be 1^0C lower. The real consequence of high relative humidity is to reduce the width of the comfort zone. Further field study conducted by Hwang et al (2006) also suggested that the role of *RH* in thermal comfort is not that significant as it was though. Therefore, in this discussion it is assumed that the impact of *RH* on thermal comfort is minimal.

	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
42°	32	32	33	33	34	34	35	35	36	36	37	37	37	38	38	38
41°	31	32	32	33	33	34	34	35	35	36	36	36	37	37	37	37
40°	30	31	31	32	32	33	33	34	34	35	35	35	36	36	36	37
39°	30	30	31	31	32	32	33	33	34	34	34	35	35	35	36	36
38°	29	30	30	31	31	31	32	32	33	33	34	34	34	35	35	35
37°	28	29	29	30	30	31	31	32	32	32	33	33	33	34	34	34
36°	28	28	29	28	30	30	30	31	31	32	32	32	33	33	33	34
35°	27	27	28	28	29	29	30	30	30	31	31	32	32	32	33	33
34°	26	27	27	28	28	29	29	29	30	30	30	31	31	31	32	32
33°	26	26	27	27	27	28	28	29	29	29	30	30	30	31	31	31
32°	25	25	26	26	27	27	27	28	28	29	29	29	30	30	30	30
31°	24	25	25	26	26	26	27	27	27	28	28	28	29	29	29	30
30°	24	24	24	25	25	26	26	26	27	27	27	28	28	28	29	29
29°	23	23	24	24	25	25	25	26	26	26	27	27	27	27	28	28
28°	22	23	23	23	24	24	25	25	25	25	26	26	26	27	27	27
27°	22	22	22	23	23	23	24	24	24	25	25	25	26	26	26	26
26°	21	21	22	22	22	23	23	23	24	24	24	25	25	25	25	26
25°	20	21	21	21	22	22	22	23	23	23	23	24	24	24	25	25
24°	20	20	20	21	21	21	22	22	22	22	23	23	23	24	24	24
23°	19	19	20	20	20	21	21	21	21	22	22	22	22	23	23	23
22°	18	19	19	19	19	20	20	20	21	21	21	21	22	22	22	22

Up to 21	No discomfort
From 21 to 24	Less than half population feels discomfort
From 25 to 27	More than half population feels discomfort
From 28 to 29	Most population feels discomfort and deterioration of psychophysical conditions
From 30 to 32	The whole population feels an heavy discomfort
Over 32	Sanitary emergency due to the the very strong discomfort which may cause heatstrokes

School		Temperature [°C]	*RH* [%]	Thom's index
LE VAN TAM	DRY	28.66	66.92	**26**
		32.32	50.54	**27**
	WET	29.74	77.14	**28**
		30.12	75.58	**27**
TRUONG CONG DINH	DRY	29.86	62.26	**26**
		33.07	50.82	**28**
	WET	30.94	69.51	**28**
		31.77	64.88	**28**
HA HUY TAP	DRY	30.57	67.59	**28**
		33.41	57.41	**29**
	WET	27.80	83.31	**26**
		28.64	76.97	**27**
LAM SON	DRY	32.57	50.71	**28**
		35.41	44.42	**29**
	WET	33.48	58.00	**29**
		31.81	62.53	**28**

Figure 7.5 Thom's discomfort index. (Eurometeo, 2010)

7.3. Thermal comfort assessments by the codes

Several theoretical methods can be used to evaluate indoor thermal performance of a room. They are discussed in chapter 3. In Vietnam, the TCXDVN: 306 (2004) is the most relevant code. Internationally, there are some popular methods such as ISO: 7730(2005), European code EN: 15251(2007) and the U.S code ASHRAE: 55(2004). The most common approach of these methods is establishing the operative temperatures which define a range of acceptable comfort temperatures. Within this range 80% of the users are predicted to be thermally comfortable. Comfort range is often defined by a neutral comfort temperature and offset temperatures which limit the width of the comfort zone.

The operative temperature, as defined in chapter 3, page 127-128, is often dependent of air temperature and radiant temperature. However, there is not a great difference between operative temperature and air temperature in the indoor environment of the size and type of surveyed space (Nicol, McCartney, 2000). Therefore, to simplify the process this discussion can be based on air temperature readings recorded by the data loggers mounted on the side.

7.3.1. The Vietnamese thermal comfort codes

The most common Vietnamese thermal comfort code is the TCXDVN: 306 (2004). This code introduces the equation to estimate thermal comfort temperatures, but this method is quite complicated and requires professional equipments to get the data. However, it should be emphasized that these standards, including the TCXDVN: 306 (2004), are either derived from the Soviet Union codes (e.g. Zuilen- Korenkov Condition Index*)* or developed from data collected from surveys in the Northern regions, and thus they may be not be appropriate for HCMC.

TCXDVN: 306 (2004) introduced two methods: the *Effective Temperature ,Teff,*[^{0}C] of and C.G. Webb, and the *Condition Index ΣH* [%] of Zuilen- Korenkov.

The *Effective Temperature* [^{0}C] is obtained by the following equation

$$T_{eff} = 0.5\ (t_d + t_w) - 1.94\ \sqrt{v} \qquad (7.1)$$

Where: T_{eff}: Effective temperature, [^{0}C]

t_d: Dry bulb temperature, [^{0}C]

t_w: Wet bulb temperature [^{0}C]

t_r: Mean radiant temperature of internal surfaces [^{0}C]

v: Air velocity [m/s]

The *Condition Index ΣH* [%] of Zuilen- Korenkov is obtained by:

$$(\Sigma H) = 0.24\ (t_d + t_r) + 0.1d - 0.09\ (37.8 - t_d)\ \sqrt{v} \qquad (7.2)$$

Where d: Humidity ratio [g/kg]

All other definitions in equation (7.1) applied

The Dry bulb temperature t_d [°C] in this case is the air temperature. As discussed above, the mean radian temperature t_r [°C] is quite small in this scenario and thus it can be ignored. In this assessment, it is assumed that the air velocity of all the surveyed classrooms is similar, taken as 0.5m/s as suggested by TCXDVN: 306 (2004) for normal conditions. The others two factors, Wet bulb temperature t_w [°C] and humidity ratio d [g/kg] can be estimated from *Psychrometric Chart*

The *Psychrometric Chart* is a basic design tool that presents the interrelation of air temperature and moisture content in a graphical form. A psychrometric chart contains a lot of information in a same graph, e.g. dry bulb temperature, wet bulb temperature, relative humidity, humidity ratio, enthalpy, specific volume. If any two of these factors are known, it is possible to estimate others. This chart is also introduced by the ASHRAE Fundamentals Handbook (2009). This study uses the standard ASHRAE psychrometric chart for normal temperature at sea level (barometric pressure =101.325 Kpa).The chart is given in appendix O of this research.

Because the Dry bulb temperature and the Relative Humidity are known (from site measurements, as presented in table 7.2 and table 7.3), it is possible to estimate other input factors which are required for calculating the Effective Temperature T_{eff} and the Condition index ΣH. These values are calculated and presented in table 7.4.

TCXDVN: 306 (2004) suggests that the neutral T_{eff} is 24.4°C and the upper limit of the comfort zone is 27°C. For the Condition index ΣH, the neutral comfort value is 13.8% and the upper limit of the comfort zone is 16.3%.

There are also other studies conducted in North Vietnam suggest different comfort temperature ranges, which vary from 21°C to 29.5°C (i.e. air temperature, see table 3.22, page 124). Site survey reveals that in reality, the mean temperature is 3°C to 4°C higher than what is recommended by these studies.

As shown in table 7.4, the T_{eff} of the surveyed classrooms at certain time are around ±1°C off the recommended upper comfort limit. This indicates that there are potential that these classrooms are overheated, but the indicator is not clear. In contrast, the Condition index ΣH shows a clear indicator that these classrooms are within comfortable conditions. Because these indices are developed from climatic data of the Northern Vietnam regions, they may not be appropriate for HCMC.

Table 7.4 Estimates of the Effective temperature [°C] and Condition Index $\sum H$ [%] using methods introduced by Vietnamese code TCXDVN: 306 (2004).

School	Season	Study shift	Dry bulb temperature t_d [°C]	Wet bulb temperature t_w [°C]	Relative humidity RH [%]	Humidity ratio d [g/kg]	TCVN:306 Effective temperature T_{eff} [°C] at air velocity 0.5m/s	Condition index $\sum H$ [%] at air velocity 0.5m/s
LE VAN TAM	DRY	Morning	28.66	23.30	66.92	16.0	25.77	7.90
		Afternoon	32.32	24.50	50.54	16.5	28.20	9.06
		Mean	30.49	24.20	58.73	16.0	27.14	8.45
	WET	Morning	29.74	26.80	77.14	22.5	28.06	8.87
		Afternoon	30.50	26.50	75.58	22.0	28.29	9.06
		Mean	30.12	26.20	76.36	21.8	27.95	8.92
	Both seasons		30.30	25.60	67.55	21.0	27.74	8.89
TRUONG CONG DINH	DRY	Morning	29.86	24.00	62.26	19.0	26.72	8.56
		Afternoon	*Classroom not in use*					
		Mean	29.86	24.00	62.26	19.0	26.72	8.56
	WET	Morning	30.94	26.40	69.51	22.0	27.30	9.19
		Afternoon	*Classroom not in use*					
		Mean	30.94	26.40	69.51	22.0	27.30	9.19
	Both seasons		30.40	25.20	65.88	20.6	26.43	8.88
HA HUY TAP	DRY	Morning	30.57	24.10	67.59	19.0	25.96	8.78
		Afternoon	*Classroom not in use*					
		Mean	30.57	24.10	67.59	19.00	25.96	8.78
	WET	Morning	30.94	27.90	83.31	23.0	28.05	9.29
		Afternoon	*Classroom not in use*					
		Mean	30.94	27.90	83.31	23.00	28.05	9.29
	Both seasons		30.76	26.90	75.45	21.2	27.46	9.05
LAM SON	DRY	Morning	32.57	29.40	50.71	19.4	29.61	9.42
		Afternoon	35.41	25.30	44.42	20.4	28.99	10.39
		Mean	33.99	25.40	47.57	20.6	28.32	9.98
	WET	Morning	33.48	26.50	58.00	22.0	28.62	9.96
		Afternoon	31.81	25.80	62.53	21.2	27.44	9.37
		Mean	32.65	26.00	60.26	22.4	27.95	9.75
	Both seasons		33.32	25.50	53.91	20.6	28.04	9.77

7.3.2 The International Standard ISO: 7730 (2005)

The international code ISO: 7730 (2005) was developed from the concept of *Predict Mean Vote (PMV)* and *Predicted Percent of Dissatisfied* people *(PPD)*. The code classifies comfort ranges under different categories (see section 3.4.3.3 of chapter 3).

According to ISO: 7730 (2005) classifications, it seems that these four surveyed classrooms are under *"cooling season"* for most of the time. Therefore, the neutral comfort temperature should be around 24.5°C. This value is quite low. Even under the lowest category, which is Cat C (min 22.5°C - max 27°C); it appears that none of the surveyed classrooms has temperatures within the comfortable range. Hence this code predicts that users are thermally uncomfortable for most of the time.

7.3.3. The European Standard EN: 15251 (2007)

The European code EN: 15251 (2007) provides a range of comfort temperatures, limited by an upper and a lower temperature limit (Θ_{imax} and Θ_{imin}). These limits are generated from the outdoor running mean temperature Θ_{rm} (see chapter 3 for method). The Θ_{rm} can be calculated from the daily mean external temperature Θ_{ed}. In this research, the Θ_{ed} is extracted from the data recorded by the Tan San Hoa station of Southern Region Meteorology Office in HCMC. The running mean temperature Θ_{rm} is obtained by the following equation:

$$\Theta_{rm} = (\Theta_{ed-1} + 0,8\,\Theta_{ed-2} + 0,6\,\Theta_{ed-3} + 0,5\,\Theta_{ed-4} + 0,4\,\Theta_{ed-5} + 0,3\,\Theta_{ed-6} + 0,2\,\Theta_{ed-7})/3,8 \qquad (7.3)$$

Where: Θ_{rm} Running mean temperature for today [°C]

Θ_{rm-1}: Running mean temperature for previous day [°C]

Θ_{ed-1}: Daily mean external temperature for the previous day [°C]

Θ_{ed-2}: Daily mean external temperature for the day before and so on [°C].

α: A constant between 0 and 1. Recommended to use α =0.8

Because there are no available site measurements of external temperature, the calculation uses the daily mean external temperatures provided by the local Meteorology Office (at Tan San Hoa Station). These values are actual data recorded on the exact days when the site surveys were taken (February–March 2007 and September-October 2008).

The running mean temperatures (Θ_{rm}) of 2007 and 2008 are then plotted in figure 7.6 and figure 7.7. These graphs also show the maximum and minimum external temperatures giving an idea of the temperature range. Once the Θ_{rm} is defined, the comfort zone of each category can be calculated by the equations given in table 7.5 below.

Table 7.5 EN:15251 equations to define the comfort zone. (EN:15251, 2004)

Category I	upper limit:	$\Theta_{i\ max} = 0{,}33\Theta_{rm} + 18{,}8 + 2$
	lower limit:	$\Theta_{i\ min} = 0{,}33\ \Theta_{rm} + 18{,}8 - 2$
Category II	upper limit:	$\Theta_{i\ max} = 0{,}33\ \Theta_{rm} + 18{,}8 + 3$
	lower limit:	$\Theta_{i\ min} = 0{,}33\ \Theta_{rm} + 18{,}8 - 3$
Category III	upper limit:	$\Theta_{i\ max} = 0{,}33\ \Theta_{rm} + 18{,}8 + 4$
	lower limit:	$\Theta_{i\ min} = 0{,}33\ \Theta_{rm} + 18{,}8 - 4$

where Θ_i = limit value of indoor operative temperature, °C

The comfort zone generated from these equations is plotted in figure 7.7 and figure 7.8. The site recorded temperatures of each school are also plotted on these graphs to evaluate whether they are within the acceptable comfort range. The results are summarized in table 7.6. The neutral comfort temperature (Θ_o) predicted by EN: 15251 method is approximately 28.04°C.

Table 7.6 Neutral comfort temperature Θ_o and its limit values (Θ_{min}, Θ_{max}) for free-running buildings in HCMC, given by the EN: 15251 (2007) method.

Year	Mean Θ_{rm}[°C]	Mean neutral comfort temperature and comfort zone [°C]						
		Θ_o[°C]	CAT I		CAT II		CAT III	
			Min	*Max*	*Min*	*Max*	*Min*	*Max*
2007	28.03	28.05	26.05	30.05	25.05	31.05	24.05	32.05
2008	27.95	28.02	26.02	30.02	25.02	31.02	24.02	32.02
Average	27.99	28.04	26.04	30.04	25.04	31.04	24.04	32.04

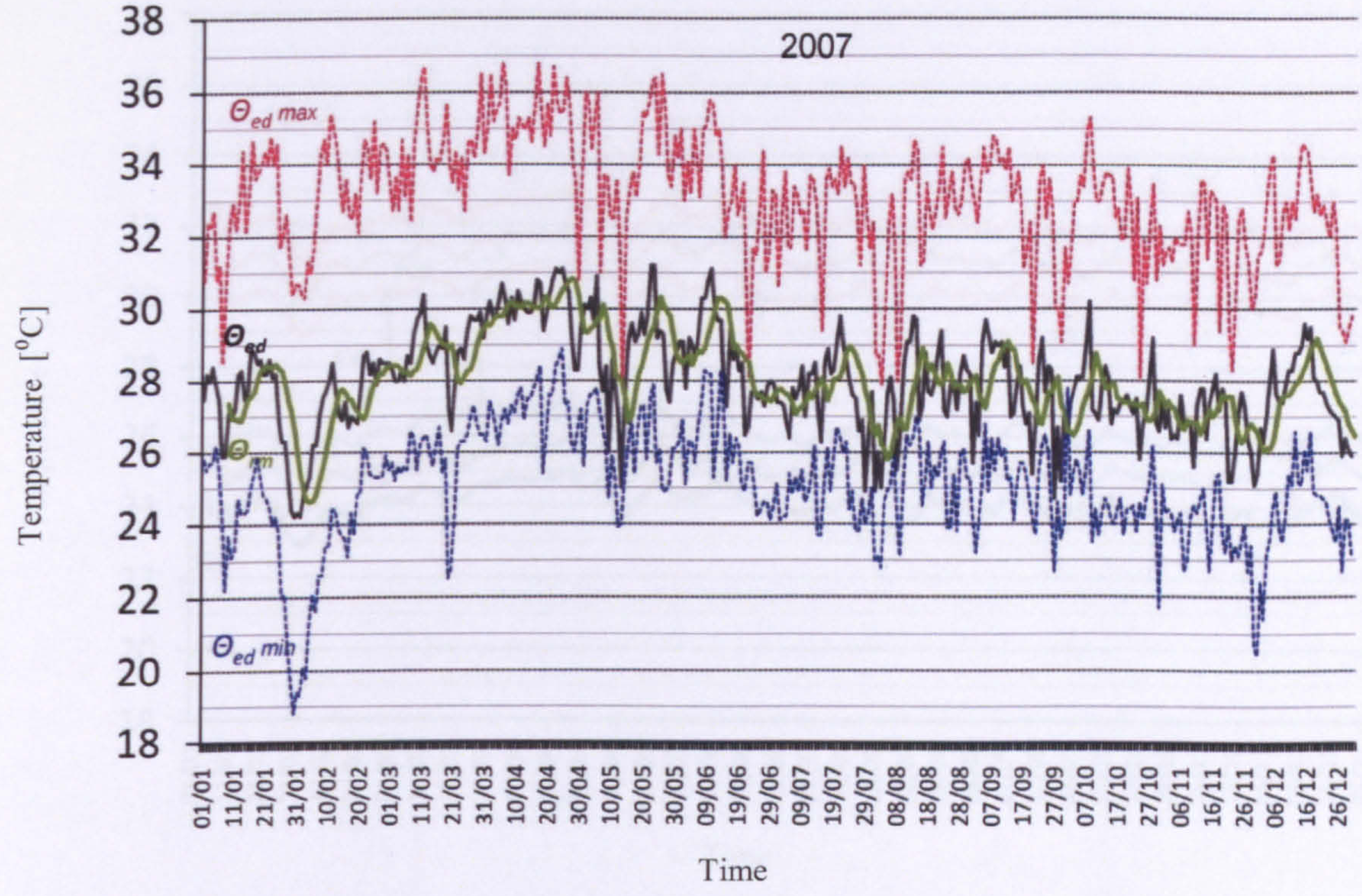


Figure 7.6 Running meaning temperature Θ_{rm} for HCMC to be calculated based on the daily mean external temperature Θ_{ed} measured in 2007. The Θ_{edmax} and Θ_{edmin} are the daily highest and lowest external temperatures provided by the local Meteorology Office.

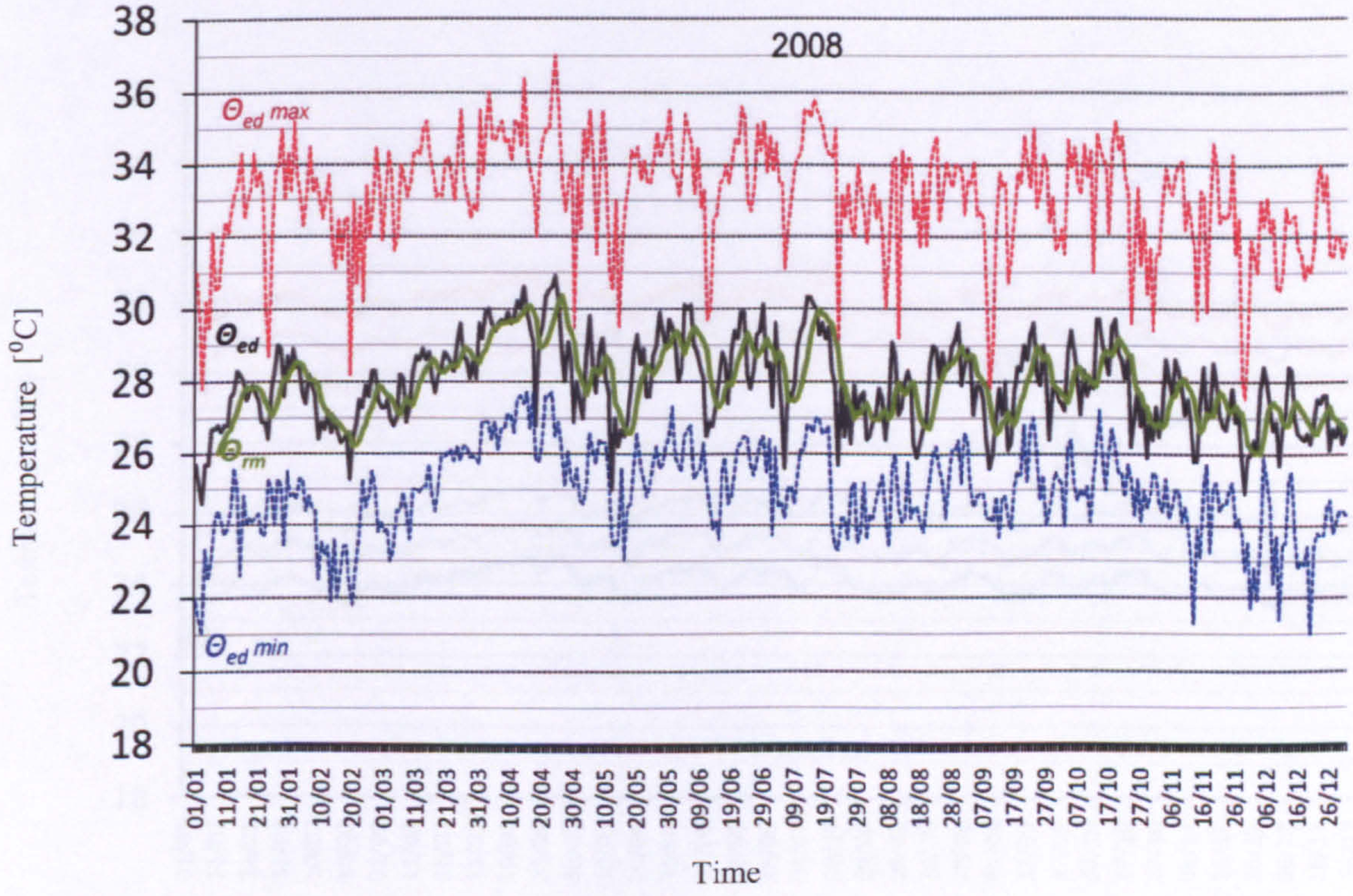


Figure 7.7 Running meaning temperature Θ_{rm} for HCMC to be calculated based on the daily mean external temperature Θ_{ed} measured in 2008. The Θ_{edmax} and Θ_{edmin} are the daily highest and lowest external temperatures provided by the local Meteorology Office.

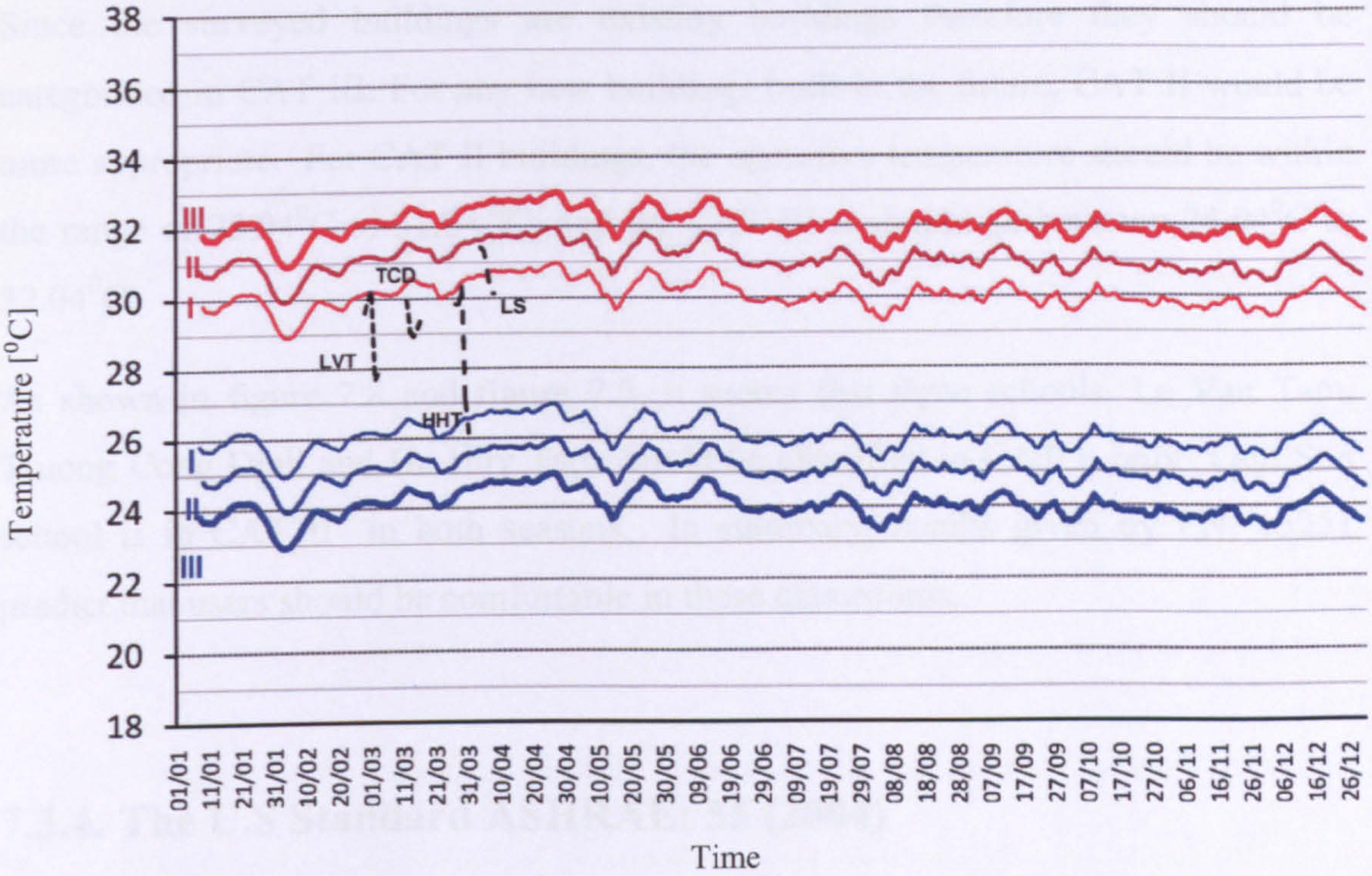


Figure 7.8 EN:15251 operative temperature comfort range [^{0}C] for 2007 for HCMC.

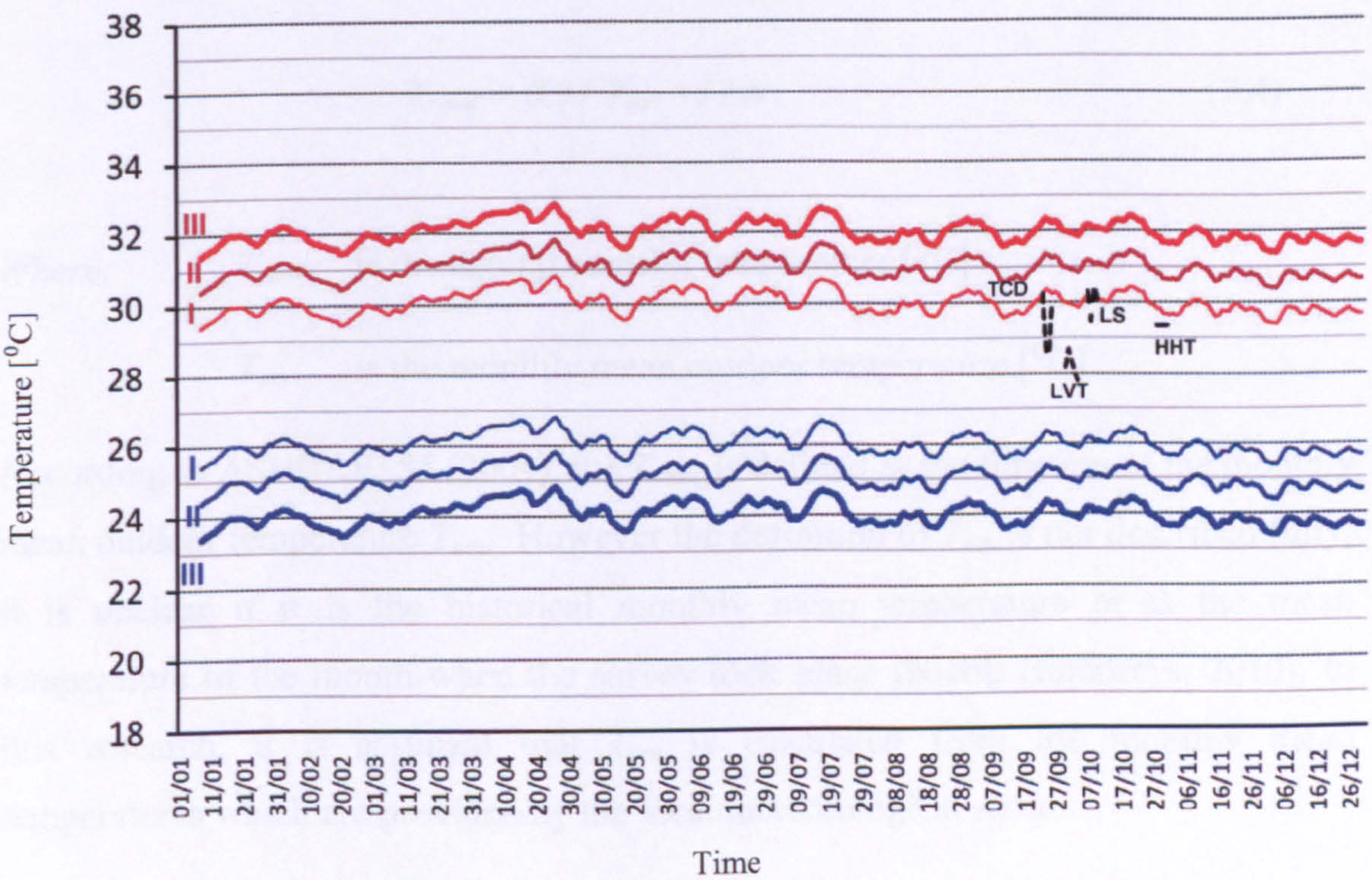


Figure 7.9 EN:15251 operative temperature comfort range [^{0}C] for 2008 for HCMC.

Since the surveyed buildings are existing buildings therefore they should be categorized in CAT III. For any new buildings built in the future, CAT II would be more appropriate. For CAT II buildings, the operative temperature should be within the range of 25.04^{0}C to 31.04 ^{0}C; and for CAT III it should be between 24.04^{0}C to 32.04^{0}C.

As shown in figure 7.8 and figure 7.9, it seems that three schools, Le Van Tam, Truong Cong Dinh and Ha Huy Tap, could be classified in CAT I; only Lam Son school is in CAT II in both seasons. In summary, results given by EN: 15251 predict that users should be comfortable in these classrooms.

7.3.4. The U.S Standard ASHRAE: 55 (2004)

The U.S standard ASHRAE: 55 (2004) provides another method of predicting neutral comfort temperature T_{comf} [^{0}C], from the monthly mean outdoor temperature. T_{comf} is obtained by:

$$T_{comf} = 0.31\ T_{om} + 17.8 \qquad (7.4)$$

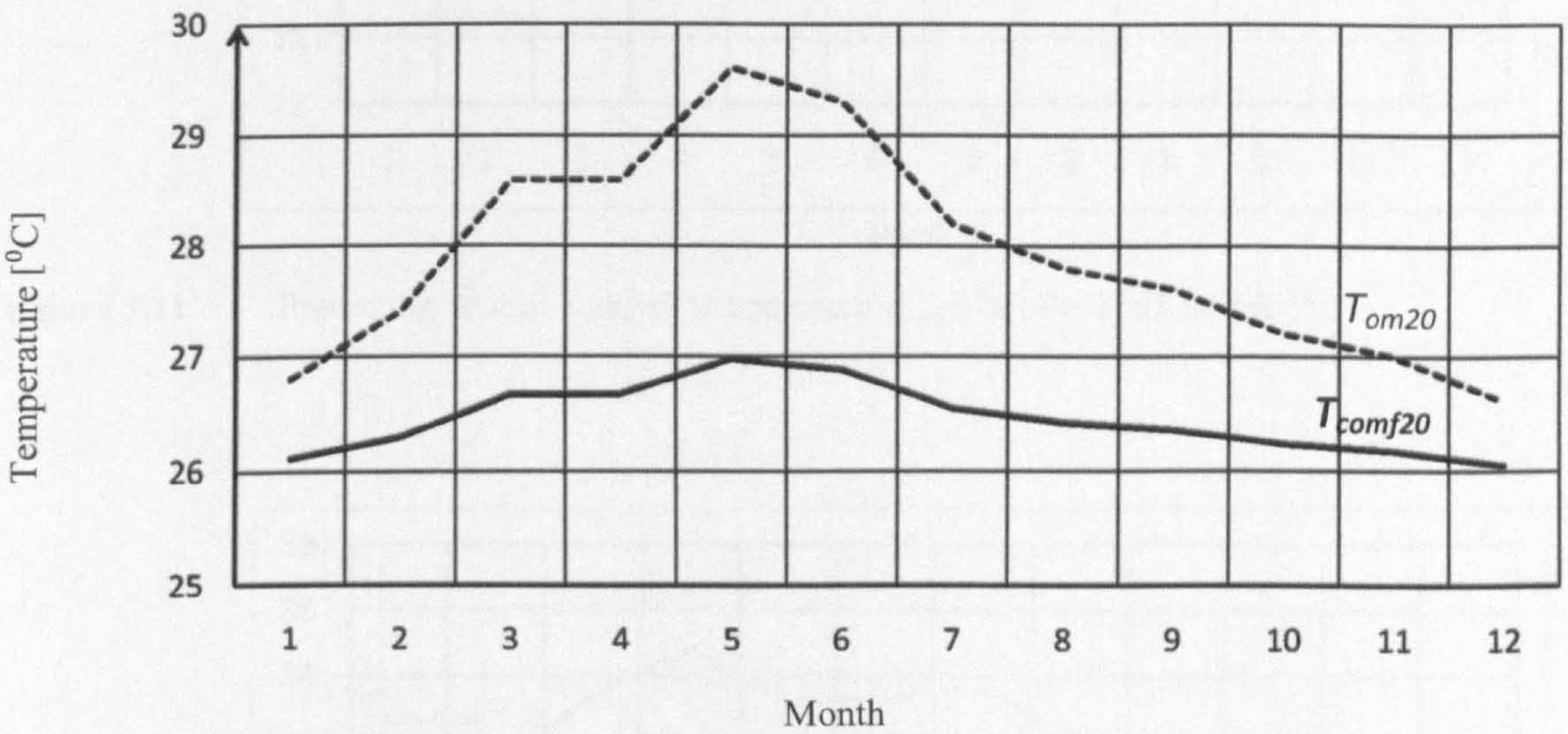
Where: T_{comf} is the neutral comfort temperature [^{0}C]

T_{om} is the monthly mean outdoor temperature [^{0}C]

According to ASHRAE: 55 (2004), the T_{comf} is defined as the function of the monthly mean outdoor temperature T_{om}. However the definition of T_{om} is not described fully; it is unclear if it is the historical monthly mean temperature or is the mean temperature of the month when the survey took place (Nicol, Humpreys, 2010). In this research, it is assumed that T_{om} is calculated from the monthly mean temperatures which are provided by the local meteorological station.

Figure 7.10 shows typical 20 year monthly mean temperatures (T_{om20}) of HCMC. This is useful because it presents general conditions recorded over a long period of time. From these values, the typical 20-year neutral comfort temperatures calculated by the equation (7.2) are obtained. The mean T_{comf20} is predicted to be at 26.45^{0}C.

Based on the same approach T_{comf} [^{0}C] calculated from the T_{om} [^{0}C] of the year 2007 and 2008 are shown in figure 7.11 and 7.12. As shown in these figures, the predicted T_{om} for 2007 is 26.48^{0}C and the predicted T_{om} for 2008 is 26.45^{0}C. Therefore, it can be concluded that the neutral comfort temperature predicted by the ASHRAE: 55 method is 26.5^{0}C (see table 7.7).



Temperature [^{o}C]	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	*Average*
T_{om20}	26.80	27.40	28.60	28.60	29.60	29.30	28.20	27.80	27.60	27.20	27.00	26.60	***27.89***
T_{comf20}	26.11	26.29	26.67	26.67	26.98	26.88	26.54	26.42	26.36	26.23	26.17	26.05	***26.45***

Figure 7.10 Typical 20-year neutral comfort temperature T_{comf20} [^{0}C] for HCMC

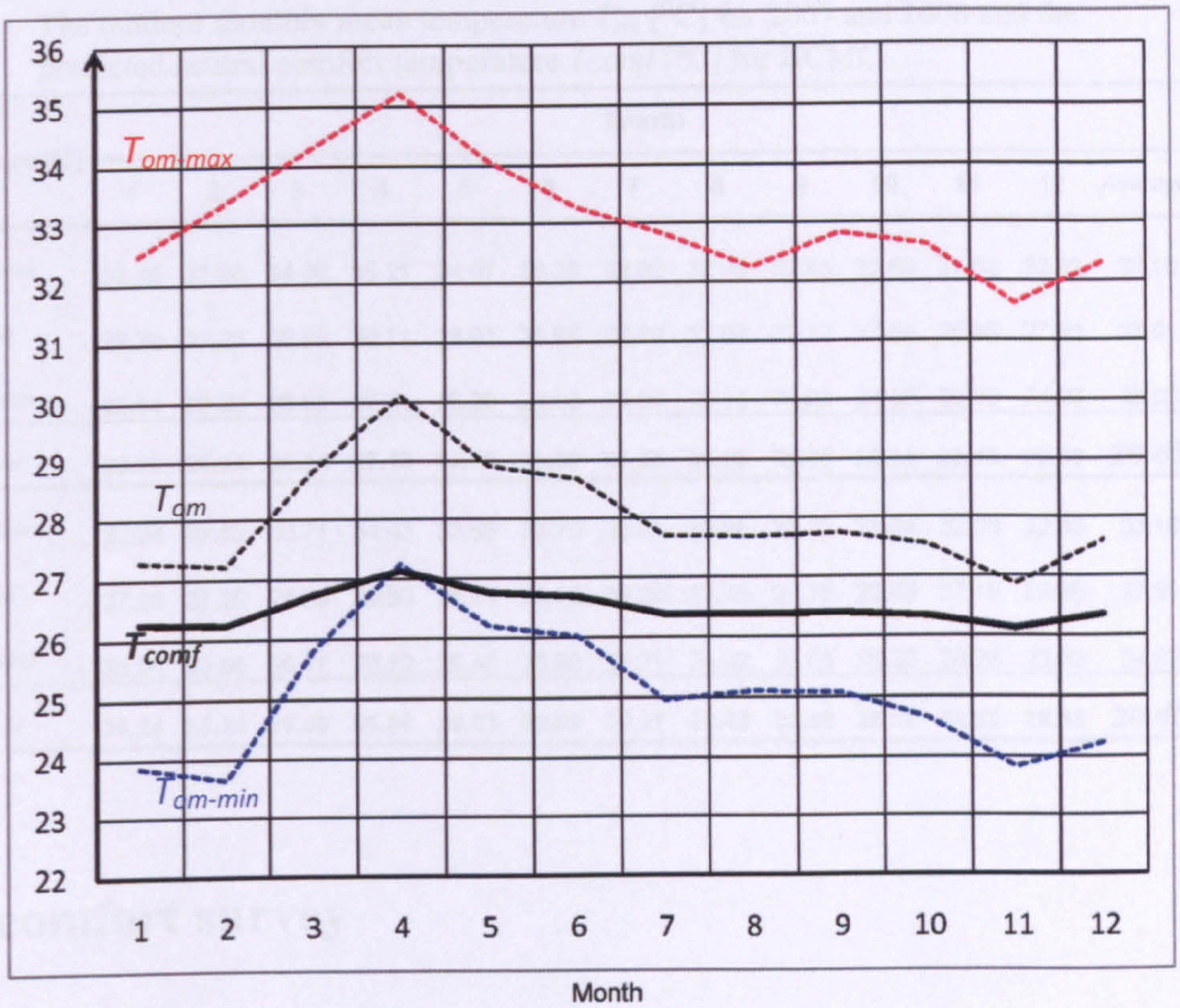


Figure 7.11 Predicting neutral comfort temperature T_{comf} [^{0}C] for 2007 for HCMC

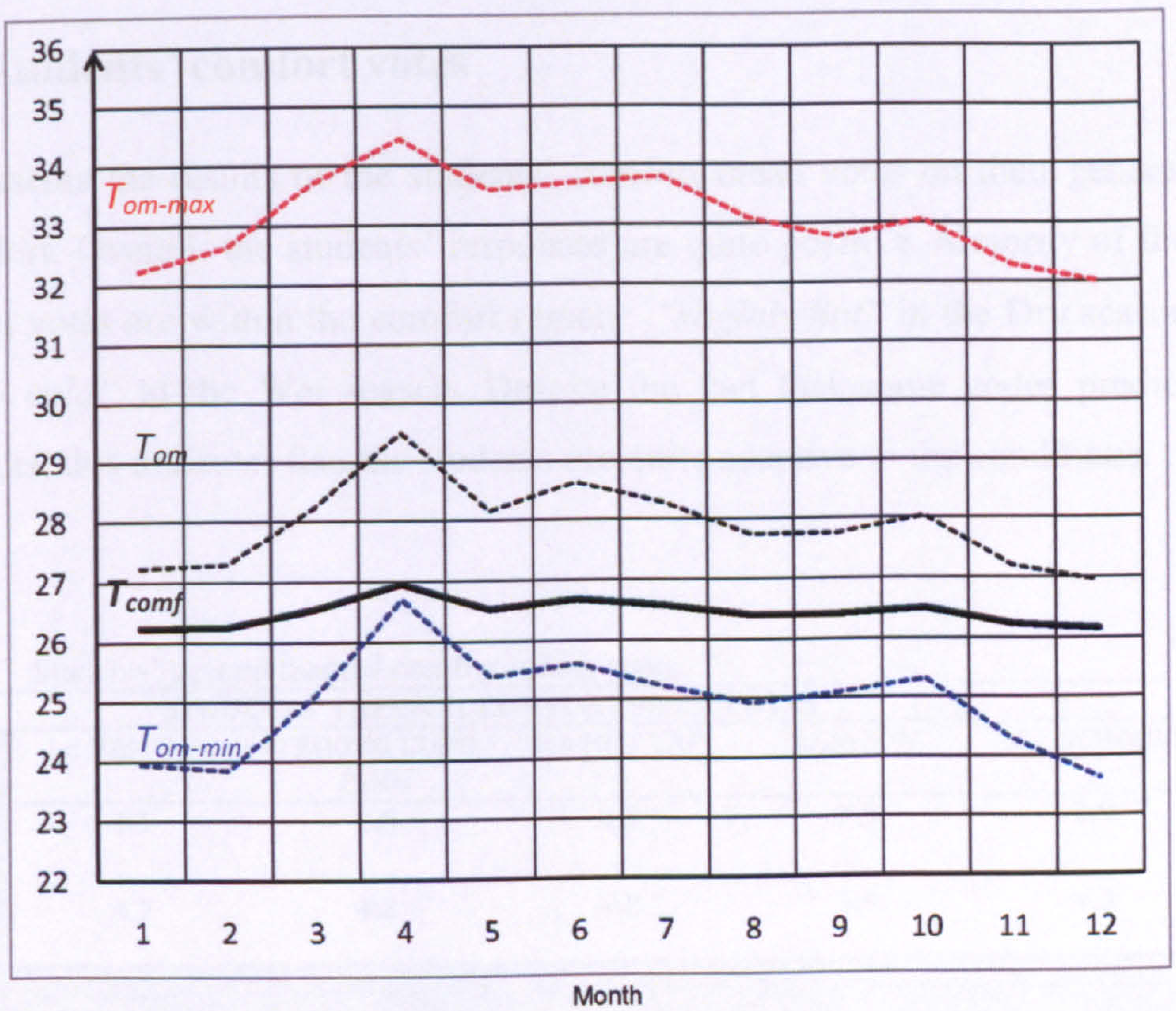


Figure 7.12 Predicting neutral comfort temperature T_{comf} [^{0}C] for 2008 for HCMC

Table 7.7 The outdoor monthly mean temperature T_{om} [^{0}C] for 2007 and 2008 and the predicted neutral comfort temperature $Tcomf$ [^{0}C] for HCMC.

Year	Temperature [°C]	1	2	3	4	5	6	7	8	9	10	11	12	*Average*
2007	$T_{om\text{-}max}$	32.49	33.36	34.30	35.21	34.07	33.28	32.82	32.25	32.83	32.63	31.62	32.32	33.10
	T_{om}	27.30	27.23	28.83	30.11	28.91	28.68	27.69	27.67	27.73	27.54	26.85	27.60	28.01
	$T_{om\text{-}min}$	23.84	23.63	25.82	27.24	26.20	26.03	24.96	25.11	25.08	24.65	23.82	24.23	25.05
	T_{comf}	**26.26**	**26.24**	**26.74**	**27.13**	**26.76**	**26.69**	**26.38**	**26.38**	**26.40**	**26.34**	**26.12**	**26.36**	***26.48***
2008	$T_{om\text{-}max}$	32.24	32.62	33.71	34.43	33.58	33.70	33.80	33.08	32.75	33.04	32.28	32.00	33.10
	T_{om}	27.23	27.29	28.23	29.50	28.15	28.63	28.28	27.75	27.75	28.03	27.19	26.95	27.91
	$T_{om\text{-}min}$	23.95	23.85	25.11	26.70	25.40	25.60	25.21	24.92	25.08	25.32	24.28	23.63	24.92
	T_{comf}	**26.24**	**26.26**	**26.55**	**26.95**	**26.53**	**26.68**	**26.57**	**26.40**	**26.40**	**26.49**	**26.23**	**26.15**	***26.45***

7.4. The comfort survey

This section presents the results and analyses of the data collected from the field comfort survey. This thermal comfort survey makes up the fourth part of the questionnaire (see appendix A for further information).

7.4.1. The students' comfort votes

Table 7.8 presents the results of the students' comfort mean votes on their general thermal comfort. Overall, the students' responses are quite positive. Majority of the mean comfort votes are within the comfort region: *"slightly hot"* in the Dry season and *"slightly cold"* in the Wet season. Despite the fact that some codes predict negative results, this indicates that the students are quite adaptive to the conditions.

Table 7.8 Students' general thermal comfort means votes.

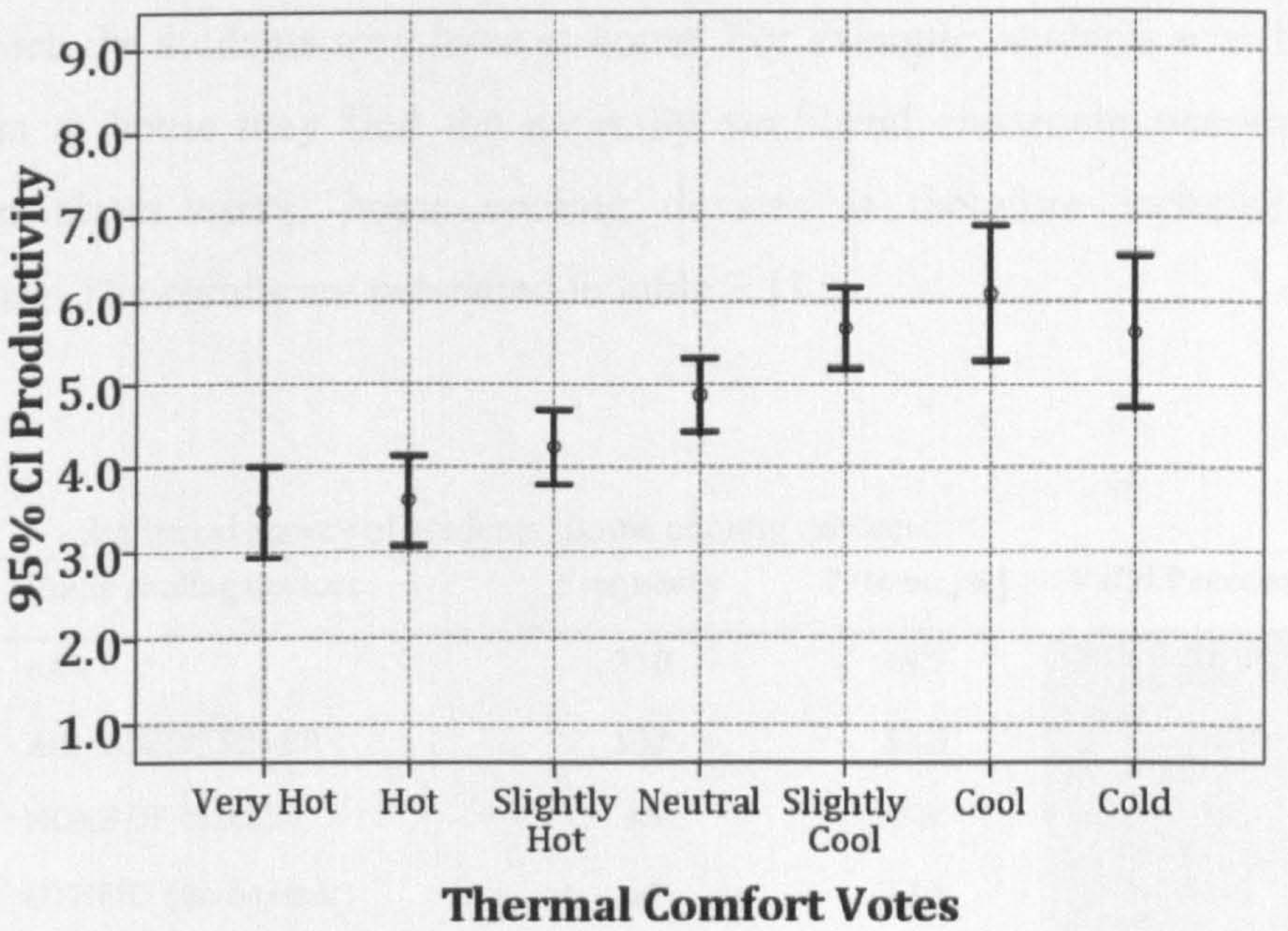
STUDENTS' THERMAL COMFORT MEAN VOTES					
SEASON	LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON	ALL SCHOOLS
DRY SEASON	**4.1**	**3.8**	**3.3**	**3.9**	**3.9**
WET SEASON	**4.7**	**4.2**	**4.8**	**3.9**	**4.3**

Comfort Scale	1	2	3	4	5	6	7
Sensation	Very hot	Hot	**Slightly Hot**	**Neutral**	**Slightly Cool**	Cool	Cold
			Comfort zone				

Table 7.9 Percentage of students' thermal comfort mean votes falling within the comfort zone.

Comfort sensation scale	Very hot	Hot	Slightly Hot	Neutral	Slightly Cool	Cool	Cold
LE VAN TAM SCHOOL							
Percentage of thermal comfort votes in the Dry season	8.9%	8.9%	**13.8%**	**29.1%**	**18.7%**	11.8%	8.9%
Percentage of votes in comfort zone in the Dry season				**61.6%**			
Percentage of thermal comfort votes in the Wet season	10.1%	7.2%	**5.8%**	**19.3%**	**16.9%**	31.4%	9.1%
Percentage of votes in comfort zone in the Wet season				**42.0%**			
Percentage of thermal comfort votes in both seasons	9.5%	8.1%	**9.8%**	**24.2**	**17.8%**	21.6%	9%
Percentage of votes in comfort zone in both seasons				**58.7%**			
TRUONG CONG DINH SCHOOL							
Percentage of thermal comfort votes in the Dry season	20.6%	9.8%	**10.8%**	**26.5%**	**9.8%**	11.8%	10.8%
Percentage of votes in comfort zone in the Dry season				**47.1%**			
Percentage of thermal comfort votes in the Wet season	13.7%	13.7%	**8.8%**	**17.6%**	**10.8%**	23.5%	11.8%
Percentage of votes in comfort zone in the Wet season				**37.2%**			
Percentage of thermal comfort votes in both seasons	17.15%	11.75%	**9.8%**	**22.05%**	**10.3%**	17.65%	11.3%
Percentage of votes in comfort zone in both seasons				**42.15%**			
HA HUY TAP SCHOOL							
Percentage of thermal comfort votes in the Dry season	20%	11.8%	**17.6%**	**31.8%**	**7.1%**	4.7%	7.1%
Percentage of votes in comfort zone in the Dry season				**56.5%**			
Percentage of thermal comfort votes in the Wet season	12.9%	8.2%	**14.1%**	**12.9%**	**12.9%**	25.9%	12.9%
Percentage of votes in comfort zone in the Wet season				**39.9%**			
Percentage of thermal comfort votes in both seasons	16.45%	10%	**15.85%**	**22.35%**	**10%**	15.3%	10%
Percentage of votes in comfort zone in both seasons				**48.2%**			
LAM SON SCHOOL							
Percentage of thermal comfort votes in the Dry season	14.5%	8.7%	**17.4%**	**24.6%**	**15.9%**	7.2%	11.5%
Percentage of votes in comfort zone in the Dry season				**57.9%**			
Percentage of thermal comfort votes in the Wet season	11.9%	10.4%	**6.0%**	**34.3%**	**28.4%**	7.5%	1.5%
Percentage of votes in comfort zone in the Wet season				**68.7%**			
Percentage of thermal comfort votes in both seasons	13.2%	9.55%	**11.7%**	**29.45%**	**22.15%**	7.35%	6.5%
Percentage of votes in comfort zone in both seasons				**63.3%**			
ALL SCHOOLS							
Percentage of thermal comfort votes in the Dry season	14.7%	9.7%	**14.3%**	**28.3%**	**14.0%**	9.7%	9.3%
Percentage of votes in comfort zone in the Dry season				**56.6%**			
Percentage of thermal comfort votes in the Wet season	11.8%	9.5%	**8.0%**	**20.0%**	**16.3%**	24.9%	9.5%
Percentage of votes in comfort zone in the Wet season				**44.3%**			
Percentage of thermal comfort votes in both seasons	13.25%	9.6%	**11.15%**	**24.15%**	**15.15%**	17.3%	9.4%
Percentage of votes in comfort zone in both seasons				**50.45%**			

Figure 7.13 shows the statistical plotting of 95% confident interval of the students' thermal comfort votes and their self assessed productivity rate, this plotting indicates that the best productivity rate (+20%) is achieved if the room is cooler about two comfort votes. From the data presented in table 7.2 and table 7.8, it is estimated that the width of one productivity comfort vote is approximately 2°C. This means the best productivity will be achieved when the room is 4°C cooler than the current room temperature.



Productivity scale:

1	2	3	4	5	6	7	8	9
-40%	-30%	-20%	-10%	±0	+10%	+20%	+30%	+40%

Figure 7.13 Statistical plotting of 95% confident interval thermal comfort vote against students' productivity rate.

Table 7.10 show the students' comfort mean votes on ventilation. The results do not provide any clear indication and it seems that the ventilation system is working well. The worst votes go to Ha Huy Tap School and this perhaps could be attributed to the wooden louvered windows which block much of air movement.

Table 7.10 Students' comfort mean votes on ventilation.

STUDENTS' COMFORT MEAN VOTES ON VENTILATION					
SEASON	LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON	ALL SCHOOLS
DRY SEASON	**3.5**	**3.3**	**4.5**	**4.0**	**3.4**
WET SEASON	3.3	3.1	4.1	3.7	4.3

Comfort Scale	1	2	3	4	5	6	7
Sensation	Very Good	Good	**Slightly Good**	**Fair**	**Slightly Bad**	Bad	Very Bad
			Comfort zone				

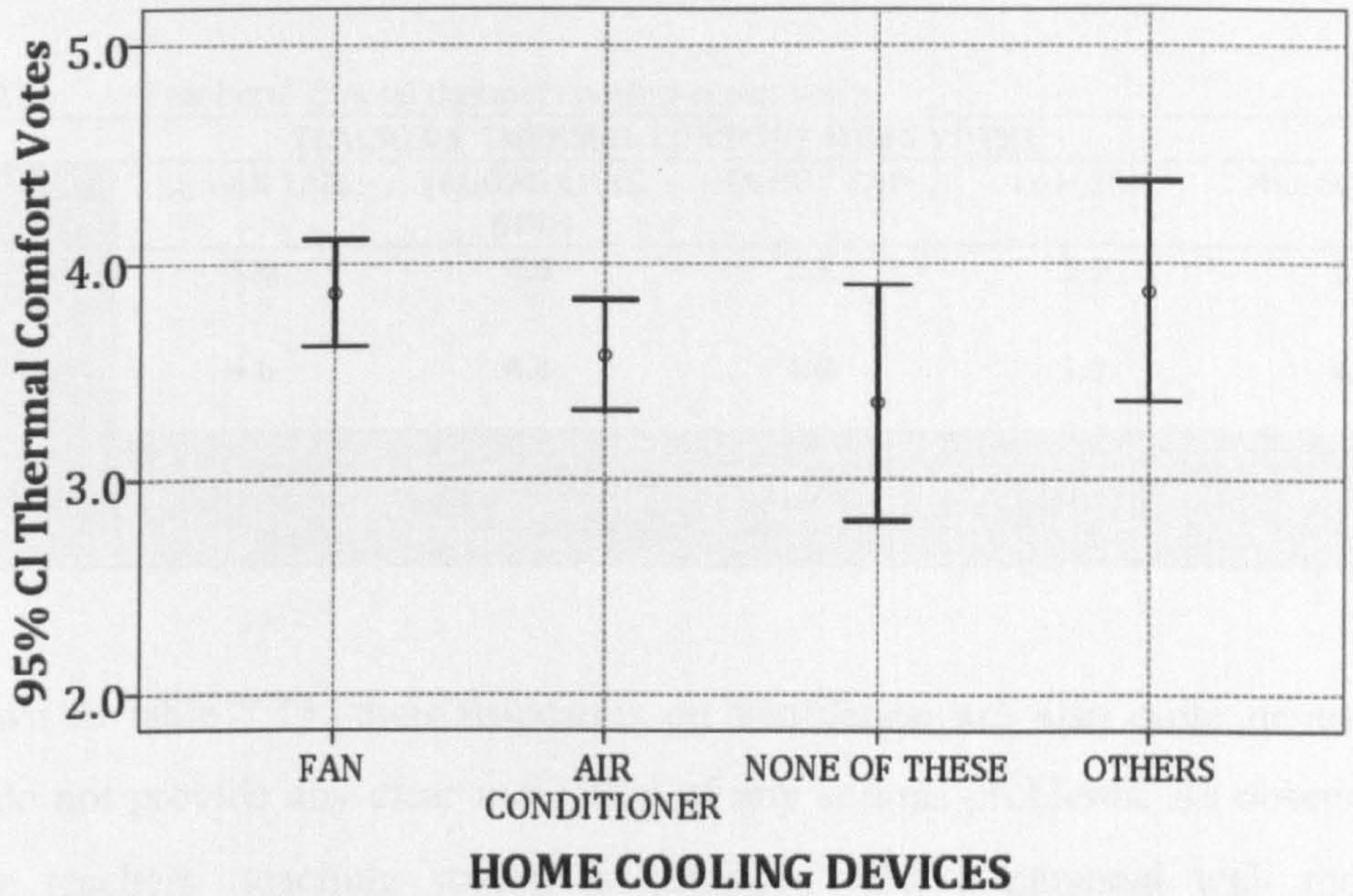
The users' thermal comfort sensation may be subject to their long term experiences with the environment, thus it is worth doing a brief review on the kind of cooling devices which the students may have at home. For example, students who have air-conditioners at home may find the naturally ventilated classroom uncomfortable. Information about users' home cooling devices is therefore included in the questionnaire. The results are presented in table 7.11.

Table 7.11 Statistical survey of students' home cooling devices.

Vote	Home cooling devices	Frequency	Percent [%]	**Valid Percent [%]**
Valid	FAN	210	44.7	**44.8**
	AIR-CONDITIONER	152	32.3	**32.4**
	NONE OF THESE	43	9.1	**9.2**
	OTHERS (no answer)	64	13.6	**13.6**
	TOTAL	469	99.8	**100.0**
Missing	System	1	0.2	
Total		470	100.0	

It is found that majority of students (44.8%) have fans at home and about one third of the population (32.4%) have air-conditioners. It seems that the fan ventilated environment is the typical condition that the students get used to, and thus they may find the naturally ventilated classroom a little uncomfortable at certain periods of the day.

Further statistical analysis indicates that the group of students who have fans at home adapt better to the existing conditions, which are perhaps quite similar to their home conditions. The group of students who have air conditioners at home feel the classroom is slightly hot. The group with no cooling device at home are actually those that are able adapt well to the wide range of temperature changes; their 95% confident interval region expands two to three comfort votes, in comparison to one vote for other group (see figure 7.14).



Comfort Scale	1	2	3	4	5	6	7
Sensation	Very hot	Hot	Slightly Hot	Neutral	Slightly Cool	Cool	Cold
			Comfort zone				

Figure 7.14 Statistical plotting of 95% confident interval thermal comfort vote against students' home cooling devices.

7.4.2. The teachers' comfort votes

Although students are the main users of the classrooms and teachers move from classroom to classroom, it is important to provide a comfortable environment for the teachers. This is because the more comfortable they are, the better would be the quality of their lectures. However, only few of the published studies address the requirements for teachers.

Another set of questionnaires were distributed among the teachers to ask about their comfort satisfaction (see appendix A for further information). This questionnaire retained the format of the questionnaire distributed among students with some revisions that were appropriate for the teachers.

Table 7.12 shows the teachers' general thermal comfort mean votes. The results are found to be quite mixed. Overall, the teachers feel the classroom is fairly comfortable. There is no clear indication of whether they are specifically uncomfortable in any of schools. What is surprising is that they feel "cooler" in the Dry season.

Table 7.12 Teachers' general thermal comfort mean votes.

TEACHERS' THERMAL COMFORT MEAN VOTES					
SEASON	LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON	ALL SCHOOLS
DRY SEASON	**5.0**	**5.8**	**3.3**	**3.9**	**5.4**
WET SEASON	**4.6**	**4.3**	**4.8**	**3.9**	**4.7**

Comfort Scale	1	2	3	4	5	6	7
Sensation	Very hot	Hot	**Slightly Hot**	**Neutral**	**Slightly Cool**	Cool	Cold
			Comfort zone				

As shown in table 7.13, their responses on ventilation are also quite neutral; the results do not provide any clear indication of any serious problems. As observed on site, the teachers' teaching station is equipped with a personal wall mounted oscillating fan and the teachers have full access to the speed control. Therefore, it is assumed that they have more opportunities to adapt to the conditions. For instance, they can move away from the heat source, adjust the fans, close the windows or change their clothing type to suit the weather (in contrast, students must wear the same uniform in both seasons). This could possibly explain why they are more comfortable and better adapted to the conditions.

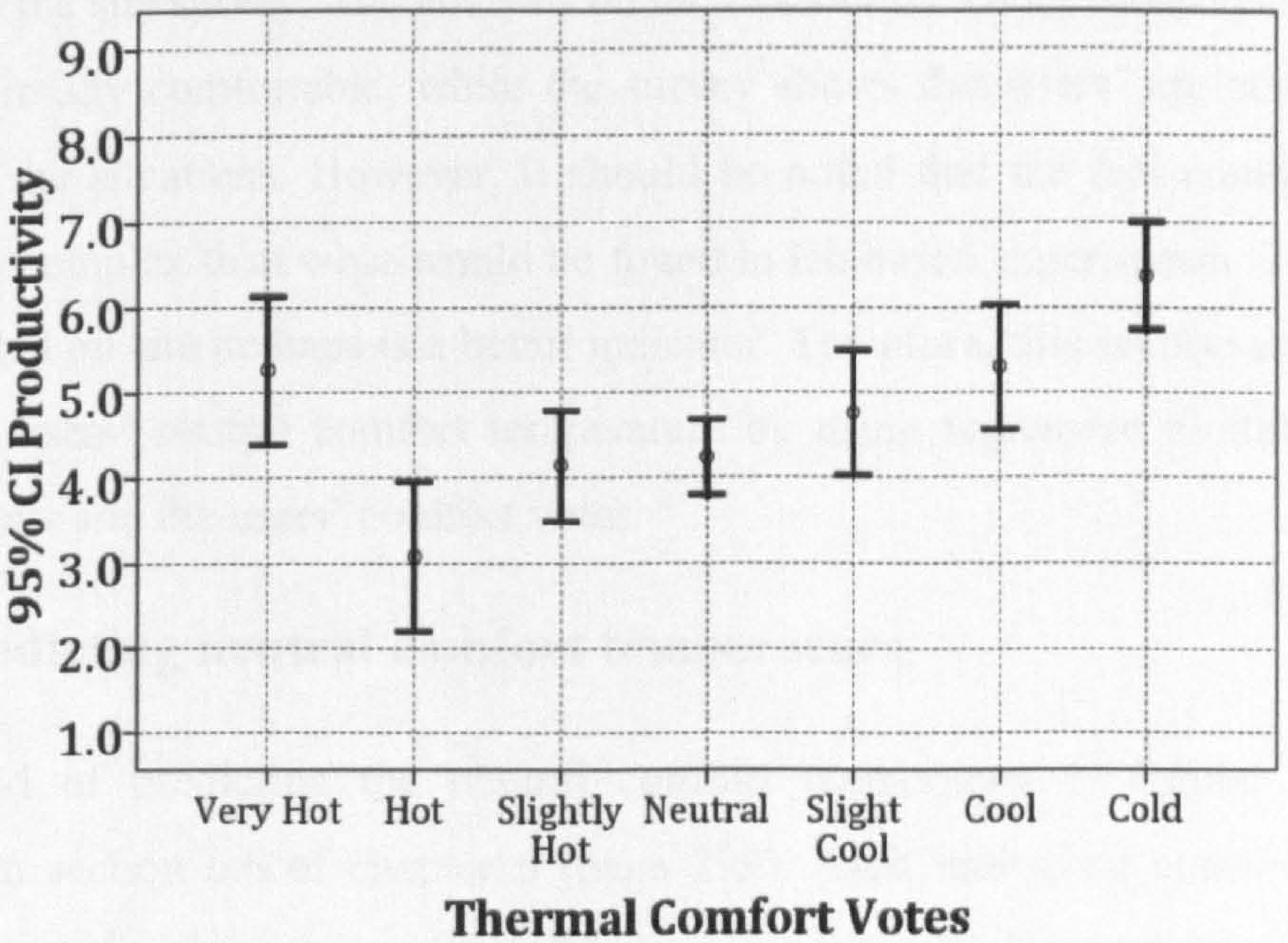
Table 7.13 Teachers' comfort mean votes on ventilation.

TEACHERS' COMFORT MEAN VOTES ON VENTILATION					
SEASON	LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON	ALL SCHOOLS
DRY SEASON	**3.8**	**4.0**	**4.5**	**5.1**	**3.8**
WET SEASON	**3.7**	**3.6**	**4.7**	**5.6**	**4.1**

Comfort Scale	1	2	3	4	5	6	7
Sensation	Very Good	Good	**Slightly Good**	**Fair**	**Slightly Bad**	Bad	Very Bad
			Comfort zone				

Table 7.14 Percentage of teachers' thermal comfort votes falling within the comfort zone.

Comfort sensation scale	Very hot	Hot	Slightly Hot	Neutral	Slightly Cool	Cool	Cold
Percentage of teachers' comfort votes in the Dry season	34.3%	19.1%	**11.9%**	**21.6%**	**8.9%**	3.8%	0.4%
Percentage of teachers' comfort votes in comfort zone in the Dry season				**42.4%**			
Percentage of teachers' comfort votes in the Wet season	17.0%	17.9%	**15.3%**	**27.2%**	**14.0%**	7.7%	0.9%
Percentage of teachers' comfort votes in comfort zone in the West season				**56.5%**			
Percentage of teachers' comfort votes in both seasons	25.65%	18.5%	**13.6%**	**24.4%**	**11.45%**	5.75%	0.65%
Percentage of teachers' comfort votes in comfort zone in both seasons				**49.45%**			



Productivity scale:

1	2	3	4	5	6	7	8	9
-40%	-30%	-20%	-10%	±0	+10%	+20%	+30%	+40%

Figure 7.15 Statistical plotting of 95% confident interval thermal comfort vote against the teachers' productivity rate.

Figure 7.15 presents the statistical analysis of the relationship between the teachers' 95% confident interval thermal comfort votes and their perceived productivity rate. Similar to the results from the student's responses, the plotting shows that the productivity rate is higher when the room gets cooler. The graph also shows that the teachers' adaptive range is much wider than that of the students'. In the thermal comfort regions of ±1 vote width, the difference in productivity rate is not statistically significant. If the room gets hotter by two thermal comfort votes, the productivity rate drops significantly; but the region of confidence is still quite wide. In comparison, similar results from students' plotting expand over two votes. This indicates that teachers can adapt to a wider range of temperature changes. Their productivity rate is not significantly affected if the change is not too much.

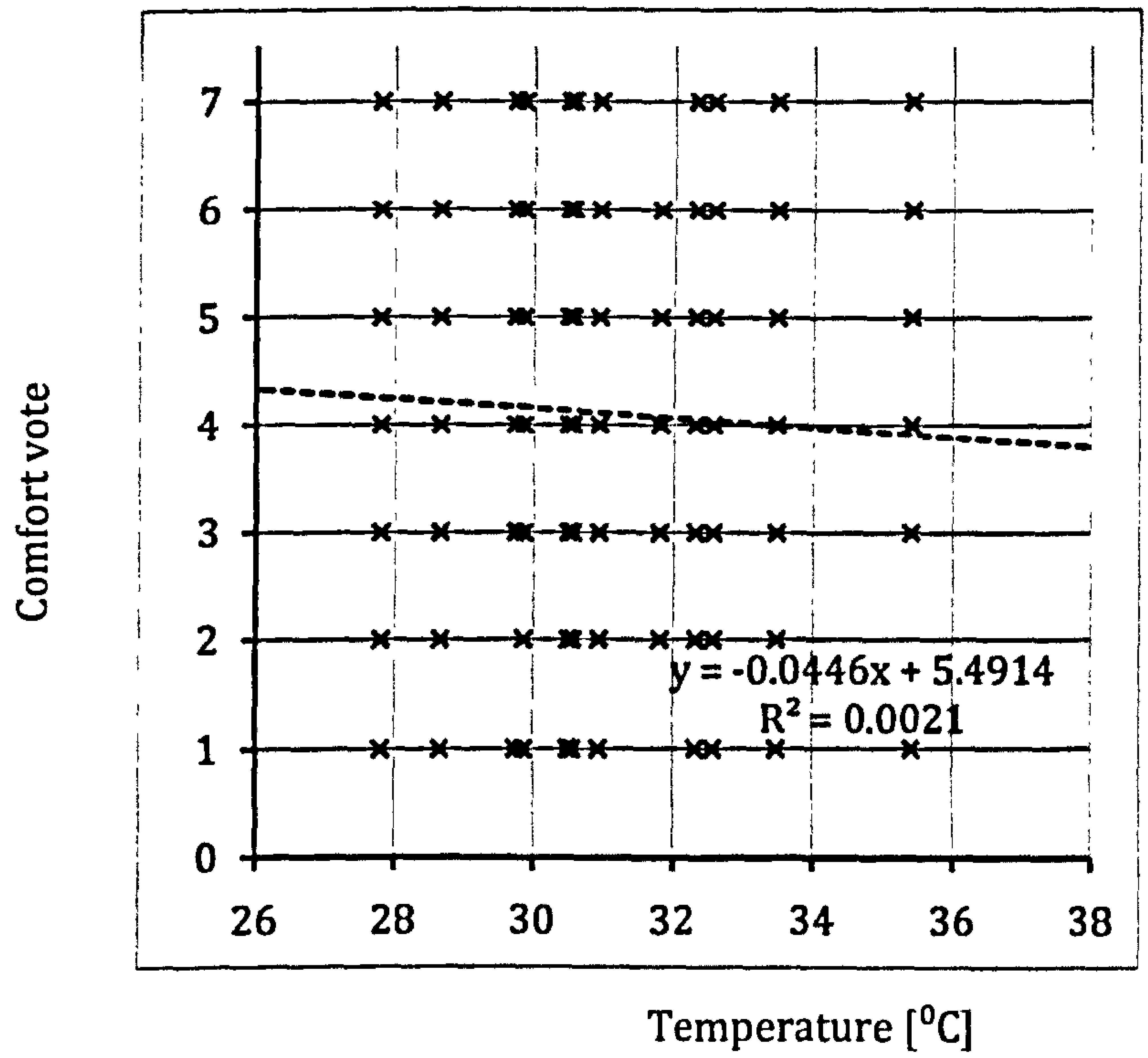
7.5. Predicting the neutral comfort temperature

It seems that there are differences between the code recommendations and what was found from the site survey. The analysis on the basis of the codes indicates that users are not thermally comfortable, while the survey shows that users' are comfortably adapted to the situations. However, it should be noted that the real conditions are much more complex than what would be found in lab based experiments. The actual data collected on site perhaps is a better indicator. Therefore, this section attempts to predict the users' neutral comfort temperature by using regressive plotting of site measurements and the users' comfort votes.

7.5.1. Predicting neutral comfort temperature

The method of predicting the neutral comfort temperature is similar to those described in section 6.6 of chapter 6 (page 299). Each individual comfort vote is plotted against the site measured temperatures respectively. Because of similar site conditions, these votes may overlap, but the weight of the population is taken into consideration.

Figure 7.16 shows the regressive graph of the user's thermal comfort votes plotted against mean temperatures accordingly (of each study shift for each classroom, as given in table 7.2).



Comfort Scale	1	2	3	4	5	6	7
Sensation	Very hot	Hot	Slightly Hot	Neutral	Slightly Cool	Cool	Cold
			Comfort zone				

Figure 7.16 Regressive plotting of student's thermal comfort votes and temperature.

Based on this graph, the neutral comfort temperature is therefore given as:

$$y = -0.0446x + 5.4914$$

$$\text{If } y=4 \rightarrow \quad x = T_{neu} = 33.44^{o}C$$

It is found that the gradient of the regression line (the regression slope) is quite small, and the R^2 value is also small (R^2=0.0021). The *P-value* in this case is 0.16, statistically corresponding to a 16% chance of rejecting the null hypothesis. This indicates that this regressive relationship is not significant. Nicol and Humpreys (2010) suggest that these errors can be the result of both limited data range as well as a small spread of temperatures. As a result it may be difficult to make an accurate estimate of neutral temperature. Furthermore, people also have the ability to adjust themselves, to adapt to the changing environment over time, this means the neutral temperature of today may not be the same for tomorrow. In this case, Nicol and Humpreys suggest using *'Griffiths constant'* as a more reliable method to estimate the neutral temperature from a fairly small sample of comfort votes on a particular day in a particular building (Nicol, Humpreys, 2010).

The *Griffiths constant* expresses the relationship between subjective warmth and temperature and assuming no adaptation takes place; there is nothing changed but the room temperature. The *'Griffiths constant'* method is expressed in the equation below:

$$Tneu = Tg - \frac{C_{ASHRAE}}{G_g} \quad (7.5)$$

Where: *Tneu:* Neutral comfort temperature [°C]

Tg: Globe temperature [°C], in this case it is mean air temperature given in table 7.15, as calculated from table 7.2.

G_g: the *Griffiths constant*, Nicol and Humpreys (2010) suggest using G_g=0.5

C_{ASHRAE}: ASHRAE Comfort votes, as defined in table 7.16 and 7.17

Table 7.15 Mean operative air temperature [°C] of the four surveyed classrooms.

The Dry season	The Wet season	Both seasons
31.56	30.71	31.14

It should be noted that the mean operative air temperature given in table 7.15 is calculated from mean shift temperatures of each classroom, as presented in table 7.2. In the case of Le Van Tam and Lam Son School, the mean shift temperatures of both morning and afternoon shift are considered. In the case of Truong Cong Dinh and Ha Huy Tap School, only the mean values of the morning shift are calculated. The final mean operative air temperature presented in table 7.15 is the average all these shift values.

Because this research and the method recommended by ASHRAE: 55 use different comfort sensation scales (as presented in table 7.16), in order to use the *Griffiths constant* equation as shown in (7.5), the comfort sensation votes of this research are converted to the equivalent ASHRAE: 55 scale (see table 7.17).

Table 7.16 The ASHRAE scale of thermal comfort and equivalent comfort survey scale.

How do you feel at this time ?

	Sensation scale	Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot
Numerical	**ASHRAE:55**	-3	-2	-1	0	1	2	3
	This research	7	6	5	4	3	2	1

Table 7.17 Mean indoor air temperatures and students' mean comfort votes.

	Descriptions	Dry season	Wet season	Both
Site measurement	Mean air temperature [^{0}C]	30.67	30.53	30.40
Students' comfort votes	Mean Vote	3.9	4.3	4.1
	Equivalent ASHRAE vote	0.1	- 0.3	-0.1
Teachers' comfort vote	Mean Vote	5.4	4.7	5.1
	Equivalent ASHRAE vote	-1.4	-0.7	-1.1

Table 7.18 shows the predicted neutral comfort temperature of students and teachers by using the *Griffiths constant* equation (7.5). The students' neutral comfort temperature $Tneu_{student}$ for both seasons is predicted at 31.34^{0}C which is 2.1^{0}C lower than what is predicted by the regressive plotting. The teachers' neutral comfort temperature $Tneu_{teacher}$ is 33.34^{0}C, which is 2^{0}C higher than that of the students.

Table 7.18 Predicted neutral comfort temperatures of students and teachers by using *Griffiths constant* method.

Descriptions	Symbol	Season		
		Dry	Wet	Both
Students' neutral comfort temperature [^{0}C]	$Tneu_{student}$	**31.36**	**31.31**	**31.34**
Teachers' neutral comfort temperature [^{0}C]	$Tneu_{student}$	**34.36**	**32.11**	**33.34**

7.5.2. Findings and theories

This research finds that the neutral comfort temperature for students is at 31.34°C. The neutral comfort temperature predicted by the codes (i.e. TCXDVN: 306, EN: 15251, and ASHARE: 55) is 2-5°C lower and other codes predict that much of the population would be uncomfortable. The comfort surveys indicate that the students are quite good at adapting to the current conditions and the overall responses are fairly neutral. This indicates that the situation in reality is contradictory to what was predicted by the codes. These differences could be attributed to several reasons: the climatic database, the methods of evaluating and calculating and the human comfort adaptation. These issues are discussed in the next sections.

7.5.2.1. Inappropriate database

All of Vietnam's current thermal comfort codes were developed from studies and surveys conducted in climate conditions different to that of HCMC. TCXDVN: 306 (2004) was developed from research conducted in the former Soviet Union, its database was collected from surveys and experiments taken under Russian European temperate climate. The NIPL99 database was developed from a survey of 1000 people living in the rural part of North Delta-Red River area (as described in chapter 3). None of the other independent studies took place in South Vietnam.

The same problem can be seen with EN: 15251 (2004). The database of EN: 15251 (2004) was built from surveys and measurements taken from various sites in Europe (Nicol, Humpreys, 2010). Among these codes, ASHRAE: 55 (2007) is the most reliable one, since its database was collected from worldwide surveys (including Thailand and Singapore, which has similar climate to HCMC). However, several studies show that in a tropic climate people are used to high temperature conditions and they can adapt very well to a higher comfort temperature than what is theoretically predicted by the codes. Therefore, it is quite doubtful whether these recommendations are applicable for HCMC.

7.5.2.2. Adaptive comfort approach

A study conducted by J.F Nicol (2004) shows that people have a natural tendency to adapt to changing conditions within their environment. This study suggests that comfort temperature is a result of the interaction between the subjects and the building or other environment they are occupying.

In Singapore, a survey by de Dear & Leow (1990) examined the indoor climate and thermal comfort of 214 high-rise public housing flats in the new town area. The findings show that the comfort temperature is 29.6° C, which is 1°C higher than what is predicted by theoretical methods (i.e. using ASHRAE: 55 and the ISO: 7730). It also shows that their empirically derived temperature is 2°C higher than the values predicted by the PMV model. In conclusion, the paper supports the idea that there are differences in human responses to temperate climate and tropical climate physically, psychologically and perceptually.

M. Indraganti (2010) carried out another survey in India using the adaptive method for a field study in Hyderabad, India to obtain indoor neutral temperature. The survey was conducted on several naturally ventilated apartments during the summer and the monsoon season and results were based on 3962 responses from building users. The acceptance comfort zone was found to be in the range between 26.0° C and 32.45° C. The upper limit value is much higher than the recommendations of the Indian code. These results show that the residents' responses varied based on their flat location. People in the top floor flats, where the recorded temperature is warmer than lower floors, had higher neutral comfort temperature and lower acceptance vote. In conclusion, this paper found that the occupants' long exposure to high temperature may lead to higher adaptation to high temperature.

In Bangladesh, another thermal comfort study in urban housings was conducted by Fuad H.Mallick (1996). This study shows that thermal comfort is influenced by long term conditioning to high temperatures and humidity, and people are highly tolerant to thermal comfort. They can adapt to a very high temperature and high humidity conditions.

Another interesting study, using the Bedford scale to investigate the impact of gender on thermal comfort responses, was carried out in Kitwe, North of Zambia, during the cool season (June-July) by Sharples and Malama (1997). This study found the neutral temperature to be 22.2°C and the comfort zone between 19.7 °C and 24.7 °C. It presents the fact that both genders, male and female, actually have the same response.

However, other studies carried on buildings located in temperate climate show results which are quite close to the code prediction. In Taiwan, a field experiment on thermal comfort was conducted by Hwang et al (2006) to survey 10 naturally ventilated and 26 air-conditioned campus classrooms. Taiwan, coordinated at 23°46'N - 121°0'E, has a marine tropical climate. The island succumbs to hot humid weather and experiences high humidity, monsoon and rainy season (ROC-Central Weather Bureau, 2006).The survey studied the data collected from 944 individuals from seven universities and 1294 completed questionnaires. The study was based on ASHRAE: 55. They found that neutral temperature is at 26.3°C. The results obtained from direct and indirect assessing methods suggest the acceptable range to be 21.1 – 29.8 °C and 24.2 – 29.3 °C respectively. Furthermore, this field study reveals that the role of humidity is not as important as it was thought to be.

In 2000, a study of thermal comfort was conducted in Japan, a subtropical climate country, conducted by Alison G. Kwok (2003) from Oregon University. Alison G. Kwok used the ASHRAE: 55 and the ISO: 7730 approach to carry out a field survey of 74 Japanese students studying in both naturally ventilated and air-conditioned classrooms. The data was generated separately for naturally ventilated and air-conditioned classrooms. It shows that although the environment of the air-conditioned classrooms falls within the comfort zones, the occupants' sensation votes are *"slightly cool"*. And although the naturally ventilated classrooms are 3° C degrees warmer, they were still be within the occupants voted comfort zone.

All of these studies suggest that the evaluation of thermal comfort cannot simply be based on theoretical lab based results. There are physical and psychological differences in human comfort perception and sensation to climate. Therefore, within the limits of this research, the fact that the students' neutral comfort temperature, found at 31.34°C, seems to be appropriate.

7.5.2.3. Impact of ceiling fan

All of the surveyed classrooms are equipped with ceiling fans. There have been several studies on the effect of ceiling fans on thermal comfort. An experiment was conducted by Rohles et al (1983) on 256 subjects under various temperature and air velocity, in an environment chamber equipped with a ceiling fan. The results show that an air plume from a ceiling fan with velocity between 0.5 and 1.0 m/s compensates for 2.8–3.3°C temperature. Another study by Morton-Gibson et al (1985) suggests that operating fans for about 1000 hours per year at 26.7° C results in approximately the same comfort levels as 24.4 °C (or 2.3°C compensated).

Another research by Son et al (2009) confirms the effect of ceiling fan on enhancement of thermal comfort and the results provide the correlation between Fan air speed and thermal comfort (see figure 7.16). The study explains that "*if the fan is used, strong circulations forced by the fan induces convective heat transfer, that creates more uniform temperature distribution in both sides of the room*" (Son et al, 2009). Therefore, ceiling fans can help to cool the room better, to over-compensate the temperature rise situation by about 2 to 3°C and to adjust users' thermal comfort.

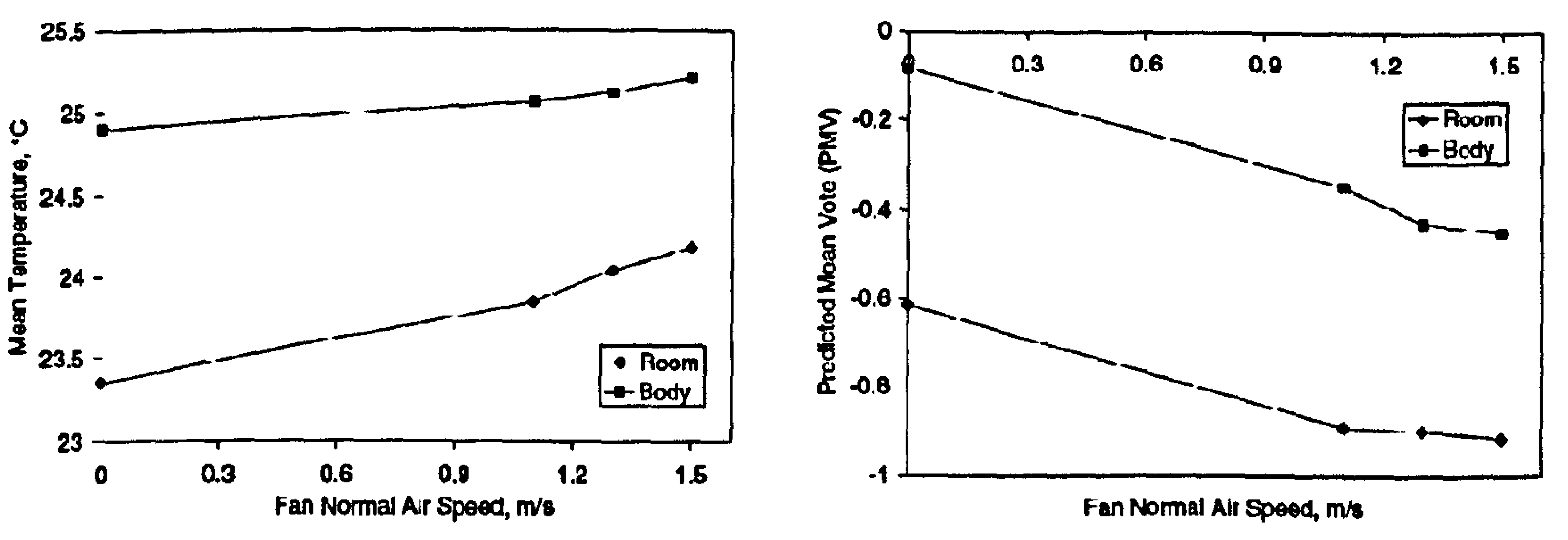


Figure 7.17 Effect of fan normal air speed on mean temperature and Predicted Mean Vote (Son et al, 2009).

In conclusion, it is suggested that ceiling fans compensate for about 2°C off the comfort temperature margins. This means that the actual $Tneu_{student}$ is then reset at 29.34 °C and $Tneu_{teacher}$ at 31.34 °C.

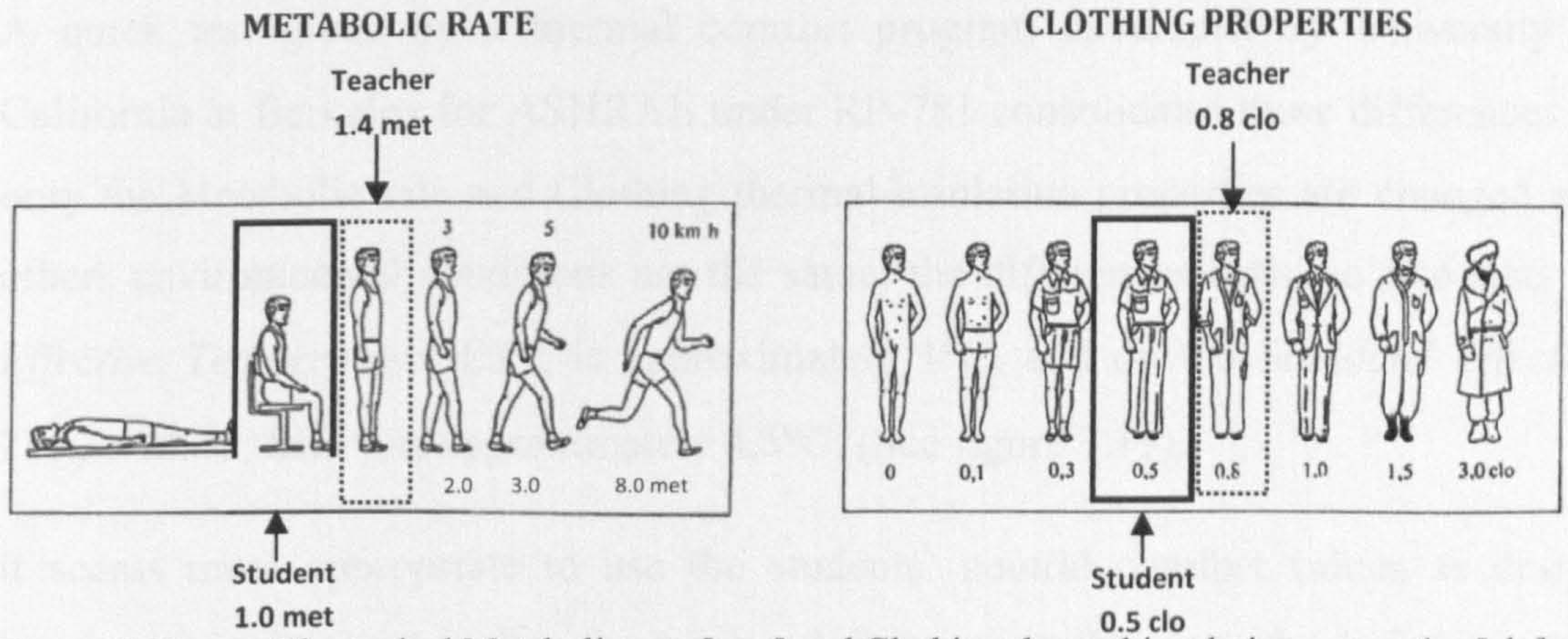


Figure 7.18 The typical Metabolic rate [met] and Clothing thermal insulation properties [clo]of students and teachers in HCMC schools. (Fanger, 1986)

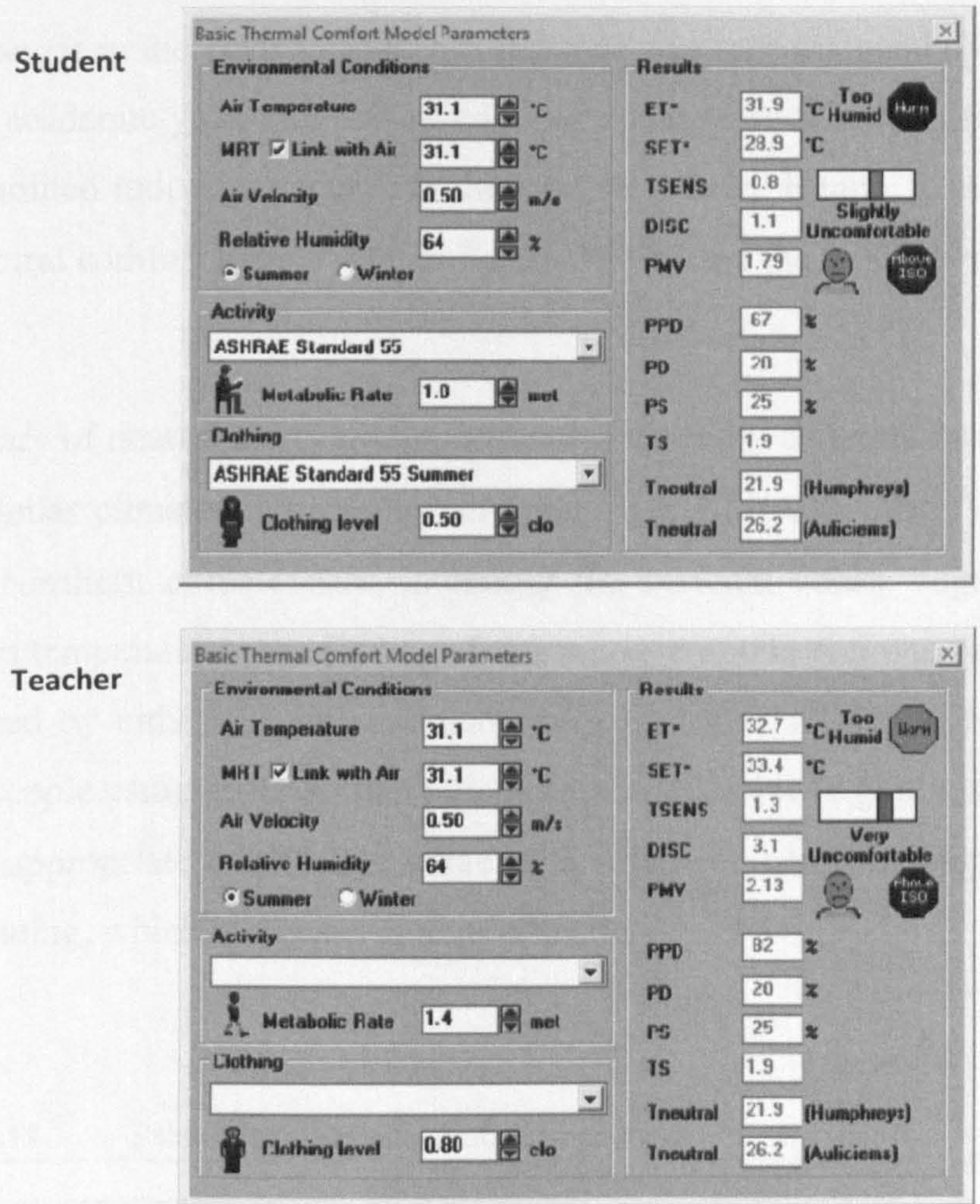


Figure 7.19 Thermal comfort results given by UC Berkeley software.

It is understandable why the teachers' neutral comfort temperature is higher than that of the students. There are two obvious factors that affect their neutral comfort temperature: the *Metabolic rate* [met] and the *Clothing thermal insulation properties* [clo]. As shown in figure 7.18, students and teachers have different Metabolic rate and Clothing thermal insulation properties.

A quick test given by a thermal comfort program developed by University of California at Berkeley for ASHRAE under RP-781 consolidates these differences. If only the Metabolic rate and Clothing thermal insulation properties are changed and others environmental conditions are the same; the differences between two tests on *Effective Temperature*, ET*, is approximately 1°C, and on the *Standard Effective Temperature*, SET*, is approximately 4.5°C. (See figure 7.19).

It seems more appropriate to use the students' neutral comfort values as design benchmark values rather than the teachers', because students are the full time users of the classroom and they have fewer opportunities to adjust and adapt themselves to the changes in the environment. For instance, they are assigned specific seats for the whole academic year, they are asked to wear the same school uniform daily and they have limited individual access to the control system. Hence, it can be assumed that the neutral comfort temperature is *Tneu* =29.3°C and the width of the comfort zone is ±2°C.

Summary of neutral comfort temperatures defined by different methods for Vietnam and similar climates is presented in table 7.19. Although other Vietnamese studies using Northern climate data, including the national codes, suggest lower neutral comfort temperatures, the findings from this research is not much different to what is predicted by either the international codes (i.e. EN: 15251, ASHRAE: 55) or by other people using different methods in similar climates (e.g. Singapore and India). It seems appropriate to use this value as a reference comfort temperature to predict overheating, which is discussed in next section.

Table 7.19 Establishing neutral comfort temperatures [°C] for HCMC.

NEUTRAL COMFORT TEMPERATURE [°C]									
Vietnames codes			International codes			Other studies in similar climate		***This research (HCMC)***	
TCXDVN 306 (air temperature)	NILP 99	Other field studies in the North Vietnam	ISO:7730 (CAT B)	EN:15251 (CAT II)	ASHRAE:55	Indraganti (2009) in India	deDear &Leow (1990) in Singapore	***Regressive plotting***	***Griffiths Constant***
25.5 to 29.5	23 to 25	24.5 to 29.5	24.5±1.5	28.04±3	26.5	26.0 to 32.5	29.6	***33.4 ±2***	***29.3 ±2***

7.6. Predicting overheating potential

Overheating, *OVH* [%] is defined as the percentage of time over the total class hours when operative temperature is higher than the comfort temperature (taking the upper limit of the comfort zone, $T.neu_{max}$). The mean air temperature in the Dry and the Wet season (T_{iD} and T_{iW}) are used as operative temperatures. This means overheating happens when $T.iD$ or $T.iW > T.neu_{max}$. Therefore, overheating is calculated from:

$$OVH = \frac{T_{ovh}}{T_{classhour}} x100\% \quad (7.6)$$

Where *OVH*: Percentage of class hours when the classroom is overheated [%]

T_{ovh}: Total hours when the classroom is overheated [hour]

$T_{classhour}$: Total class hours that the classroom is in used [hour]

In this research, the total class hour $T_{classhour}$ is calculated as total hour of study during the four days of the survey in each season, accordingly to the actual times that each group of students used their classrooms. The T_{ovh} is calculated as the total time when the temperature is higher than the upper limit temperature of the neutral comfort zone during that period. The estimates of *OVH* are presented in table 7.20.

Table 7.20 Estimates of overheating *OVH* [%]

School	Overheating *OVH* [%]							
	TCVN:306		EN:15251		ASHRAE:55		**This research** ***(Griffiths constant)***	
	$Tneu_{max}$=29.5°C		$Tneu_{max}$=31.04°C		$Tneu_{max}$=26.5°C		$Tneu_{max}$=31.3°C	
	Dry	Wet	Dry	Wet	Dry	Wet	**Dry**	**Wet**
Le Van Tam	60	73	50	24	100	100	**45**	**10**
Truong Cong Dinh	64	86	18	52	100	100	**13**	**38**
Ha Huy Tap	85	0	40	0	100	100	**47**	**0**
Lam Son	99	100	88	75	100	100	**83**	**73**

If the *OVH* is calculated from the ASHRAE: 55 (2007) neutral comfort temperature (*Tcomf*), all classrooms are suggested to be overheated in both seasons. If the *OVH* is calculated from the upper limit of the neutral comfort temperature set by this research, $Tneu_{max}$ = 29.3°C+2°C=31.3°C, the results seem to be more concurrent to the results of the users' comfort survey.

The results also show that, although the mean temperature in the Dry season is higher than that in the Wet season, the *OVH* in some cases seems to be lower than that of the Wet season. Perhaps it is the result of the differences on solar distribution during the day in different facades. The East and West façades have higher *OVH* in the Dry season (i.e. Le Van Tam School), while South facing façade (Lam Son School) has similar *OVH* in both seasons.

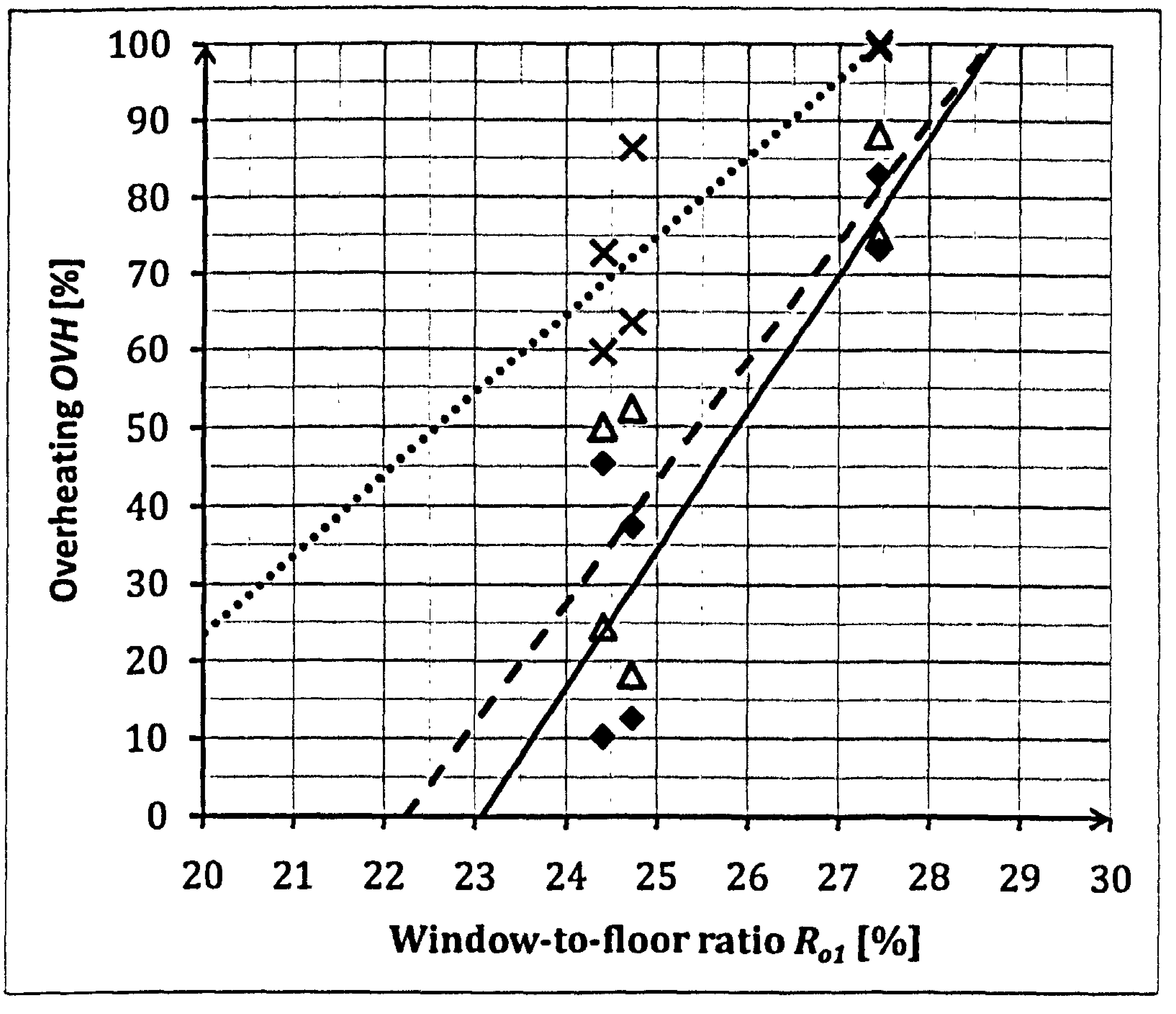
7.7. Overheating and window-to-floor ratio

A factor that is relevant to both daylight access and indoor solar heat gain is the window-to-floor ratio R_o [%], which relates to the proportion of the opening to the geometry of the room. Optimizing this value therefore helps to set the balance between adequate daylight access and acceptable overheating. This discussion attempts to establish the relationship between the window-to-floor ratio and the overheating. The aim is to find an effective window-to-floor ratio that provides adequate daylight access while its thermal consequences, defined by overheating, are still within acceptable range.

Theoretically, solar gain from direct sunlight is the main contributor to overheating the interior environment. Numerous studies address this issue, but very few of them look at the impact of reflected solar radiation and the role of window-to-floor ratio in indoor thermal conditions.

The role of effective window-to-floor-ratio which provides meaningful daylight contribution to the interior has been discussed in chapter 5. However, it is unclear if the same principle is applicable for thermal comfort. Firstly, because there are several mechanisms by that the heat is transferred such as convection, conduction. Secondly, because the window-to-floor ratio also relates to other environmental factors such as natural ventilation and air speeds, which have significant impact on cooling the indoor environment. Currently there are no specific procedures for predicting the thermal comfort impact of windows. (Lyons et al, 2000).

Figure 7.20 shows the initial regressive plotting between the different *OVH* values defined by different methods to the actual window-to-floor ratio Ro_1 (as defined in table 5.20, section 5.5.2 of chapter 5). Data of Ha Huy Tap School is excluded due to the errors caused by the wooden louvers.



KEY

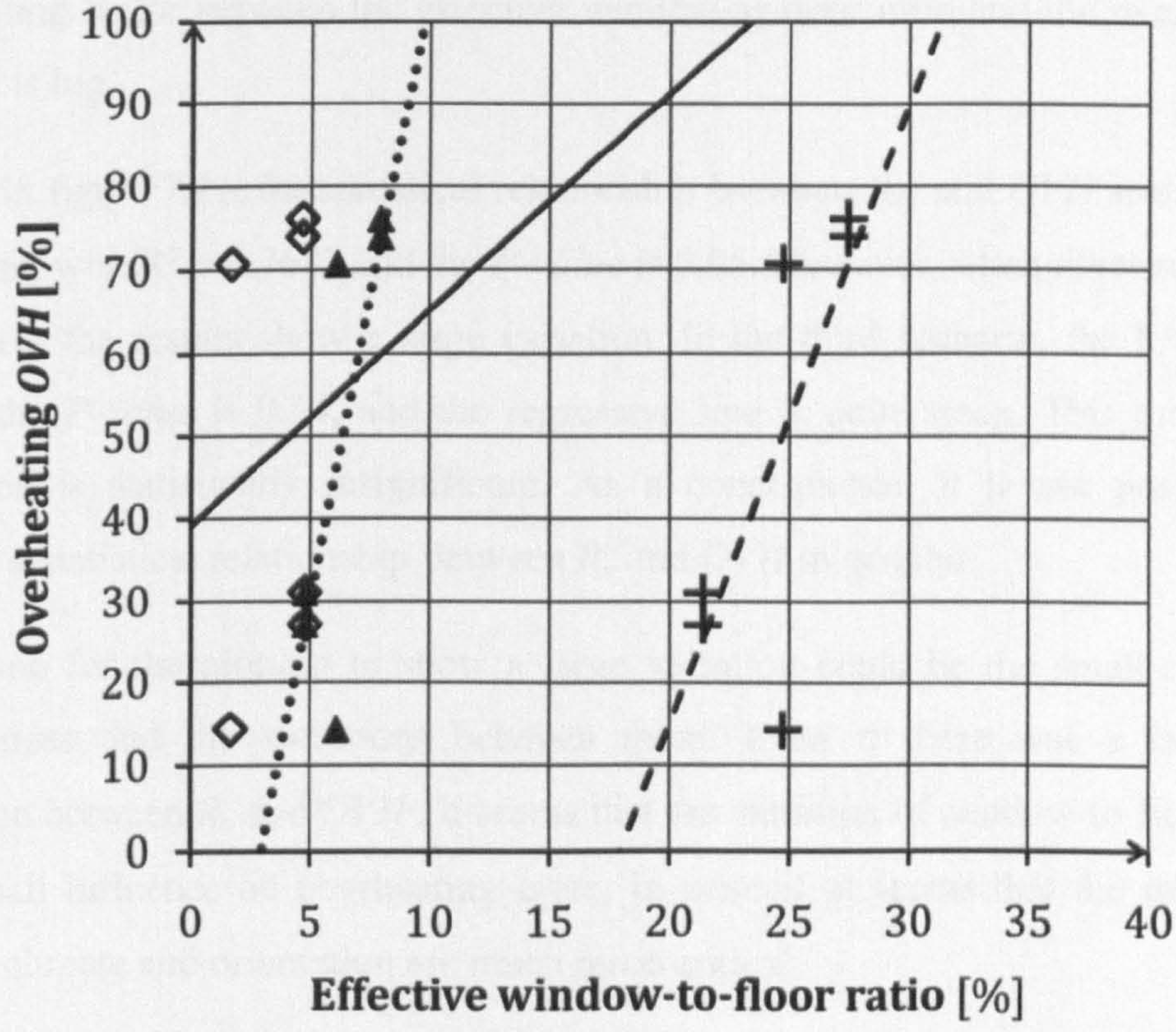
Code	This research	TCVN:306 (2004)	EN:15251(2004)
Neutral temperature	$Tneu_{max}$=31.3°C	$Tneu_{max}$=29.5°C	θ_{max}=31.4°C (CAT II)
Data symbol	◆	×	Δ
Regressive line	——	•••••	- - -
Equation	y = 17.767x - 409.88	y = 15.585x - 346.51	y = 10.307x - 182.79
Coefficient of determination, R^2	R^2 = 0.7687	R^2 = 0.7209	R^2 = 0.7587

Figure 7.20 Regressive graph of the window-to-floor ratio R_{o1} [%] and overheating *OVH* [%]

In this plotting, data presented in the graph suggests that:

$$OVH = 17.767 \times R_{o1} - 409.88$$

If the effective R_{o1} is 25%; the overheating percentage OVH is approximately 34%.



Scenario	1	2	3
Effective window-to-floor ratio	R_{o1}	R_{o2}	R_{o3}
Effective opening area	A_w	Overhang A_w	Overhang A_w Obstructions
Data symbol	+	▲	◆
Regressive line	— — — —	• • • • •	———
Regressive relationship	y = 17.767x - 409.88	y = 16.818x - 62.41	y = 8.5414x + 11.824
Coefficient of determination, R^2	$R^2 = 0.7687$	$R^2 = 0.6178$	$R^2 = 0.2017$
P-value	0.05	0.08	0.54

Figure 7.21 Regressive plotting of different effective window-to-floor ratios R_{o1}, R_{o2}, R_{o3} [%] and potential overheating OVH [%] defined at the neutral temperature $Tneu_{max}=31.3^{o}C$ (finding of this research)

Following the discussion in section 5.5.2 of chapter 5, it is important to review other scenarios where the overheating potential *OVH* (at $Tneu_{max}=31.3^oC$) is plotted against different effective window-to-floor ratio R_{o1}, R_{o2}, and R_{o3} . It should be noted that scenario 3 and 4 (as in section 5.5.2 of chapter 5) are similar in this case The R_{o3} represents the realistic daylight access conditions, but it is unclear if the confounding factor between the effective window-to-floor ratio and the overheating potential is big.

As seen in figure 7.21, the statistical relationship between R_{o1} and *OVH* seems to be significant, with $R^2 = 0.7687$ and the *P-value* is 0.05. However, when other scenarios are plotted, the results show a large variation. In the third scenario, the R^2 is only 0.2017, the *P-value* is 0.54, and the regressive line is quite steep. This means the correlation is statistically insignificant. As a consequence, it is not possible to establish a statistical relationship between R_o and *OVH* in general.

One reason for the plotting to show a large variation could be the small range of sample sizes and the variations between them. Even if there was a statistical correlation between R_o and *OVH*, it seems that the variation of window-to-floor ratio has a small influence on overheating issue. In general, it seems that the impact of seasonal climate and orientation are much more critical.

7.7. Conclusions

The site measurement shows that the classroom thermal conditions in the Dry and in the Wet season are 1°C to 3°C different, and the temperatures recorded on site are +3 to +4°C higher than the comfort temperatures recommended by Vietnamese codes. This indicates that the classroom is overheated. Several popular methods introduced by international codes are also employed to define the range of comfort temperatures. Each method suggests different comfort temperatures. The U.S. code ASHRAE: 55 (2007), which was developed from a worldwide database including hot and humid climates, suggests that the surveyed classrooms are overheated most of the time.

However, results from the users' comfort survey presents that users feel *"slight discomfort"* under these conditions. This survey also shows that there are differences in comfort preferences between student and teachers. Adaptive comfort approach suggests that users are able adapt to the changes of environment over time, and the comfort state is a result of the interaction between the subjects and the building or any other environment they are occupying.

Further analyses using regressing plotting method and the Griffiths constant method suggest that neutral comfort temperature for HCMC classroom is approximately 29.3°C and the width of the comfort zone is ±2°C. These findings suggest that there are differences between the values predicted by methods developed from lab-based experiments and what happened in reality.

This study attempts to establish a relationship between window-to-floor ratio and its corresponding overheating potential for classrooms in HCMC. This information is particularly useful for defining an optimal window-to-floor ratio which provides adequate daylight access and acceptable solar heat gain. However, due to limited data ranges, the confound factor between these two variables is small and it is not possible to confirm a statistically significant correlation between these two factors. In general, the results collected from the field survey indicate that there potentially is a statistical relationship between R_o and OVH, but it seems that the variation of window-to-floor ratio has a small influence on overheating issue.

Chapter 8

Summary of findings and implications

8.1. Introduction

It is necessary to summarize the significant findings and implications that have emerged from this research as all the reviews, analyses and discussions are immersed within the body of the research. These findings are summarized and presented in this chapter.

This research reveals that there may be existing problems in the current classroom conditions that would have to be considered. It should be noted that the actual conditions are usually very complex and improving visual and thermal comfort in a classroom should not be dependent on architectural design solutions alone.

8.2. Current conditions: advantages and challenges

8.2.1. Advantages

Education identified as one of the key factors for the sustainable development of Vietnam, has been well established for a considerable period of time. This can be seen by the fact that the first Vietnamese university was founded in the 11th century. School systems have been established in HCMC since early 20th century. Because HCMC is the most important financial centre of the country, HCMC schools receive better investment than other parts of the country. Moreover, environmental friendly school design is currently receiving increased public attention. Thus, it seems that schools in HCMC receive the best available resources and support than anywhere else in the country.

Although it is a young city with just over 300 years of history, HCMC has a rich social and cultural background blending with the different layers of history. Several types of architecture with influences from different cultures can be seen around the city. Some of them are the finest examples of architecture adapting to and integrating with local characteristics; and these are the features that should be absorbed and brought into future school design, including classroom lighting design.

HCMC has a regional strategic position with geographical advantages. Buildings in this populous metropolitan city share the same type of terrain of flat land area, 5 to 10 m (62 ft) above sea level, connected by an extensive network of canals and rivers. The city enjoys a tropical monsoon climate divided into two distinct seasons: the Dry season and the Wet season. The climatic conditions are quite stable and therefore, simple and similar design parameters can be applied for a large area

There is high availability of daylight. Average annual direct solar radiation is 717 W/m^2 and annually there are 2497 sunshine hours, 8 days of clear sky, 267 days of half cloudy and 90 days of cloudy skies. During working hours (from 9h00 to 17h00), overall daylight often exceeds 10klx. Because of its proximity to the equator, buildings enjoy good access to daylight at both the North and the South facade. Thus, there is a very good potential for using natural daylight in classrooms.

8.2.2. Difficulties and challenges

Vietnam has been in wars for nearly half of the 20^{th} century. Wars not only devastate the infrastructure of the country including school buildings but also are responsible for holding back the development of school design. Before 1990, very little resource was prioritised for building schools; most of the schools in HCMC that were built during the 60s-90s are low budget buildings. These schools were built to accommodate the increasing number of students rather than for quality. For many years schools and classrooms have been designed and built without taking into consideration local characteristics and demands, and neither have they been designed to provide any inspirational atmosphere for the teaching-learning activities.

Although the city's recent economic success has provided more capital for building better classrooms, it has also lead to the redevelopment of urban settings. As a result other commercial interests often compromise classroom lighting. This means higher plot ratios; tall and dense neighbourhoods reducing daylight access and creating urban heat islands; air and noise pollution intrusion from crowded streets. The rapid growth of the urban areas has put a strain on the city's inadequate infrastructure. Schools are often overcrowded and thus the quality of educational environment is compromised. Hence these can be considered as the modern challenges for school classrooms in HCMC.

Studies and reports show that the current methods of learning and teaching delivery require critical changes to meet the new challenges. It has been reported that plans are being made to amend them in near future (Youthnews, 2008). The development of technologies also changes the way of studying. More media equipments, such as screen projectors, computers and personal laptops, will be brought in. This means that writing and reading will not be the main activities. Architecturally, the foreseeable changes in teaching and learning methods will definitely have an impact on classroom design and thus requiring changes in lighting design as well.

Although the city has a rich daylight resource, there is a marked lack of extensive research on the daylight climatic data. There is also lack of specific design guidelines. The only available useful design guidelines are the national codes, which were modelled after the former Soviet Union codes and mostly use the climatic database of the North Vietnam regions and other countries with temperate climate. Applying this data for HCMC may mean that the daylight contribution could be underestimated; and thus the thermal comfort could be worsened. Most of the established daylight literature e.g. American and European codes are for temperate climates. They are developed for different climatic and cultural conditions, and thus they may not be appropriate to be adopted in Vietnam. Hence a knowledge gap has been identified in daylight literature with regards to the Vietnamese climate.

Similar problems are found in the current Vietnamese thermal comfort codes, which adopted methods derived from former Soviet Union codes which use data base of different climate. The only code that has developed from data base of similar climate (e.g. Bangkok and Singapore) is the U.S code ASHRAE:55 (2007), but the findings from this research suggests that this code also does not predict accurately the users' thermal comfort preferences.

8.3. Theories and findings

This research indentifies issues in the current literature that may be particularly pertaining to HCMC schools. It also reveals some critical findings that have not been addressed in current literature. They are presented below.

8.3.1 Traditional architecture and daylight strategies

Wars, budget constraints and low public awareness are just some of the difficulties that have held back the development of school design in HCMC for many years. It can be seen by the fact that very little of the city's rich cultural background and new innovations in design and technology are integrated in the city schools, until recently. There is a gap between the traditional school architecture (before 19^{th} century) and the modern school architecture. Modern school and classroom design, particularly in HCMC, is moving away from traditional design. However, with the changes in educational methods particularly the introduction of westernized teaching systems, the traditional school architecture does not seem appropriate for modern standardized teaching-learning activities. But some features from traditional architecture perhaps may still useful in modern architecture.

8.3.2 Findings and current literature

A. The current classroom lighting codes require revision. This study finds that there are several probable problems in the current codes which are conflicting and inappropriate for modern classroom lighting, particularly for classrooms in HCMC.

- The current relevant classroom lighting codes are outdated. They were published in the 80-90s. Many of their recommendations are not feasible or no longer valid in real practice. Recent innovations in construction and teaching methods and the use of modern equipments and technologies are also not addressed in the code.
- There are conflicts in the recommendations set by the codes. This arises initially from the fact that different codes are issued by different government institutions and there is a lack of coordination between them. The second reason perhaps is due to historical context. Most of the relevant Vietnamese codes were developed from climatic data based on the Northern regions which were then historically applied for the South after 1975. Before 1990, the design codes were often modelled after the Soviet Union codes and after 1990, the codes were based on the codes of the U.S and Western European countries (e.g. TCVN: 09: 2005).
- The definitions, descriptions, methods of testing and further details are not well and clearly defined. Some critical design factors (e.g. effective window area, window and shading properties and room geometry indices) are poorly described. Hence they can be quite confusing and difficult to verify both in initial design stages and in the implementation. This could lead to inappropriate interpretations and variations.
- The recommendations set by the codes are not user-friendly. They are too technical in nature and do not take into consideration the regional differences and the impact of local, social and cultural context e.g. the users' adaptation, local traditions and availability. Particularly, in dense and populous urban areas like HCMC, it is found that many recommendations are not feasible.

B. The current daylight calculation methods are not appropriate. Firstly, most of the established literature is for temperate climates. Secondly, HCMC, being a populous metropolitan city, is a special case that requires more specific recommendations. Critical problems have been found in:

- Inappropriate climatic daylight database. This is seen in the inappropriate choice of sky type, sky design values and also daylight design strategies. The current Vietnamese daylight code uses the overcast sky model which sets the design sky at 4000 lux. The review of HCMC climate shows that during daylight hours, the external daylight normally exceeds 10 000lux (see section 2.3.3 of chapter 2, page 16-21) Sunny climate is quite dominant and even during the Wet season there are considerable hours of sunlight intervals. However, sunlight is excluded in the daylight code. As a consequence, the potential of using daylight in classrooms is underestimated and there is risk of the classroom being overheated.

- Inappropriate daylight estimation methods. First, the current method is technically complicated and not user-friendly. It employs too many manual calculation steps and coefficient factors. Second, and the most critical, the method underestimates the role of external obstructions and thus it is not able to accurately predict the daylight contribution in a complex urban context like HCMC. For instance, trees have an important influence on the urban daylight context, but they are not addressed in the codes.
- The common daylight factor approach, from which most of the current daylight codes including Vietnamese codes are derived, does not seem appropriate for a tropical sunny climate. This method is developed for cloudy skies in temperate climates and there are limitations when it is applied to a sunny climate. This is particularly important as it excludes sunlight and underestimates the contribution of ground reflected light and also in all the calculations (e.g. *ĐRASTN*, Danhiluc chart, Waldram diagram and *BRE ADF*). The most critical finding is that external reflected light (from both sky and sunlight), plays a significant role in classroom illumination. As seen in figure 8.1, reflected light contributes up to 68% of the daylight received at the outer surfaces of the window. Particularly, when the school is heavily obstructed, a common situation of a dense metropolitan city, reflected light plays a critical role. Moreover, ground reflected light, which is often underestimated in current codes, has a major influence on classroom illumination (see section 5.5 of chapter 5, page 219-236). The estimates of average contributions of each of the daylight component are presented in table 8.1. These contributions vary depending on the time; at peak time in the Dry season reflected sunlight may contribute up to 48% of the total light. Furthermore, the daylight factor approach is based on simple average cloudy

sky situations. The results from this research show that in HCMC there are significant differences in the sky conditions between the Dry and the Wet season and therefore maintaining a stable indoor comfort is a challenging task.

Table 8.1 Average estimates of contributions from each daylight component received at the window vertical external surface. These percentages describe the balance between the different components. These are the mean estimates in both seasons from daily values recorded from 9h00 to 16h00. It should be noted that, as the position of the sun changes, these values vary during the day.

Daylight component received at window's external surface	School: Le Van Tam			Truong Cong Dinh			Ha Huy Tap			Lam Son		
	Dry	*Wet*	*Average*	*Dry*	*Wet*	*Average*	*Dry*	*Wet*	*Average*	*Dry*	*Wet*	*Average*
Direct light from sky	51%	79%	62%	21%	28%	24%	39%	86%	53%	31%	45%	36%
Reflected light received from sky	11%	17%	14%	50%	68%	58%	3%	7%	4%	0%	0%	0%
Direct sunlight	20%	0%	12%	21%	4%	14%	11%	8%	10%	55%	42%	50%
Reflected sunlight from ground	18%	4%	12%	0%	0%	0%	0%	0%	0%	14%	13%	14%
Reflected sunlight from buildings and trees	0%	0%	0%	8%	0%	5%	48%	0%	33%	0%	0%	0%

Table 8.2 Average estimates of contributions from direct and reflected daylight components. These percentages are another interpretation of the results presented in table 8.1 and they describe the balance between the direct and reflected component. These are the mean estimates in both seasons from daily values recorded from 9h00 to 16h00. It should be noted that, as the position of the sun changes, these values vary during the day.

Daylight component received at window's external surface	School: Le Van Tam			Truong Cong Dinh			Ha Huy Tap			Lam Son		
	Dry	*Wet*	*Average*	*Dry*	*Wet*	*Average*	*Dry*	*Wet*	*Average*	*Dry*	*Wet*	*Average*
Direct daylight components	71%	79%	74%	42%	32%	38%	49%	93%	63%	86%	87%	86%
Reflected daylight components	29%	21%	26%	58%	68%	62%	51%	7%	37%	14%	13%	14%

C. The visual comfort in classrooms is poor, mostly due to design faults. Problems are found in the effectiveness of artificial light system, spatial brightness distribution and glare.

- The artificial light system does not work effectively both in terms of providing adequate visual comfort and being energy efficient. The low effectiveness comes from several minor errors due to the design as well as operation. Critical problems are found in the luminaire optical control, the layout and mountings and control strategies.
- The spatial brightness distribution receives very little attention from the design aspect. It is found that the interior lighting scheme is not inspiring for learning-teaching activities. This problem appears due to underestimation of the contribution reflected light, ineffective artificial lighting system and very little integration between lighting and architectural design (e.g. choice of finishes, room layout, coordinating details). It has also been found that the users prefer higher vertical illuminance than what is predicted by common guide lines. The brightness ratio between the surrounding and the task area can be as high as 1.1.
- Glare from artificial light poses a great threat to visual comfort. Glare from daylight, although theoretically is quite high, seems to be much more tolerable in practice.

D. It is found that the users' preferred visual comfort conditions may be different to what is predicted by the current codes. This study indicates that evaluation of comfort cannot simply be based on theoretical lab results. Adaptive approach should be taken into consideration, because there are physical and psychological differences in human comfort perception. Some critical findings are:

- The users' comfort survey shows that that 55.5% of the students and 37.0% of the teacher are not satisfied with the current visual conditions (see section 6.6 and 6.7 of chapter 6). This percentage varies for each school and depending on the task that the users carry out. The users can adapt well to the changing seasons and this is evident from the fact that comfort votes in both the seasons seem to be similar despite differences seen in numeric measurement.

- It is revealed that users prefer a brighter classroom. The visual comfort votes are more moderate in the schools which seem to be over lit. The students prefer a slightly higher task illuminance than what is commonly recommended. Their preferred task illuminance is found as 362 lux while the teachers prefer a much higher value of 557 lux. Overall, students seem to be more adaptive and they can cope better to a wider range of variations than the teachers. For every 10-15% improvement on task illuminance, the students' productivity rate also improves by 5-7%, but this correlation is only valid within a given range. If light is increased or decreased too much, the productivity rate drops. However, the relationship between change of daylight and the rate of productivity of the teachers is not clear. It seems that teachers prefer a stable environment lit by artificial light rather than changing daylight situation (see section 6.6 and section 6.7 of chapter 6).

E. The current thermal comfort codes also require revision. There are similar problems to what has been found in the lighting codes:

- They are out dated.
- They are not user-friendly. The calculation of neutral comfort temperature requires professional equipments and it is not a straight-forward process. The process requires calculations that have to refer to many other design coefficient factors, which can only be obtained from several tables of values. They complicate the design progress in the early stages and thus reduce opportunities of developing a good design scheme.
- They use inappropriate database which is not applicable for HCMC climates.
- The common thermal comfort prediction methods are also not applicable in many criteria (e.g. most of the time HCMC would be classified as "hot season" and there is no such considerable "cold season" period as per definition by the Vietnamese codes)

F. It is found that the thermal comfort parameters set by the code are not applicable for HCMC case, mostly due to differences in the climatic database used in the Vietnamese codes. Other common prediction methods, e.g. EN15251, ASHRAE: 55, are also employed to estimate the appropriate neutral comfort temperature for an

HCMC classroom. However, this study finds that the neutral comfort temperature for HCMC in practice is $2^{0}C$ to $5^{0}C$ higher than what is theoretically predicted.

8.4. Findings and implications

In the light of the findings presented above, the following are the recommendations proposed for improving classroom lighting design in HCMC:

A. It should be noted that a classroom is not a standalone object in a void space. The external context has a large influence on the internal environmental quality. Moreover, how school classrooms are used and operated in reality is also important. Standard classrooms were originally designed for 40 students in one shift. In reality 50-55 students, which means 20-30% overcrowded than original designed capacity, are accommodated in one typical 7.2 x 7.2m classroom and two classes or even three classes have to share the use of same room at different times. As a consequence the original comfort parameters are compromised (e.g. difficulty in maintaining stable visual and thermal conditions in all study shifts due to constant change of the external conditions and poor air quality and overheating due to being overcrowded). These issues suggest that the theoretical comfort parameters should be more flexible and have greater tolerance. Designers should investigate the real operating conditions to define the design strategies and comfort criteria more appropriately.

B. In a tropical climate, reflected light, particularly reflected sunlight from the ground and buildings, has significant influence on interior illumination. Therefore, external landscapes, particularly in an urban space, should be examined carefully in a daylight design. In light of this finding, especially for HCMC climate, it is suggested that optimal daylight strategies should be designed according to the sunny conditions to minimize the threat of overheating, with the compromise that artificial light provides supplement during the rainy season.

C. There should be two separate sets of task illuminance: one for the student desk areas and one for the teaching station. Particularly, task illuminance at student desk should be slightly higher than the code and should be approximately 350 lux. Teaching station should be lit at 550 lux.

D. Daylight-artificial light linking control system should be installed in classrooms for the benefit of both visual comfort and energy saving. Artificial light should be grouped in zones and should be flexibly controlled and dimmable according to the daylight availability.

E. Based on the results found from this research, It is proposed that the effective window-to-floor ratio for HCMC classrooms should be 10% for adequate daylight, the details of how these values are derived are given in section 5.6.2 of chapter 5.

F. This study suggests that a classroom can be naturally ventilated and that the air-conditioners are not necessary. This recommendation is meaningful both in terms of energy saving and also in terms of the air quality and hygienic conditions of the classroom.

G. It is recommended that the neutral comfort temperature for HCMC classroom should be 29.3^{0}C and the width of the comfort zone be ±2^{0}C. This research reveals that for a temperature change of 2^{0}C interval, the students' productivity rate changes by 7.5% accordingly (see table 8.3, further details are discussed in section 7.4 of chapter 7, page 340-356).

Table 8.3 Establishing neutral comfort temperatures for HCMC.

NEUTRAL COMFORT TEMPERATURE [^{0}C]									
Vietnamese codes			International codes			Other studies in similar climate		*This research (HCMC)*	
TCXDVN 306	NILP 99	Other field studies in the North Vietnam	ISO:7730 (CAT B)	EN:15251 (CAT II)	ASHRAE:55	Indraganti (2009) in India	deDear &Leow (1990) in Singapore	***Regressive plotting***	***Griffin Constant***
25.5 to 29.5	23 to 25	24.5 to 29.5	24.5±1.5	28.04±3	26.5	26.0 to 32.5	29.6	***33.4±2***	***29.3±2***

8.5. Further implications

The contributions of this study have value beyond the particular case of school buildings in HCMC.

A. A large part of the research is based on an adaptive approach, with real data, real conditions and real responses from actual users. Therefore, these results are much better at predicting neutral comfort parameters, particularly the thermal comfort criteria, than those based on lab experiments. The results can be used as a good and reliable reference for further studies in this field.

B. The results from this research can be applied to other types of buildings which have similar functions, for instance, office buildings. Particularly, the recommendations on effective window-to-floor area and neutral comfort temperature can be used as effective design indicators for many other types of buildings.

C. This research can be very useful, because much of what is described in this study can be related to conditions in many other parts of South-East Asia. For instance, Cambodia and Laos share similar historical context of the 20^{th} century. Climatic conditions in HCMC are similar to other South-East Asian metropolitan cities such as Jakarta (Indonesia), Bangkok (Thailand) and Manila (the Philippines).

D. This research also benefits other fields of studies, for instance, studies in urban planning and energy efficiency. Furthermore, it can be useful not only in architectural and engineering fields, but also in the area of social science studies (e.g. statistical surveys, researches on teaching-learning methods, researches on education). It is also useful for the study in education managements at school and city level, for research in health and safety and in many other indirectly related fields.

8.6. Limitations of this research

The availability of equipments and resources, permissions from relevant authorities and time scale of the PhD restrict the outcome of this research. The following are some of the limitations:

A. The results are generated from analyzing data collected from groups of samples, so that they cannot cover all the specific cases in actual practice.

B. The availability of data is limited, and some analyses have to be dependent on data provided by external sources, such as sky illuminance and outdoor temperature.

C. In some cases, the context has been simplified without significantly altering the results, to be able to analyze the data within acceptable accuracy and affordable resources.

Chapter 9

Conclusions

9.1. Results and goals

Three specific goals were set at the beginning of this research to provide the basis for answering the research question. These goals have been well addressed in the body of the research:

i. The first goal of this research is to provide an in-depth review of factors that may have major impact on the visual comfort quality of school classrooms, particularly within the relevant context of HCMC. This issue has been well addressed through the extensive review of existing background and literature of classroom lighting in HCMC.

- An in-depth review of classroom lighting settings seen from several perspectives is presented in chapter 2. This chapter presents the natural settings for HCMC classroom lighting, which is the foundation for the technical literature on classroom lighting. The chapter also describes the social settings illustrating how classroom lighting is positioned within civic life and civic and/or national policy which are the foundations for the development of classroom lighting in the present and also for the future.
- Chapter 3 then presents an extensive review on the current literatures on classroom lighting and its thermal comfort consequences. It describes how these

literatures are derived, summarizes relevant recommendations and defines their applicable domains. And on the basis of this, potential incompatible issues that need further review when applied in HCMC are identified.

- The development of school design in HCMC, which is a city with several layers of architectural history, is then briefly discussed in chapter 4. This chapter further provides an overview and comparison of current schools and classroom types, e.g. how they have been built, how technical and social factors have influenced school classroom design, what the current conditions are in the light of results from users' comfort responses.

These three chapters have addressed the issue adequately thus accomplishing the first goal.

ii. The second goal is to provide an evaluation of classroom lighting and its thermal comfort consequences and based on the results from this evaluation, potential conflicts and problems are indentified. This goal is addressed in chapter 5, chapter 6 and chapter 7.

- First half of chapter 5 identifies the main mechanism of classroom illumination and from this discussion critical problems and conflicts are revealed. It is discovered that reflected light plays a significant role in interior illumination and that the existing daylight assessing method introduced by the Vietnamese codes, largely derived from studies in temperate climates, is incapable of providing accurate predictions.
- Further assessment on visual comfort is discussed in chapter 6. The first half of this chapter provides the evaluation of important criteria of visual comfort in keeping with existing literature. It is found that poor visual comfort in classroom environments is the result of several minor design errors. The second half of this chapter presents the visual comfort evaluation as assessed by the users, particularly how comfortable they feel and what their preferences are.
- The evaluation of thermal comfort is provided in the first half of chapter 7. The evaluation is done using the same approach as done in chapter 6. First, the current conditions are assessed using the comfort criteria set up by the relevant codes. They are then evaluated by the users.

These three chapters provide in-depth analyses covering all the important issues and findings are described in details. These evaluations are meaningful for establishing appropriate design parameters for best classroom lighting in HCMC. The second goal is therefore accomplished.

iii. The third goal is establishing a simple design indicator and providing suggestions for improving current conditions and establishing initial literature for developing classroom lighting design guideline for secondary schools in HCMC. This issue is addressed in the last section of chapter 5 and it is furthered discussed in chapter 7 which presents the results generated from the field comfort surveys. A simple design indicator, identified as effective window-to-floor ratio that provides adequate daylight within acceptable thermal comfort conditions, is established. Some suggestions for improving current conditions are integrated within each analysis, and presented in the core chapters of the research. All the findings and specific recommendations are summarised in chapter 8, and therefore the third goal is accomplished.

In the light of these discussions, the answer to the research question is:

There are prospective indicators suggesting that students and teachers are not visually and thermally comfortable. However, the users seem to adapt to the current conditions with great tolerance. The conditions in reality are very complex and thus it is difficult to evaluate "comfort" quality using simple numeric measurements. It should be emphasized that the nature of 'human comfort' is a cultural and social desideratum that pertains to the climate and physical and psychological behaviour of the people.

9.2. Recommendations

Following from the findings presented above, some important recommendations are outlined below:

A. Since there are seasonal climatic differences and these affect the environmental conditions of the classrooms, it is suggested that the study curriculum should be scheduled accordingly to take advantage of this fact and improve users' comfort satisfaction.

B. Both the current Vietnamese and other popular daylight calculating methods for classroom lighting are not capable of providing accurate predictions for classroom lighting in HCMC. Particularly, it is found that the daylight climatic data used in the current codes is not appropriate and classroom lighting in HCMC requires specific design guideline.

C. It is found that reflected light has a major influence on interior illumination, not only on task illuminance but also on spatial brightness distribution. Particularly in a tropical urban space with dense neighbourhoods, the contribution of reflected sunlight is significant. Reflected sunlight also has considerable impact on thermal comfort conditions but it is underestimated in the current daylight calculation methods.

D. It is recommended that the effective window-to-floor ratio should be 10% for classrooms located in HCMC. This ratio is established as a premise for providing adequate daylight for most of the time yet also takes into consideration acceptable overheating from solar gain.

E. It is found that students and teachers have different visual comfort preferences. The classroom lighting code should therefore establish individual recommendations for the students' desk areas and the teaching station. It is found that the users prefer higher vertical illuminance due to not only better visual comfort harmony but also that it fosters the learning-teaching activities.

F. Neutral comfort temperature for a classroom in HCMC has been found to be at 29.3°C and the comfort zone width is ± 2°C. It is also recommended that adaptive approach should be the foundation for thermal comfort design strategies.

9.3 Suggestions for further research

Several recommendations for further research are outlined:

A. Establishing reliable database for daylight climate in HCMC

At the time when this research took place, there was very little useful data for daylight design in HCMC. Future studies can focus on establishing the climatic data of daylight availability and determination of appropriate sky type and design sky value for HCMC.

B. Developing appropriate daylight predicting method for an HCMC classroom

HCMC is characterised by specific climatic conditions, urban influences and social cultural diversity. It is necessary to develop an appropriate and effective daylight predicting method for buildings in HCMC.

C. Conducting visual and thermal comfort surveys on larger populations to establish appropriate design parameters for classroom lighting in HCMC

Studies on a larger scale with higher number of samples and population should be done. The findings would therefore have better validity and would also be able to cover specific issues better. The results from these surveys can help to establish appropriate comfort parameters for classrooms in HCMC.

D. Research on new strategies and technologies for classroom lighting

There is a lot of potential for research in the area of new technologies and strategies, for instance studies on developing effective shading devices and controlling systems; researching new materials for glazing, blind and insulation; designing new types of light sources.

E. Cross-studies on daylight and other environmental factors

It is seen that there are quite a few cross-field researches that take into consideration the correlation of daylight and other environmental comfort factors, for instance between daylight benefit, natural ventilation and acoustic quality. Further research can be done in theoretical literature, in field survey, or even in developing effective modelling software which is able to analyse daylight and other environmental factors together.

9.4. Conclusions

This research has provided a complete overview of the conditions of the HCMC school classroom lighting and its thermal comfort consequences. Critical problems have been identified and recommendations have been proposed.

In summary, this research has achieved all the aims and goals that were set at the beginning of the research. It has established meaningful knowledge contributing to the literature of lighting and thermal comfort in classrooms, and this knowledge is also useful for studies in other types of buildings and other fields of study.

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Appendix A

Description of the field study
Site measurements and Comfort survey

The field investigation consists of three surveys: the physical measurements, site documentation and the users comfort survey. Four secondary schools that participated in the surveys are: Le Van Tam (LVT), Truong Cong Dinh (TCD), Ha Huy Tap (HHT) and Lam Son (LS). These schools are all located in the Binh Thanh District, Ho Chi Minh City.

A.1. Physical Measurements

These measurements were set to measure physical data at the sites: Illuminance [lux], Air temperature [°C], Relative humidity [%] and CO2 concentration [ppm]. However, the data obtained of CO_2 concentration was not used later in the analysis. These measurements were set to obtain the operative data for classrooms of four secondary schools in Binh Thanh District, Ho Chi Minh City.

Two site visits were required for each surveyed school: one during the Dry and one during the Wet season. The first visit was made between February and April of the Dry season of 2007 and the second visit was made between September and November of the Wet season of 2008. The survey had to be extended to two years due to the limited accessibility granted, time and equipment availability and capacity.

A.1.1 Measurements taken

In each school, environmental monitoring equipments were installed in one selected classroom to measure its operating conditions continuously. There were two main measurements processed at these selected classrooms:

a. Continuous monitoring of environmental conditions by mounted monitoring devices
b. Immediate measurements by portable devices.

A.1.1.1. Continuous monitoring of environmental condition

There are three positions (called P1, P2, and P3) in the classroom where the environmental conditions were recorded (see figure A.1).

- P1: to measure external conditions, lighting only (illuminance level). The position of P1 is at 2 metre high from the classroom floor, vertically in the external wall.
- P2: to measure internal conditions, including lighting (illuminance level), air temperature and relative humidity and CO_2 levels. The position of P2 is at 2 metre high from the classroom floor, vertically in the internal wall.
- P3: to measure work place conditions including lighting, air temperature and relative humidity. The position is at a student desk, middle of the classroom, at 0.8 metre horizontally.

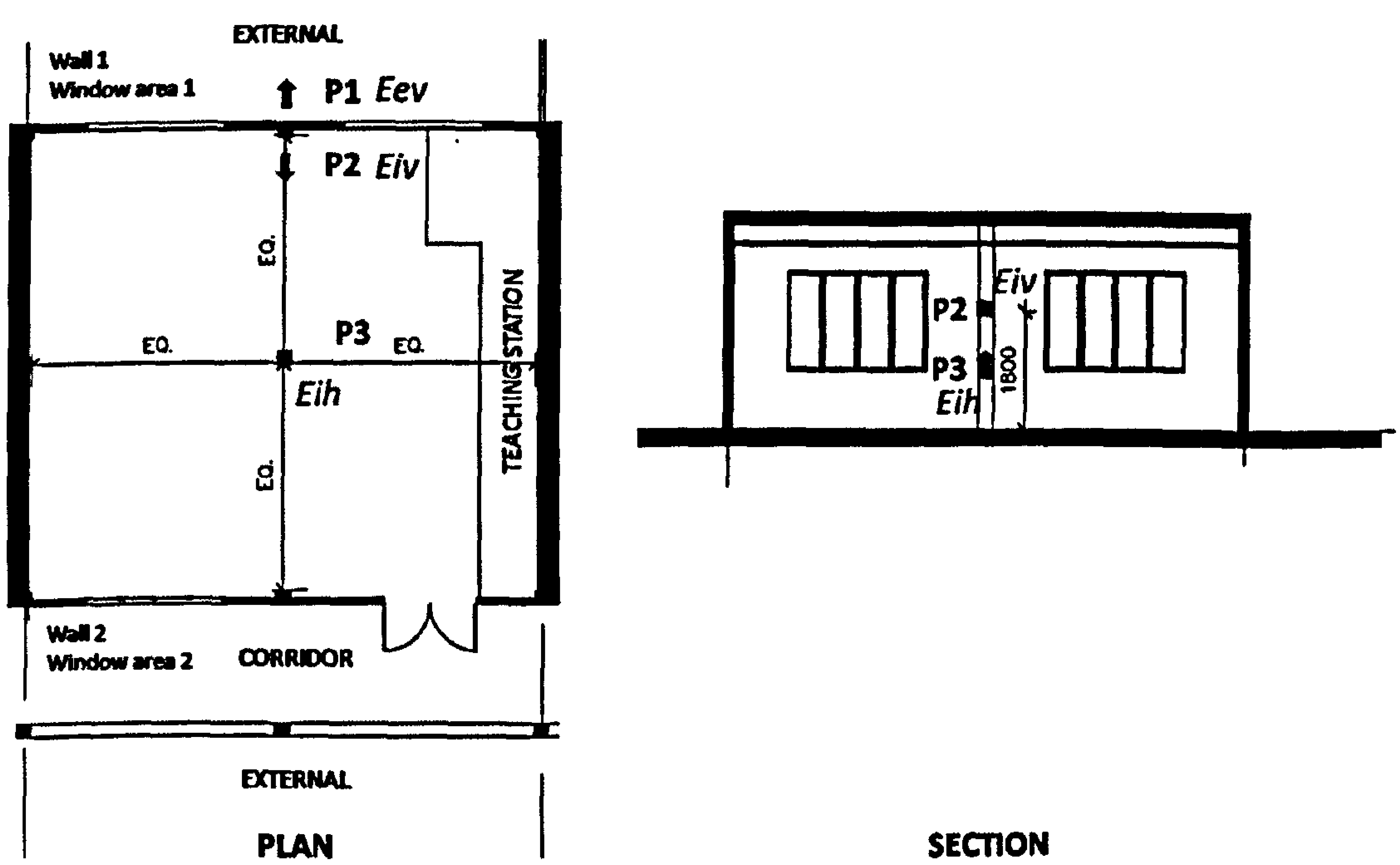


Figure A.1 Environmental monitoring positions.

Data was collected by small data loggers mounted at P1, P2, and P3 positions. The measurement was taken continuously in four day operative week (24 hour each day). These devices were programmed to automatically measure the conditions every 10 minutes. During the measurement, these classrooms were asked to operate normally. However, depending on the study curriculum and the class shift, some classrooms were used only half day (one shift), while others were used full day (two shifts). There was a third shift class operated in some of the classrooms (Le Van Tam and Truong Cong Dinh school), but that was for an adults' vocational community school hiring the premise. This third shift class was not subject of the survey.

A.1.1.2. Immediate measurements

Portable devices were used to measure immediate data of lighting (illuminance level), air temperature and relative humidity. Measurements were taken at the three positions (P1, P2, and P3) at different times; and at other additional positions such as, at several students' desks and vertically on different wall surfaces. They were recorded along with time, operative conditions and weather conditions for further reference.

A.1.1.3. Instrumentation

There are three types of environmental data loggers installed in the classroom: the illuminance data logger, the air temperature data logger, and the relative humidity data loggers.

- ***Illuminance data logger***

The illuminance measurements were taken by bespoken illuminance data logger built by John Solomon at London Metropolitan University, they are the same type that used in similar field survey previously conducted by L.Brotas (2004). An illuminance data logger consists of three main components: a photocell, an amplifier and a data logger. The amplifier and data logger are housed within a water-proof box.

The small amplifier has the range of 0 to 10 V. The output from the amplifier is linear with respect to the photocell exposure.

The Data Logger is a "Tiny Talk" model RS-196-7421 which records the voltage output from the amplifier. It consists of an analogue to digital converter, an amplifier, a non-volatile memory and a 3.6V ½ AA lithium battery. It was set to record voltage output in the range of 1-10V. The data logger has 16 000 reading capacity. The recorded data is downloadable by connecting the data logger to the computer via a USB port by a special cable and read by Tinytag Explorer software (See figure A.3). The A/D converter has an 8 bit resolution (Brotas, 2004).

The data logger ran on its own battery. The other components were powered by two nine-volt (PP3) batteries and thus the light box could run independently and wirelessly once set up. The battery powering the light box was the Duracell Ultralite 9V lithium battery. This battery was used because it has a long life, and the voltage output remains stable during its life time. This was to make sure the light box was powered properly during its recording and the collected data was as accurate as possible.

There are total three illuminance data loggers: one was mounted externally and has the capable range of 0 to 100 000 lux (type L1), other two were mounted internally and have the capable range of 0 to 10 000 lux (type L2 and L3). The resolution of the external illuminance logger is 392 lux; and the resolution of the other two internal illuminance loggers is 39.2 lux.

In the site measurement, the reading interval was set to 10 minutes.

The illuminance logger type L1 was mounted at P1 position, facing vertically outward to measure the exterior vertical illuminance. L2 was mounted at P2 position, facing vertically inward to measure interior vertical illuminance. L3 was mounted at the student desk (P3 position), facing up horizontally, to measure the interior horizontal illuminance. Artificial lighting was asked to be switched on during the class hours.

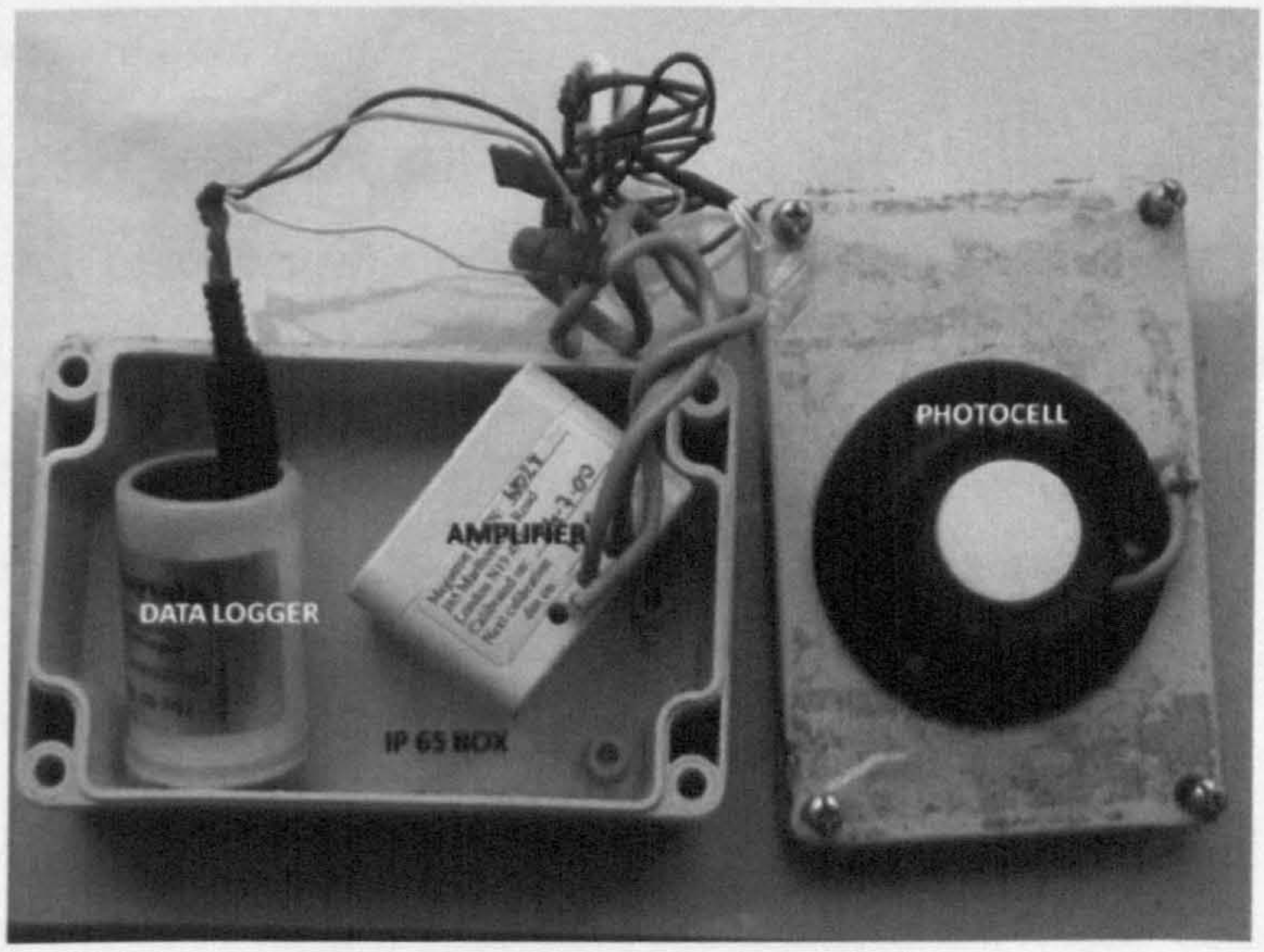


Figure A.2 Components and construction of the bespoke light box used in site measurement.

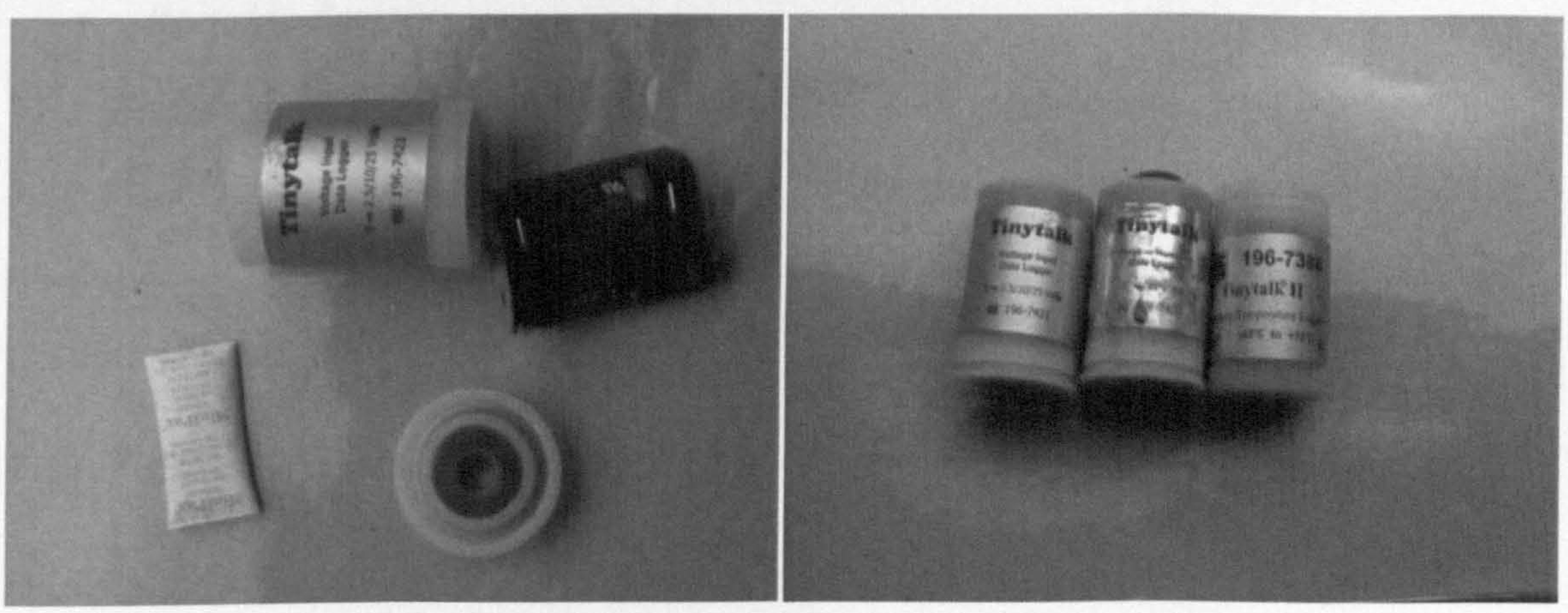


Figure A.3 Left: construction of a data logger used in the measurement. Right: three types of data loggers: the voltage logger, relative humidity logger and temperature logger.

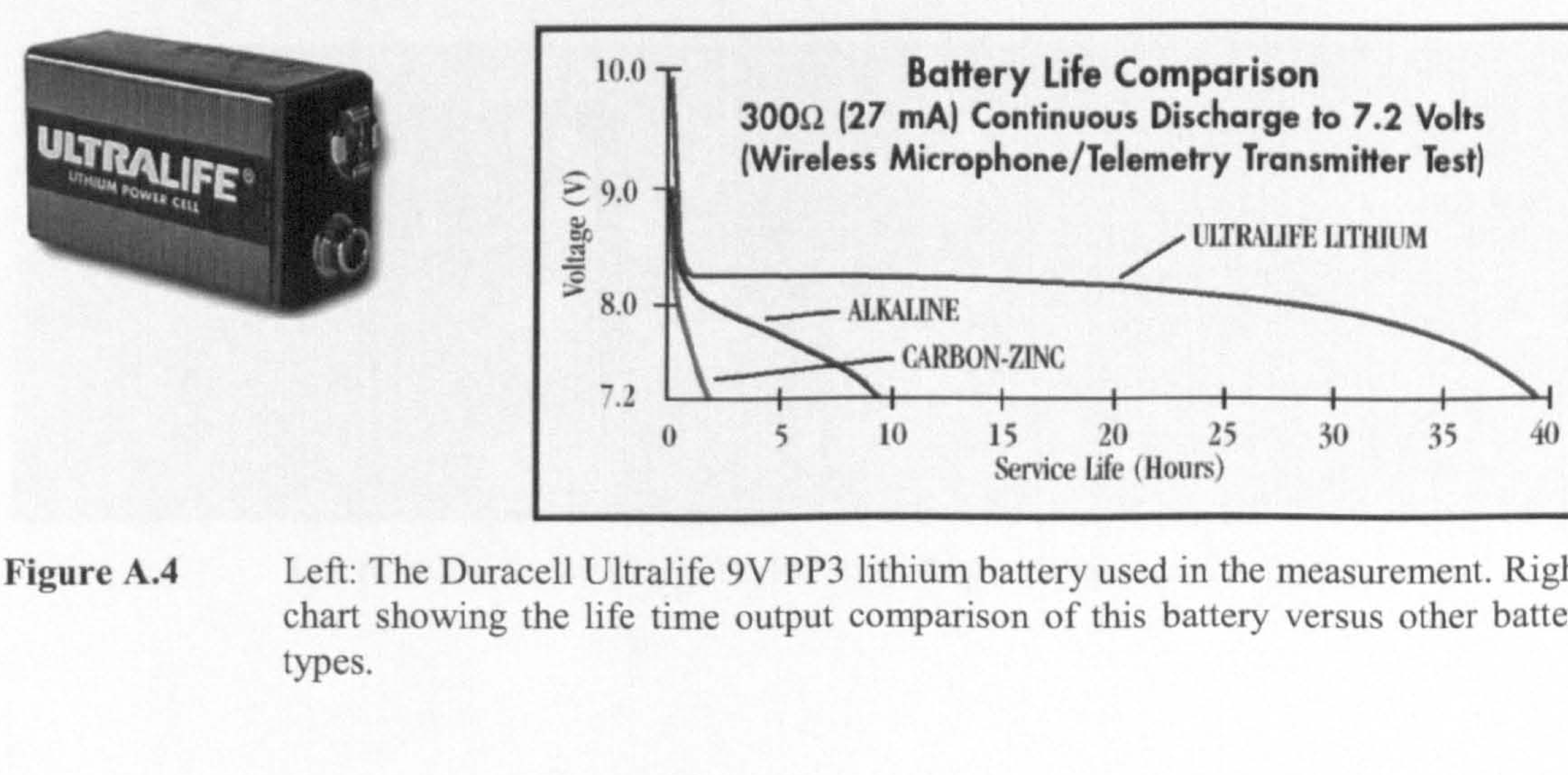


Figure A.4 Left: The Duracell Ultralife 9V PP3 lithium battery used in the measurement. Right: chart showing the life time output comparison of this battery versus other battery types.

- ***Temperature data logger***

The air temperature was recorded by a temperature logger similar to the voltage logger used in the bespoken illuminance logger described overleaf. The temperature logger was the Tinytalk II RS-196-7386 model, which has a capable range of -40°C to +75°C. There are two temperature loggers T2 and T3, mounted at P2 and P3 positions respectively. They were set to 10 minute reading interval.

- ***Relative humidity data logger***

The relative humidity (RH) was recorded by another data logger, type RS-196-7489. It has a range of 0% to 95%. It is similar to the temperature logger above. There were two humidity loggers H2 and H3, mounted at P2 and P3 positions respectively. They were also set to 10 minute reading interval.

- ***Portable devices***

The portable devices consisted of a light meter with cable range up to 500.000 lux, an environmental meter which can measure air temperature from -20°C to +50°C at a resolution of ±0.5°C and relative humidity within the range from 0% to 100% at a resolution of ±2.5%.

There was another measurement for CO_2 level. However, the data was not used later.

All the equipments were calibrated before taking site measurements. As illuminance is the most sensitive measurement, the Light Boxes were calibrated in the light lab to ensure accuracy.

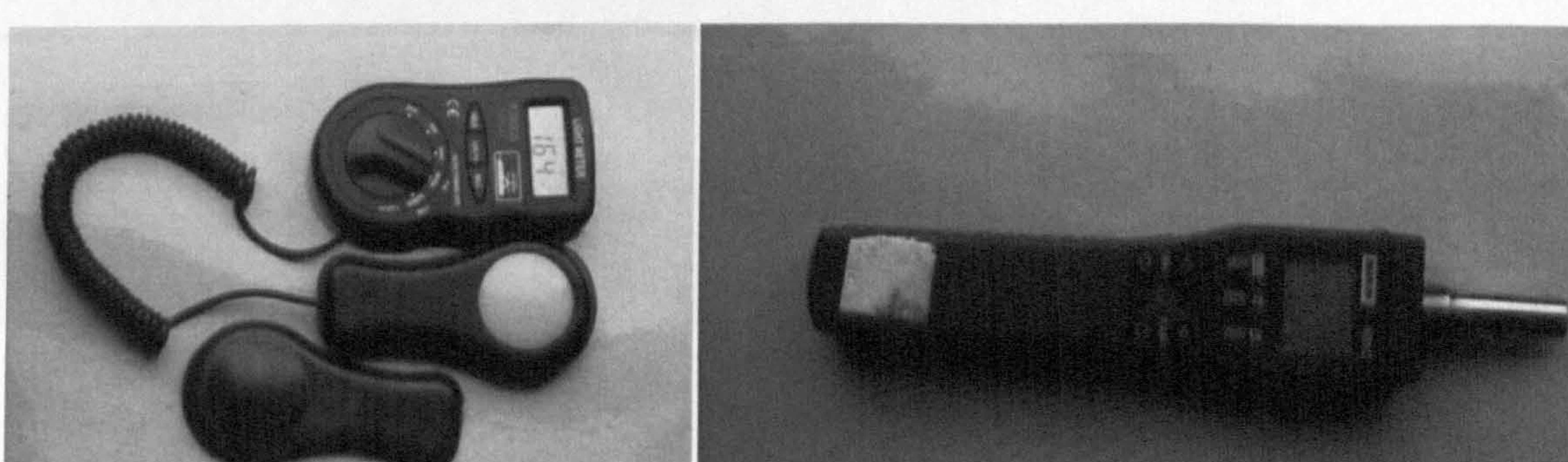


Figure A.5 The portable devices. Left: Light meter. Right: Environmental meter.

A.2. The Comfort survey

A.2.1 Description

In addition to the physical measurements, a users' comfort survey was carried on the four secondary schools. The comfort survey was done by questionnaire. Students of the surveyed classrooms were asked to fill in a questionnaire. In some cases when permission was granted, students from other classes also participated in the survey. These other classes have similar construction and architecture. The two visits coincided with the physical measurement. One was done in the Dry season of 2007 and one in the Wet season of 2008. 289 students participated in the first survey and 188 students participated in the second survey. In the second survey in 2008 permission was granted to question the teaching staff. In the second visit a total of 247 teaching staff from these four schools were asked to fill the comfort survey questionnaire.

Table A.1 Statistic data of students who participated in the comfort survey.

School	Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son	Total
First survey (2007)	155	52	44	38	289
Second survey (2008)	53	46	45	44	188
Total students of each school	208	98	89	82	-
Total			477 students		

Table A.2 Statistic data of teachers who participated in the comfort survey.

	Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son	Total
Second survey (2008)	54	78	39	76	247

A.2.2. The construction of the questionnaire

The questionnaires were modelled after the Smart Controls and Thermal Comfort (SCATS) project (Nicol & McCartney, 2000). The SCATS is a Joule III project approved by European Commission to carry out wide-ranging environmental comfort surveys throughout Europe. Results from SCATS survey were later used notably to develop the European Standards EN 15251. The questionnaires were also built from references of other approved international comfort surveys based on adaptive approaches, such as the ISO: 7730 and the ASHRAE: 55.

There are two separate questionnaire forms developed, coded HS and GV. The form HS was used for students while the form GV was used for teaching staff. The contents are mostly similar, but the form GV has minor revisions which are more applicable for the teachers.

The students' questionnaire consists of 46 simple questions with multiple-choice answering options, which can be finished in 30 minutes. Before the survey, there was a briefing on the questionnaire, definition and meaning of technical words used in the form and time required for "question and answer" all the enquiries on how to complete the questionnaire correctly. The questionnaires were in Vietnamese. The aim was to obtain subjective comfort response and user preferences on the classroom environment. The questionnaires were divided in to six sections:

1. Personal Information.
2. Evaluation of the working environment: building design, operation and maintenance.
3. Evaluation of Environmental Comfort covering the following subjects: visual comfort, thermal comfort, ventilation and noise. There were two set of questions for the Dry and the Wet season.
4. Perceived Productivity.
5. Comfort responses for current condition
6. User's Comfort Preferences and Suggestions.

Table A.3 Examples of thermal sensation scales using for the comfort survey.

Thermal Comfort Sensation Scale

ASHRAE		BEDFORD		FANGER		PHAM NGOC DANG	
Hot	7	Much too warm	7	Hot	+3	Hot	+3
Warm	6	Too warm	6	Warm	+2	Slight hot	+2
Slightly warm	5	Comfortably warm	5	Slightly warm	+1	Upper comfort limit	+1
Neutral	4	Comfortable neither cool or warm	4	Neutral	0	Comfort	0
Slightly cool	3	Comfortably cool	3	Slightly cool	-1	Lower comfort limit	-1
Cool	2	Too cool	2	Cool	-2	Slight cold	-2
Cold	1	Much too cool	1	Cold	-3	Cold	-3

Table A.4 Statistic details of students participated in the comfort survey.

1.2.STUDENT AGES

		Frequency	Percent
Age	11	77	16.1
	12	83	17.4
	13	83	17.4
	14	154	32.3
	15	51	10.7
	Not answered	29	6.1
Total		477	100.0

1.3.GENDER

		Frequency	Percent
Valid	MALE	156	32.7
	FEMALE	219	45.9
	Not answered	102	21.4
Total		477	100.0

1.4. CLASS SHIFT

		Frequency	Percent
Class shift	Morning	206	43.2
	Afternoon	174	36.5
	N/A	97	20.3
Total		477	100.0

1.7. TIME STUDYING IN THIS CLASSROOM

		Frequency	Percent
Valid	< 6 MONTHS	228	47.8
	6-12 MONTHS	108	22.6
	12-24 MONTHS	38	8.0
	> 24 MONTHS	31	6.5
	Others	72	3.8
Total		477	100.0

Responses were obtained from multiple-choice answers. In Section 1: Personal information, there were questions about the user's background such as age, class and gender. The answering scale is kept variable to suit appropriate answering options.

Section 2 contains questions evaluating the quality of the working - studying environment such as: design, overall comfort conditions provided, operation and maintenance. Here multiple choice answers are set on seven point scales, example is given as below:

1	2	3	4	5	6	7
Very Satisfied	Satisfied	Slightly Satisfied	Neither Satisfied or	Slightly Dissatisfied	Dissatisfied	Very Dissatisfied

Section 3 contains questions evaluating the environmental parameters. There are three sub sections asking about the following subjects: visual comfort, thermal comfort and other aspects (such as noise and air pollution). The following are some questions asked:

a. Visual Comfort vote for both natural and artificial light source in the Wet and the Dry season: illuminance, glare and perceived comfort (seven point scale).
b. Thermal Comfort vote for both the Wet and the Dry season: air temperature, ventilation and air movement and preference (seven point scale)
c. Noise and Pollution (seven point scale)

The examples of the multiple choice answers are given below:

Question: *How do you feel about the natural lighting level at your desk in Wet season?*

There are seven answering options:

1	2	3	4	5	6	7
Very Bright	Bright	Slightly Bright	Neutral	Slightly Dim	Dim	Very Dim

Question: *How do you feel about the air temperature at your desk in Wet season?*

There are seven answering options:

1	2	3	4	5	6	7
Very Hot	Hot	Warm	Neutral	Cool	Slight Cold	Very Cold

Section 4 contains questions evaluating the perceived productivity in nine point scale. (From -40% to +40%, which means fifth point in the scale is read as neutral). This section also has further questions on user's preferences and suggested improvements (seven point scales).

Section 5 contains questions about the immediate environmental comfort responses at the surveying time. Section VI contains users' comments.

All the responses were later computerized by using the Statistical Package for the Social Science Software (SPSS). SPSS is among the most widely used program for statistical analysis in social science. This software is specifically designed for statistical survey, data management, data mining and statistical analysis.

A.3. Site Documentation

The site documentation includes photographing, site measuring, examinations and taking samples and note taking. The school and classroom design was documented in various formats. The focal concerns are the school's construction, materials, type of shading devices, ventilation design and any other factors contributing to the environmental conditions of these sites.

Based on data collected from the site documentation, digital constructional drawings of the entire surveyed classroom were rebuilt on computer, using AutoCAD software.

There were special series of site photographs taken in different exposures. These special images were analyzed and processed by the *WebHDR* software to produce a useful three luminance map of the classroom. The camera was calibrated in the lab before and after photographing to ensure that the data obtained is accurate and compatible to *WebHDR*. *WebHDR* is specially built software developed by Axel Jacobs at the Low Energy Research Unit, London Metropolitan University. *WebHDR* has the capacity to produce High Dynamic Range (HDR) images created from a series of exposure-bracketed images, to reconstruct the actual luminance distribution within the photographed scene. Information can be read from either the false colour image output or the luminance contour image output. The information stored in the HDR image can also be used to simulate how the scene would appear to a human viewer using RADIANCE Image Viewer software.

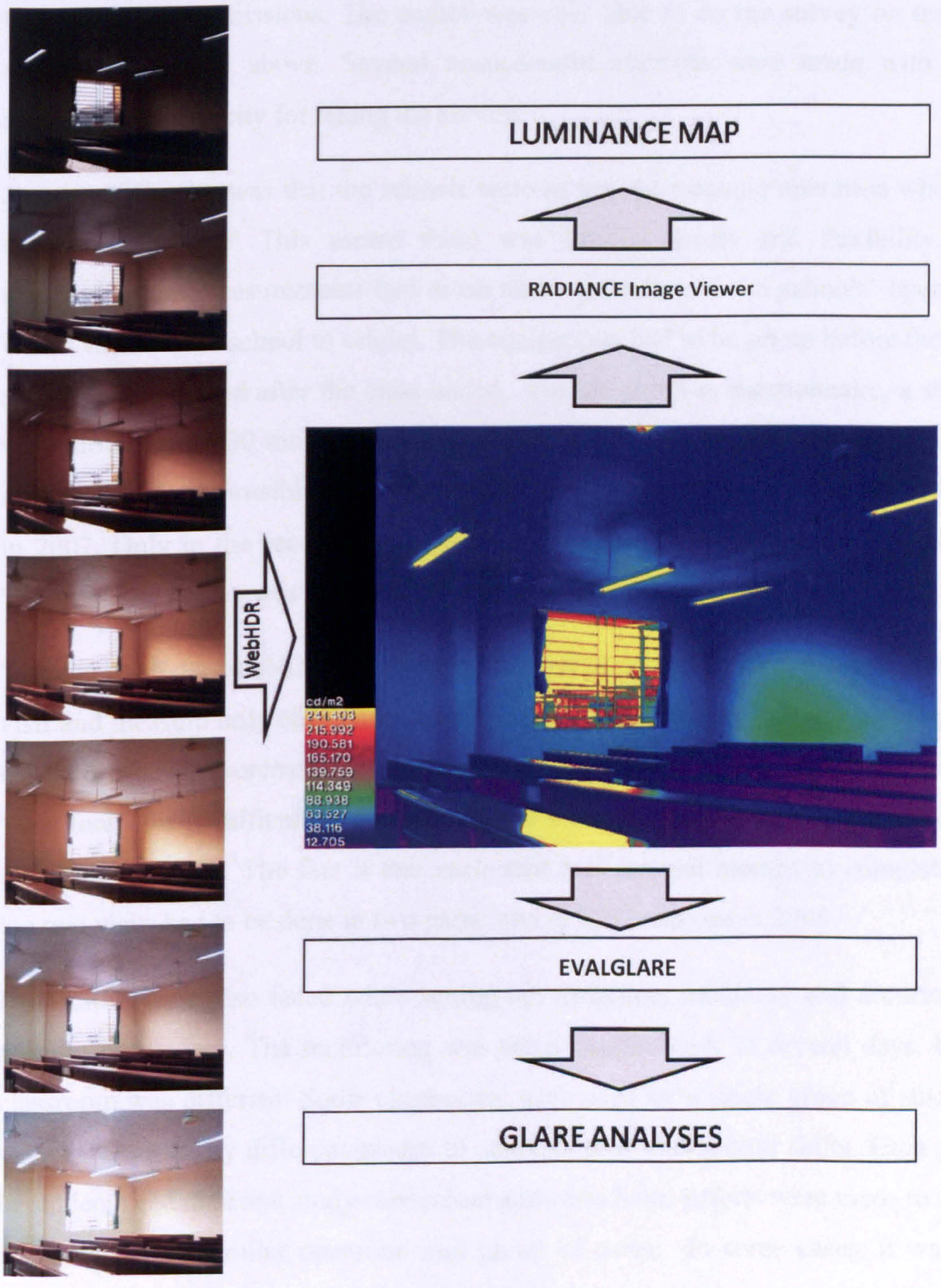


Figure A.6 Images taken by digital camera with different exposures are converted into High Dynamic Range images with lighting information embedded and then analysed by other computer software to construct the luminance maps and calculate glare indices.

A.4 Difficulties encountered

It was difficult to obtain permission from relevant authorities to do the survey in the on-operating schools. The selection of the surveyed schools was very much subject to the granted permissions. The author was only able to do the survey on the four schools mentioned above. Several unsuccessful attempts were made with other schools across the city for taking the survey.

Another difficulty was that the schools were in normal teaching operation when the survey took place. This means there was limited access and flexibility. The monitoring and measurements had to be taken according to the schools' operation, which varied from school to school. The equipments had to be set up before the class started and collected after the class ended. For the comfort questionnaire, a student was allowed only 30 minutes maximum during the class hour to participate in the survey. It was not possible to do the comfort survey on teaching staff in the first visit in 2007. Only in the second visit in 2008, permission was granted for this survey. The teachers' survey was taken during a school staff meeting.

There is limited availability and capacity of equipments. Therefore, it was possible to visit and measure only one school classroom at a time. Setting up time was required between each measurement and the schedule was subject to the school permission. Therefore, it was difficult to have the all the measurements in all the schools at the same specific time. The fact is that each visit took several months to complete and the two visits had to be done in two parts; one in 2007 and one in 2008.

Difficulties were also faced while setting up, installing, mounting and securing the monitoring devices. The monitoring was taken continuously in several days. Every classroom was different. Some classrooms were used by a single group of students; others were used by different groups of students split into several shifts. Each group of students had different study curriculum and class hour. Efforts were made to select classrooms with similar operation and group of users. In some cases, it was not possible to measure the full continuous measurements of four operating days. One classroom measurement had to be extended over two weeks to obtain environmental data of four full operating days.

There were plans to mount and position the equipment accordingly. However, in some cases, it was not possible to mount the equipments at desired positions. The external light box was mounted on the vertical facade instead of the roof since no access was granted to the roof area. The equipments had to be mounted in safe positions not easily accessible to student's reach while maintaining accurate and reliable measurement. During the second visit in 2008, some equipment was removed and damaged by students. They were sent back to the UK for repairing; but all the monitored data was lost and the measurement had to be retaken.

There was also time and budget allowance constraint. Therefore, it was not possible to obtain some other useful data, e.g. absolute humidity, noise level and air pollution. However, hard effort has been made to ensure that the data collected is useful and reliable.

Appendix B

Site drawings of the surveyed schools

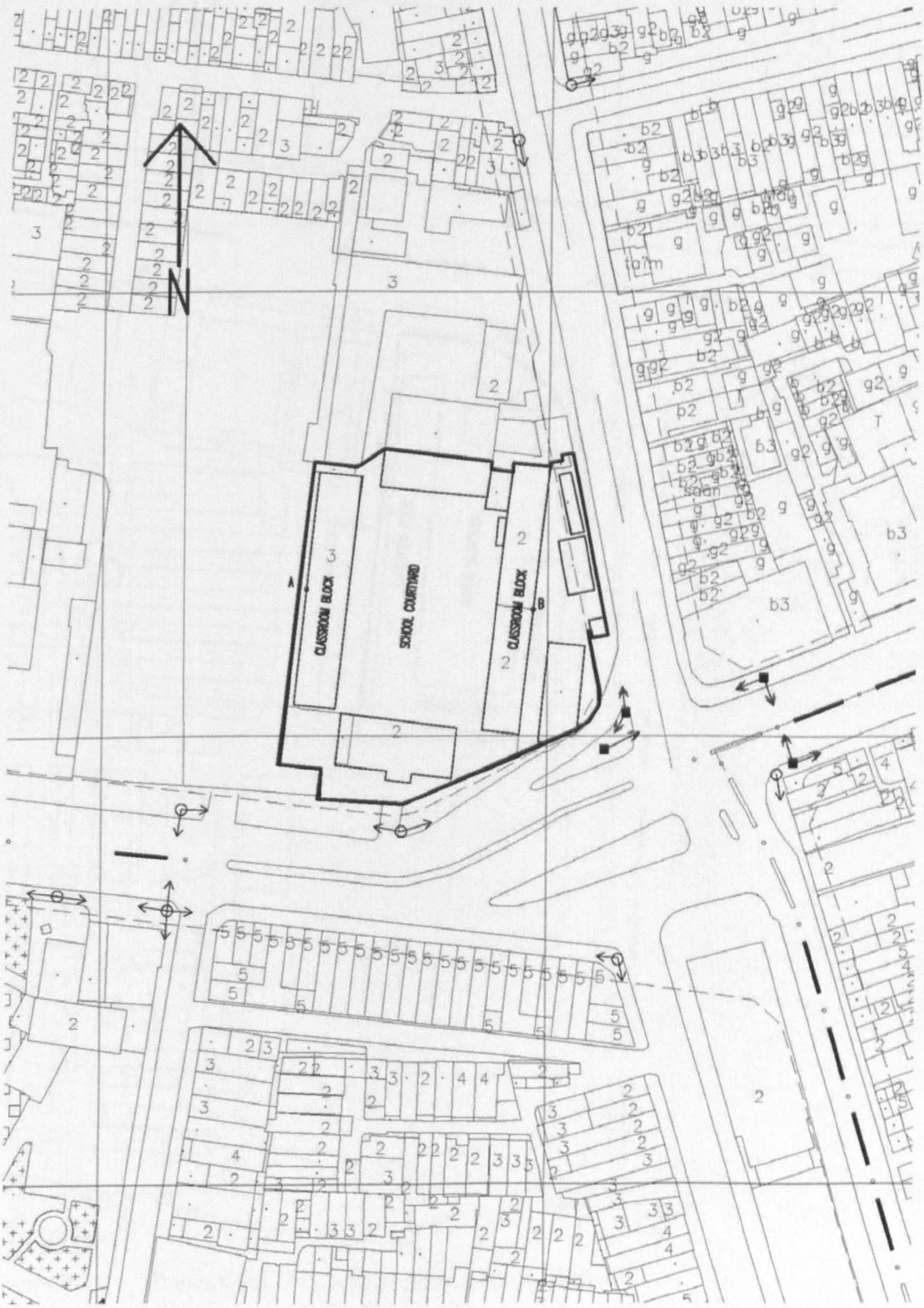


Figure B.1 Le Van Tam School site plan (not to scale).

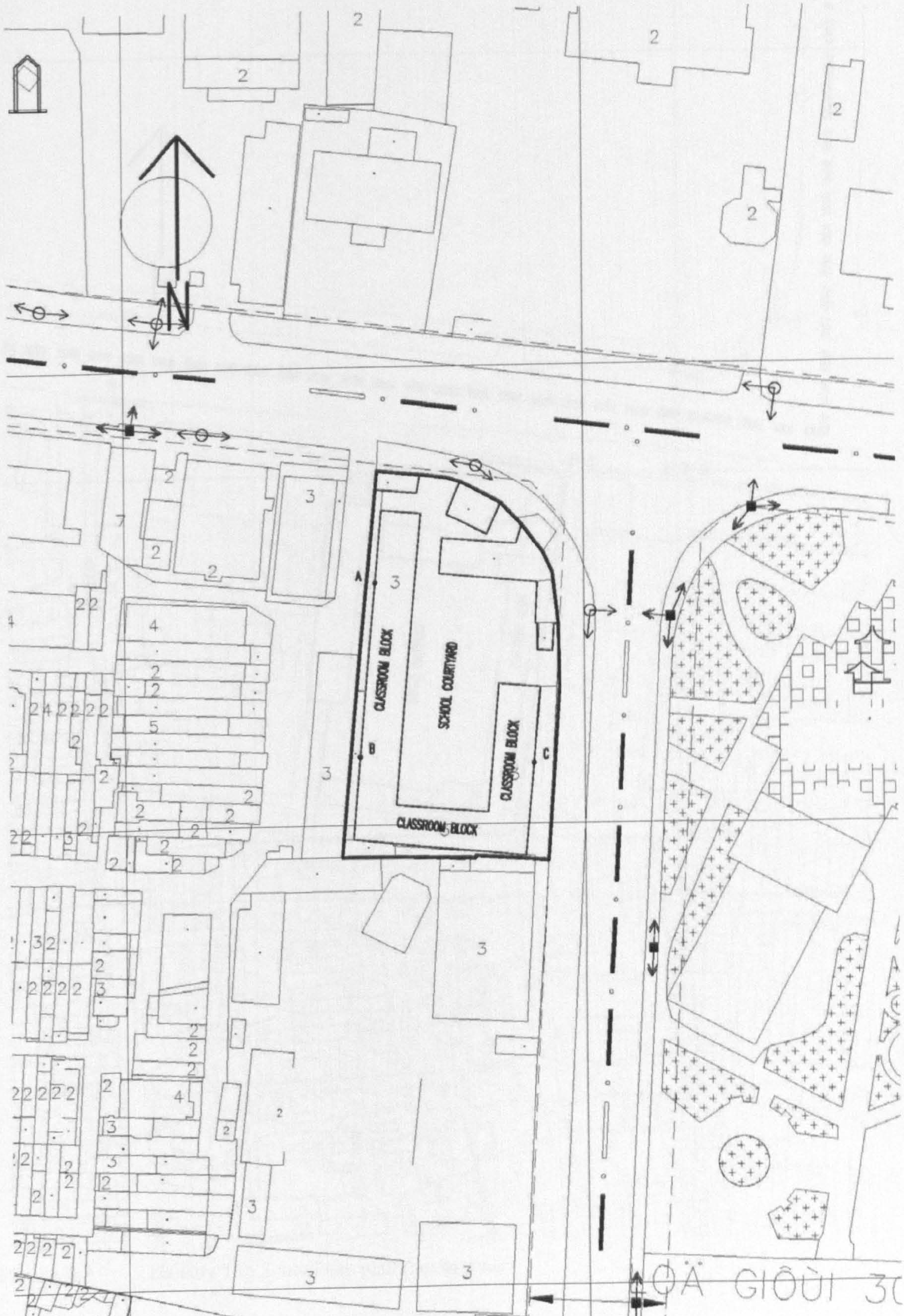


Figure B.2 Truong Cong Dinh School site plan (not to scale).

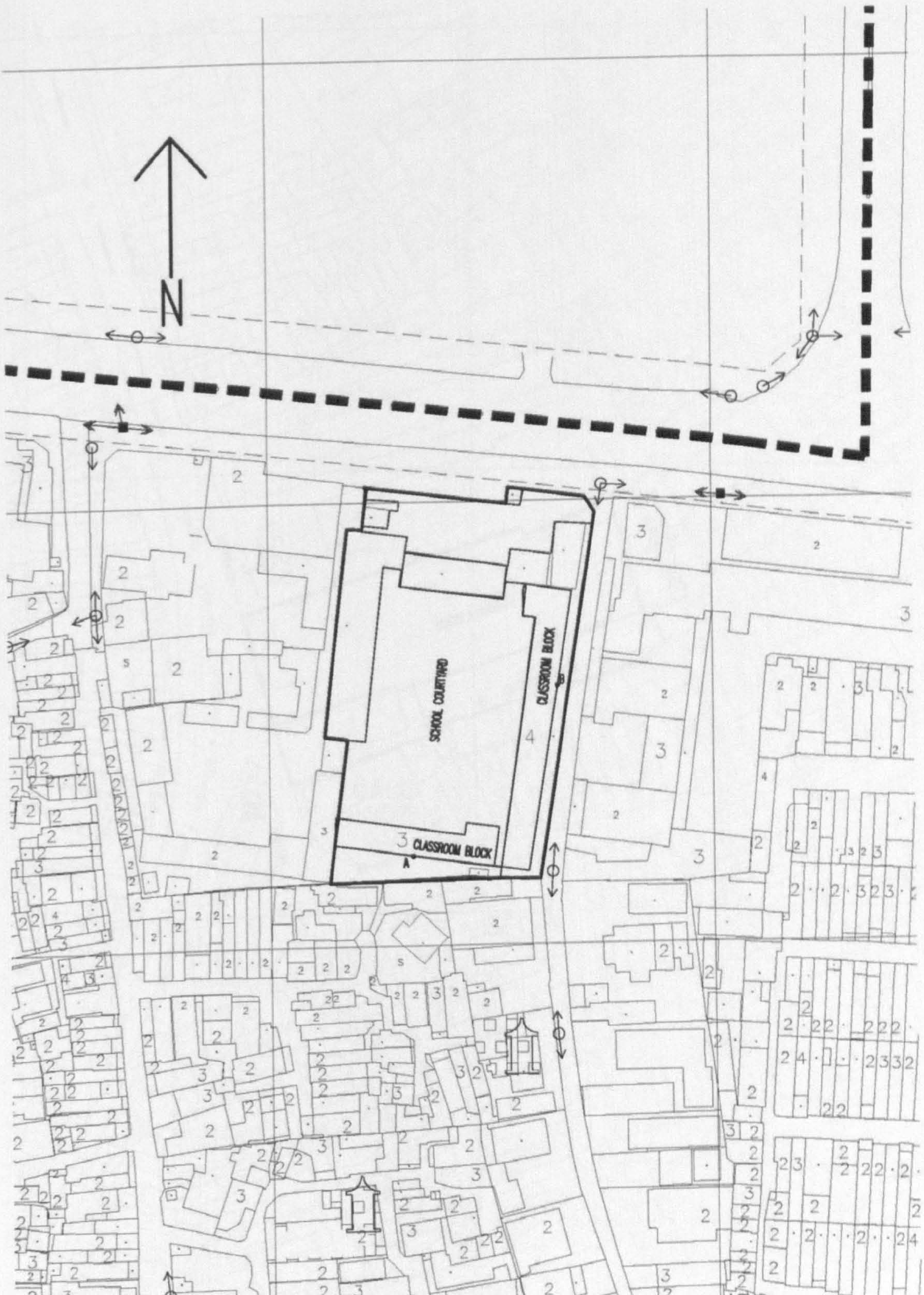


Figure B.3 Ha Huy Tap School site plan (not to scale)

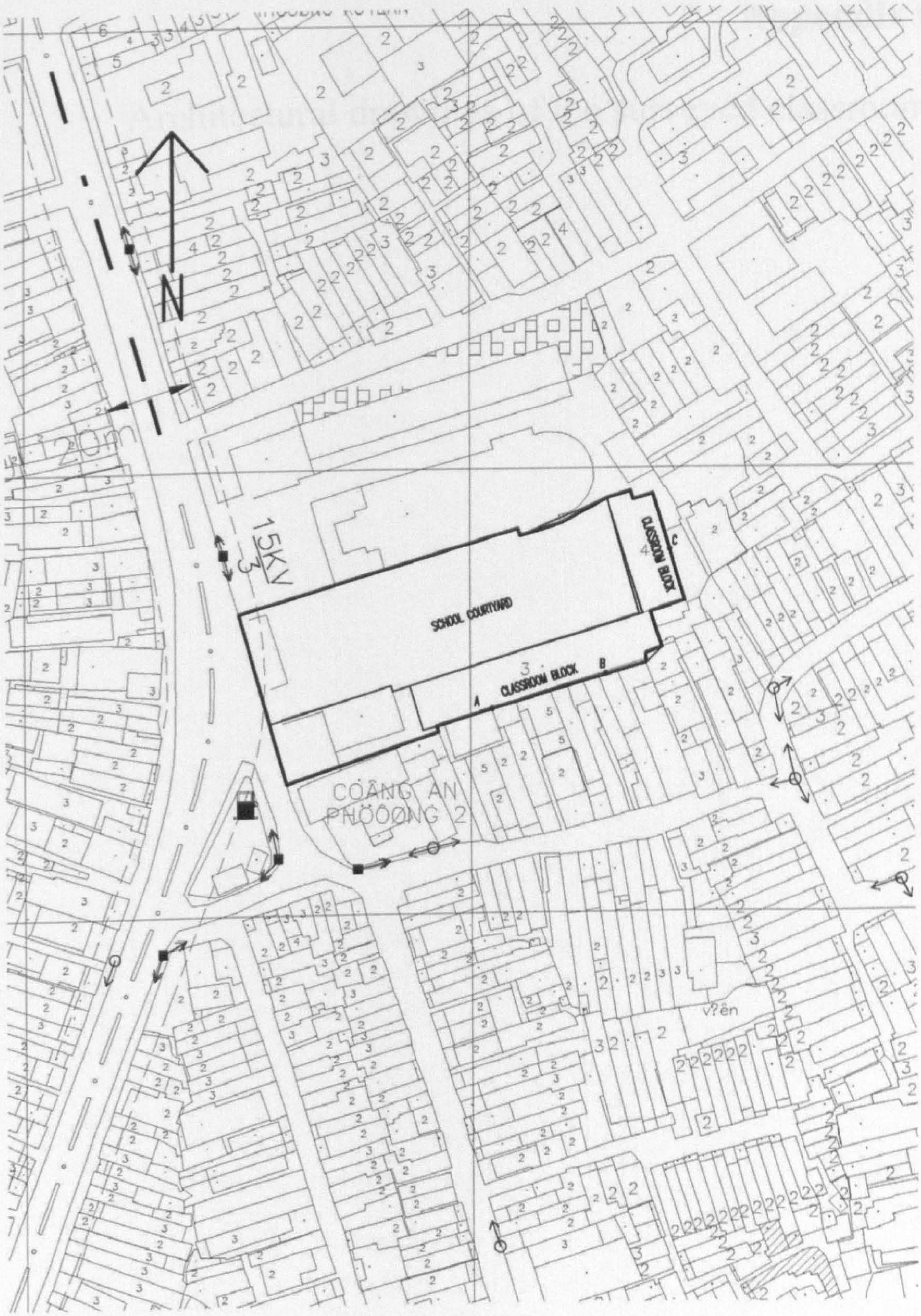
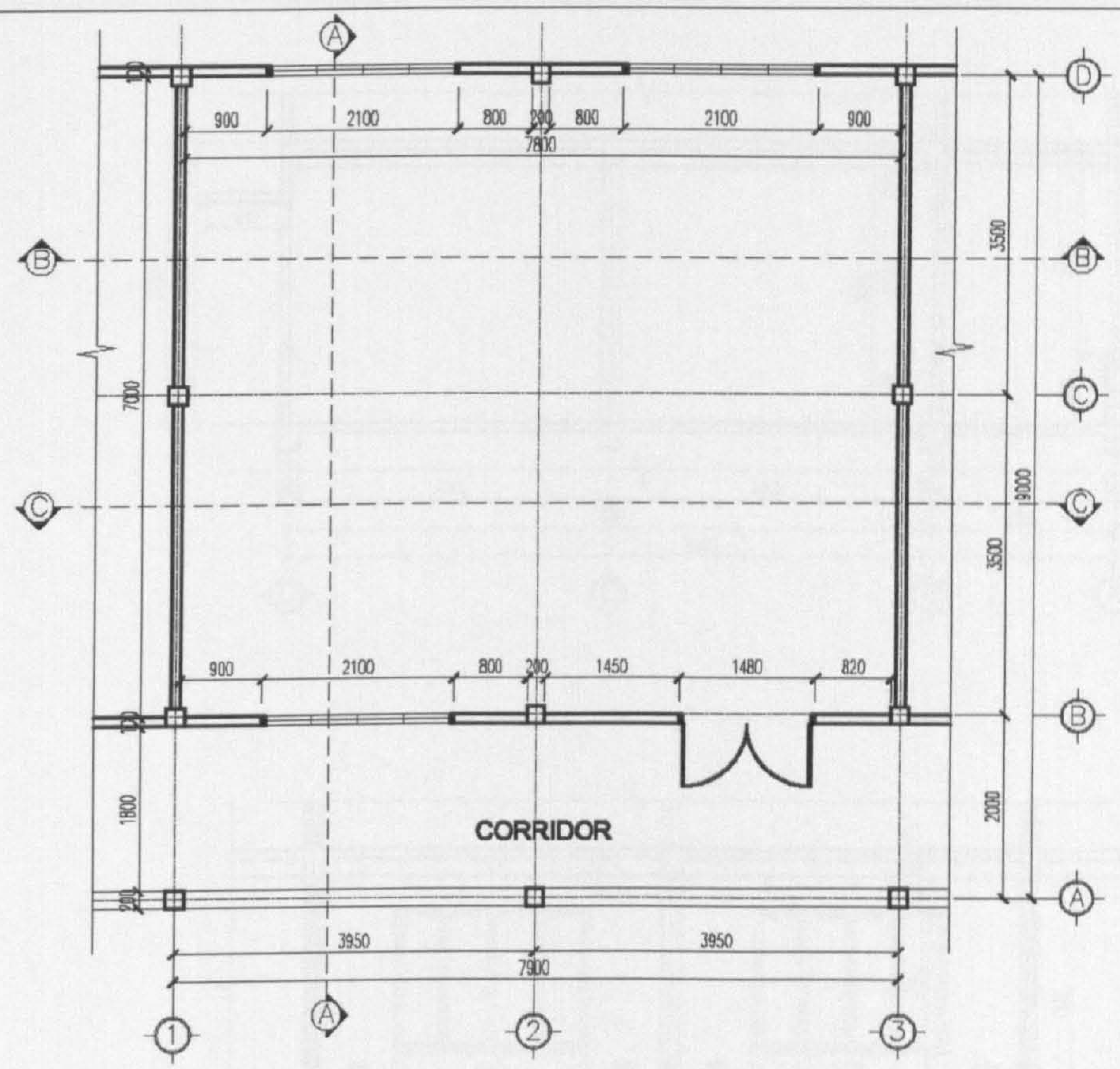


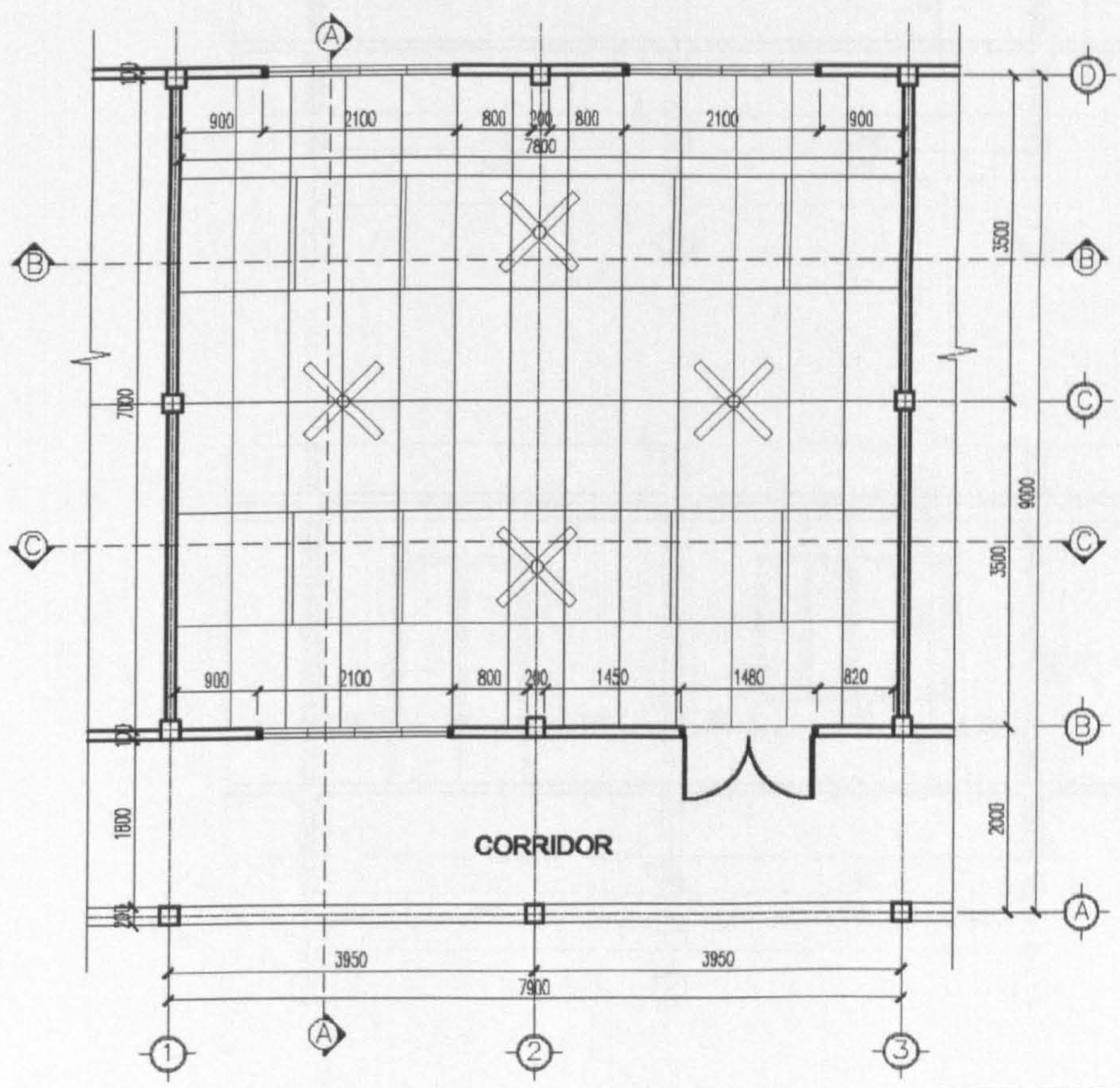
Figure B.4 Lam Son School site plan (not to scale).

Appendix C

Architectural drawings of the surveyed classrooms

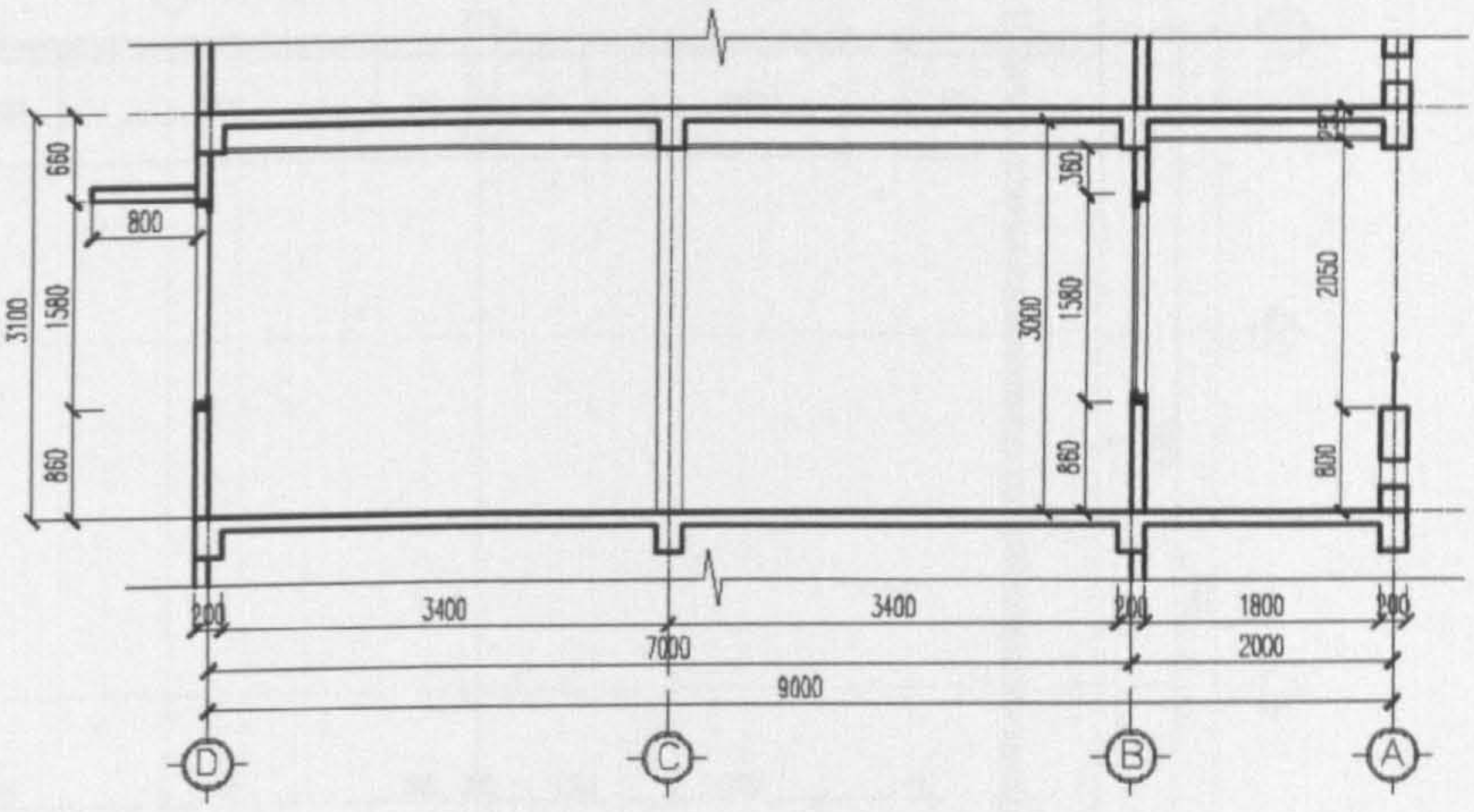


FLOOR PLAN
SCALE 1:100



REFLECTED CEILING PLAN
SCALE 1:100

LE VAN TAM SCHOOL



SECTION A - A
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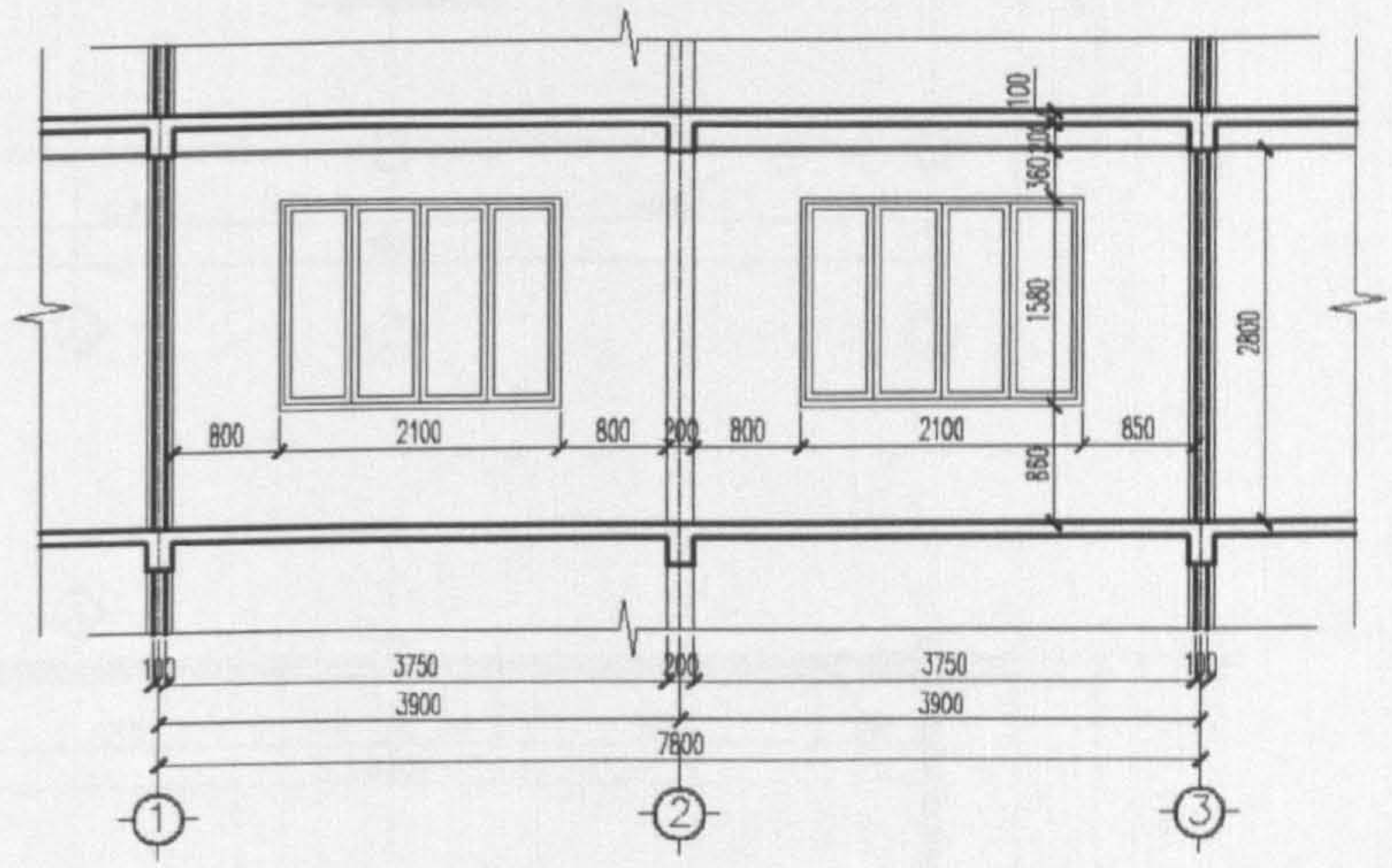

SECTION B - B
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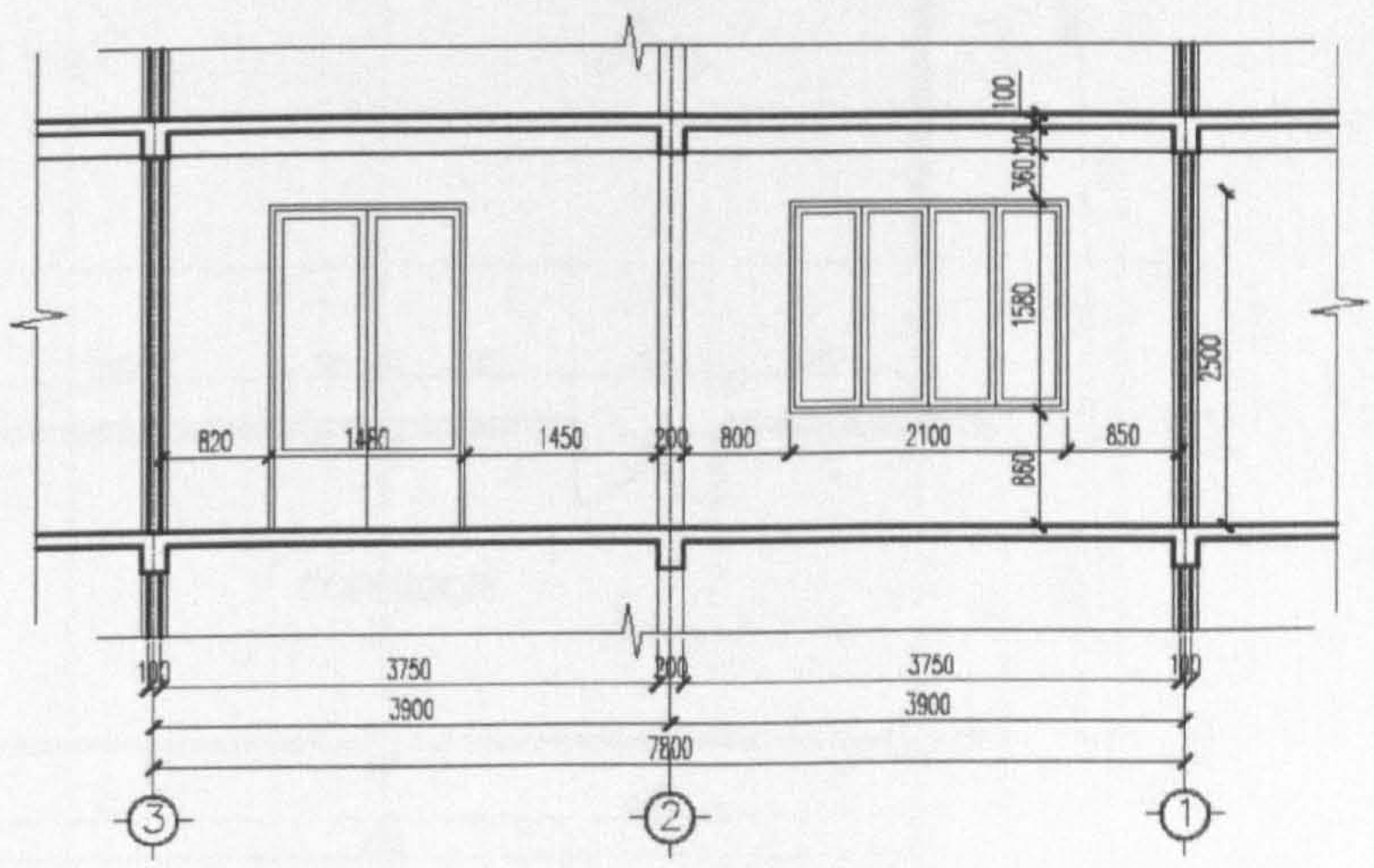

SECTION C - C
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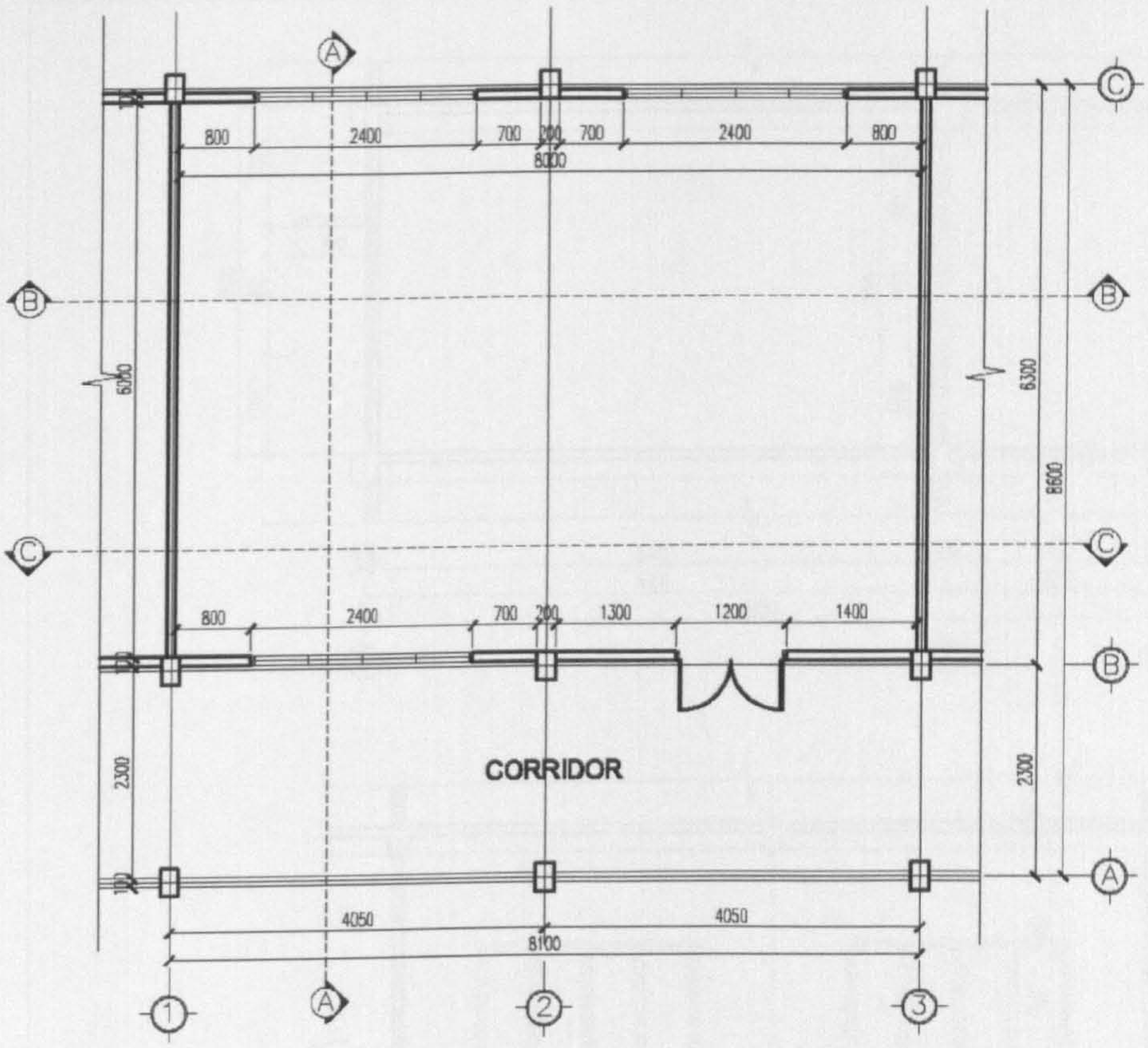
LE VAN TAM SCHOOL



FLOOR PLAN
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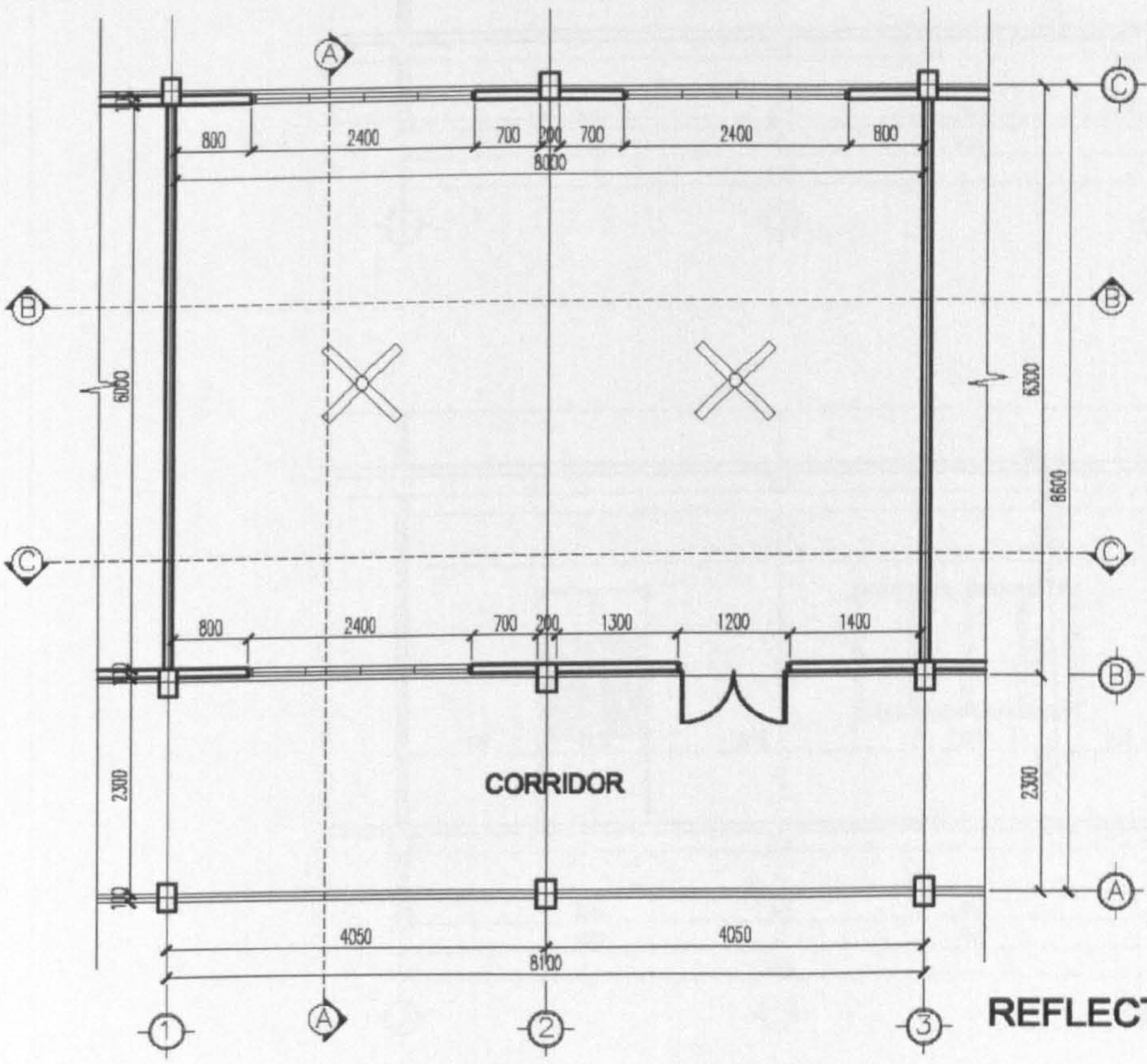
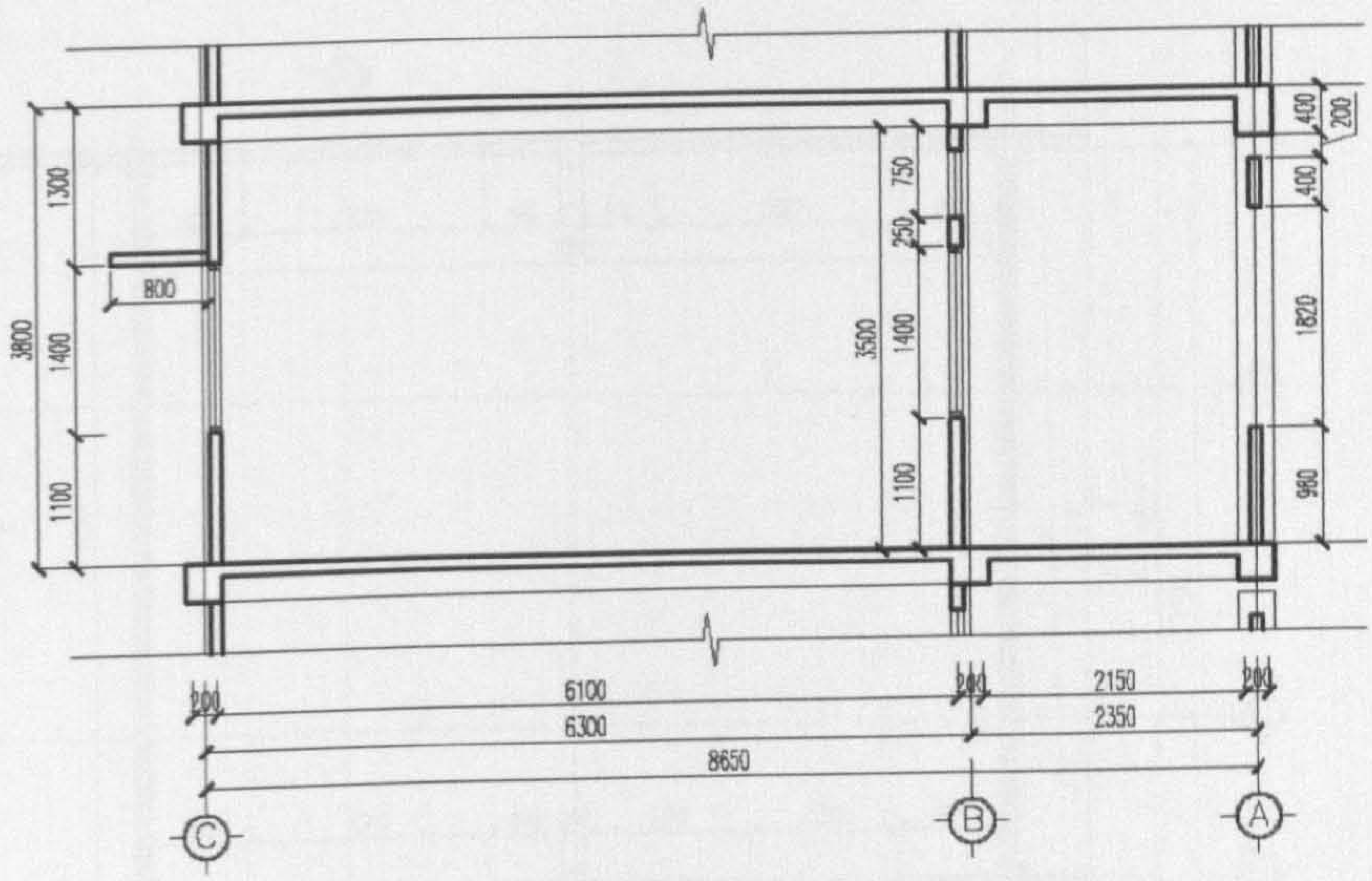


REFLECTED CEILING PLAN
SCALE 1:100

TRUONG CONG DINH SCHOOL



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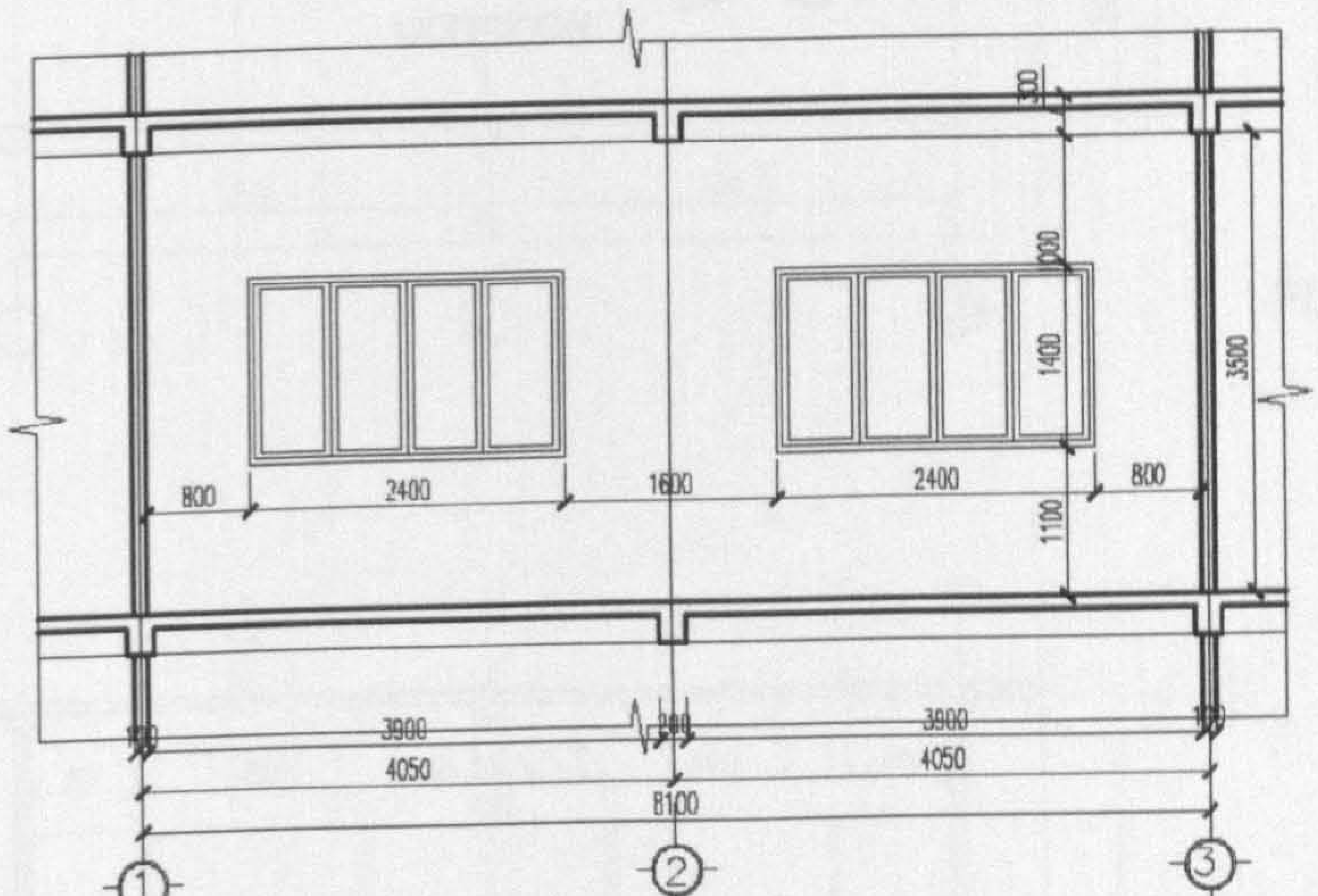

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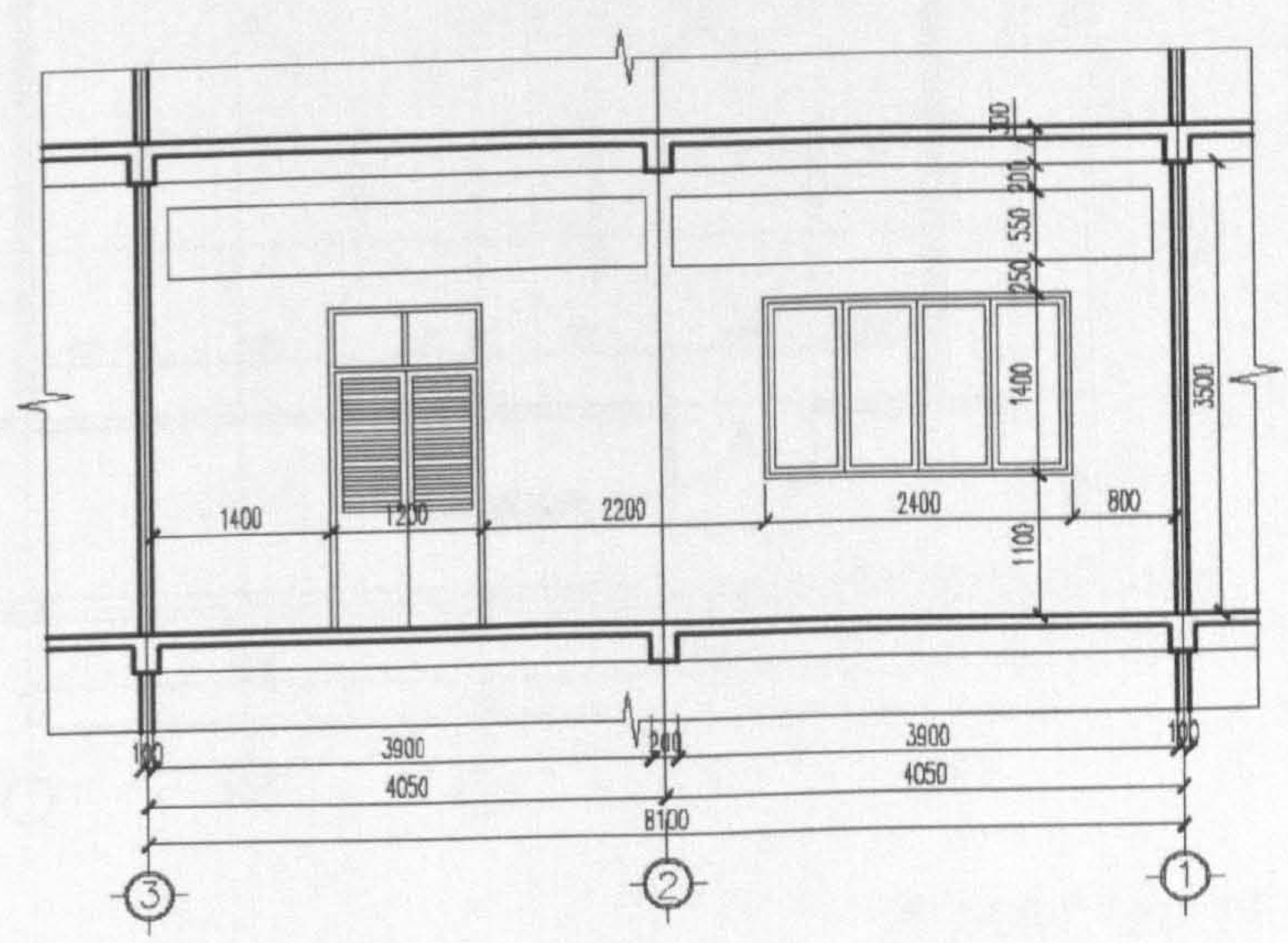

SECTION C - C
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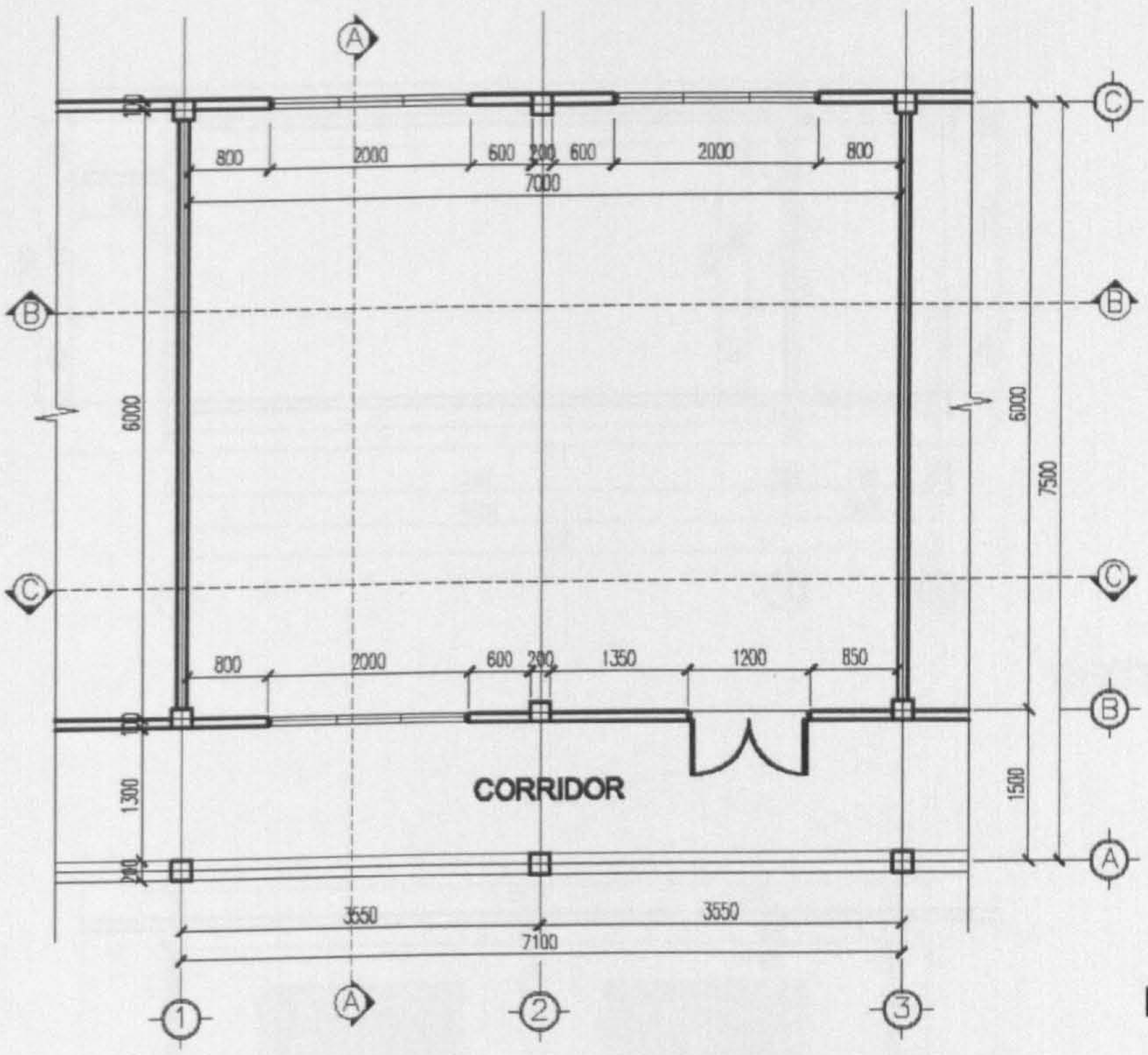
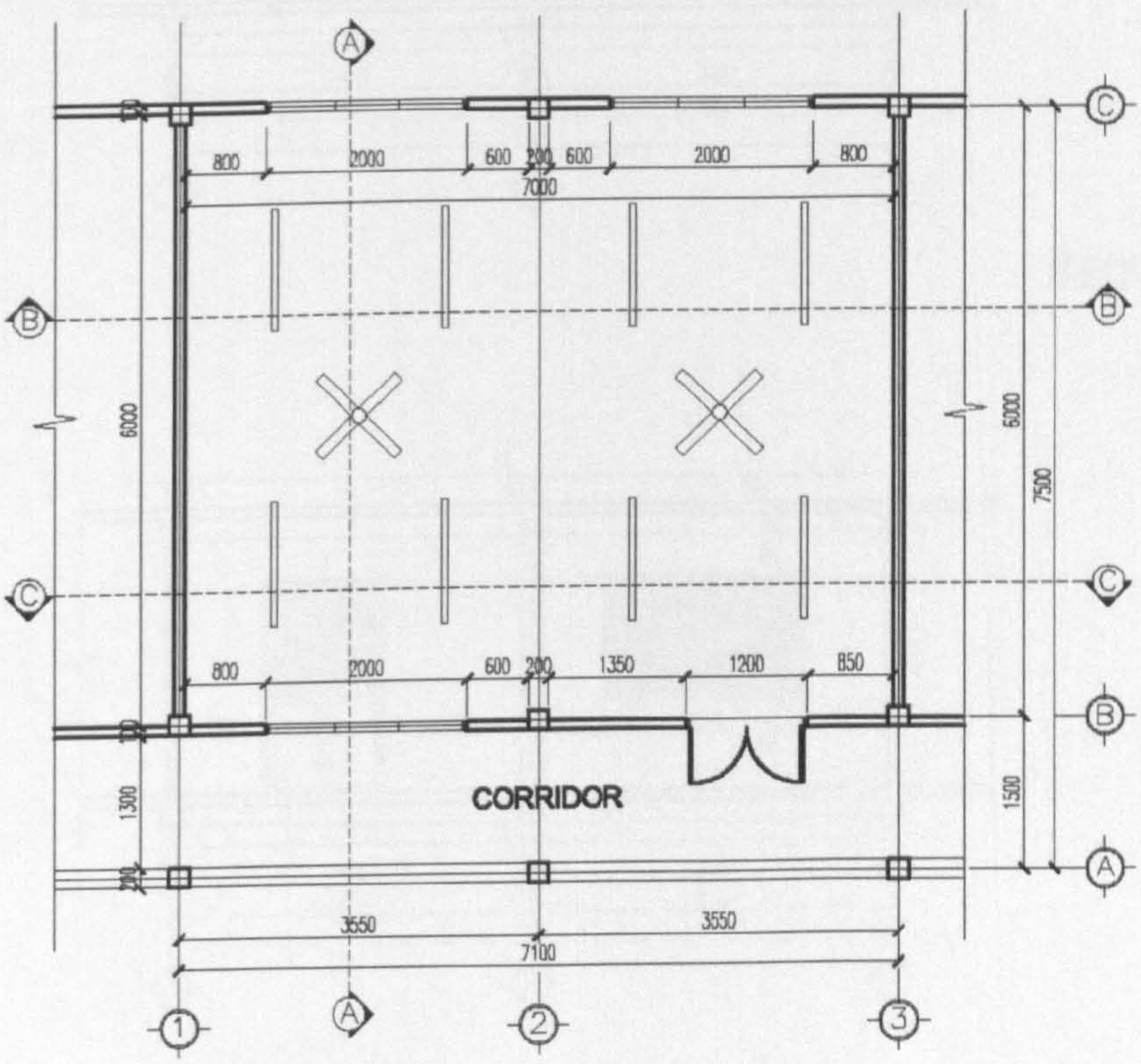
TRUONG CONG DINH SCHOOL

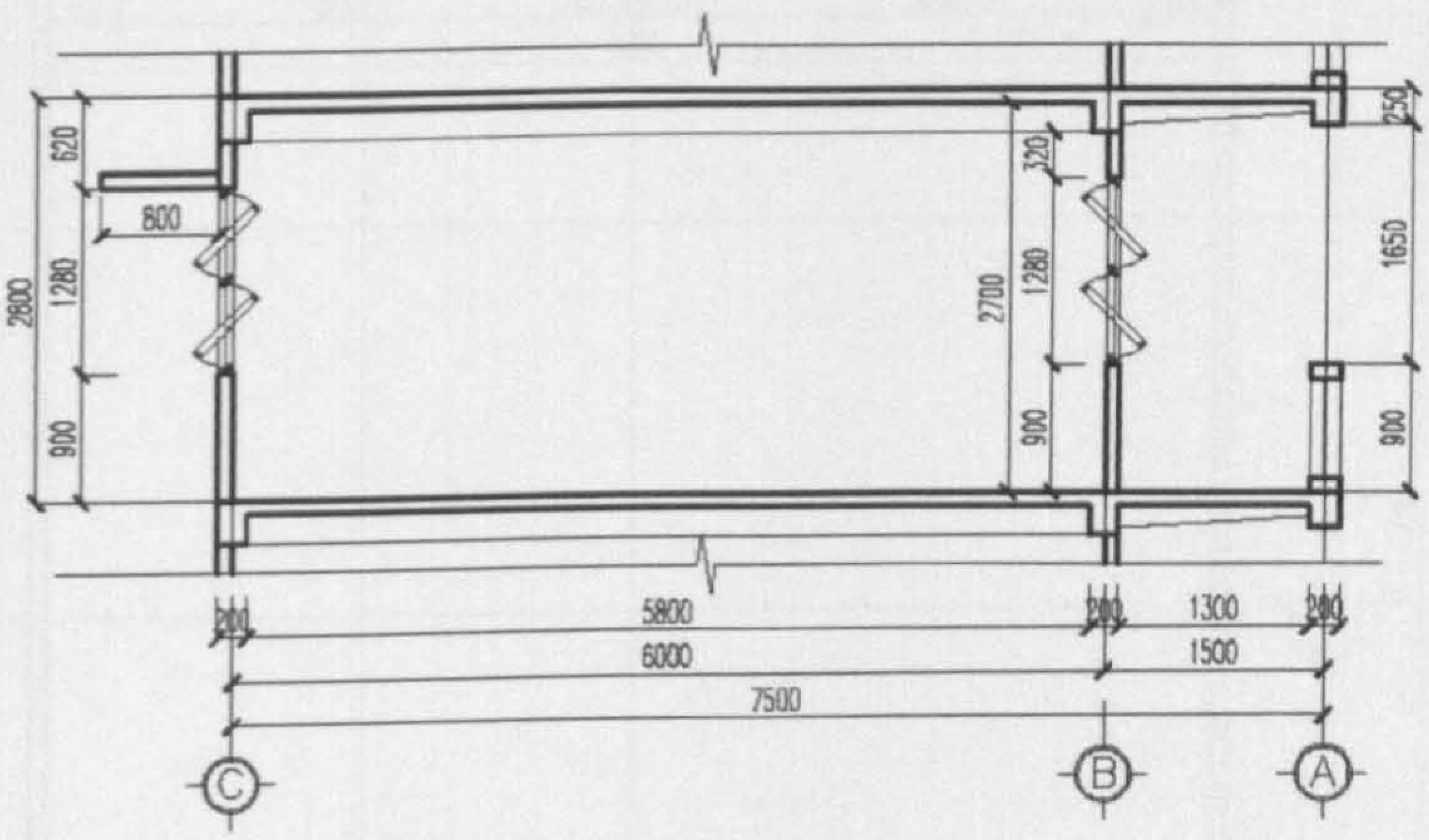


FLOOR PLAN
SCALE 1:100



REFLECTED CEILING PLAN
SCALE 1:100

HA HUY TAP SCHOOL



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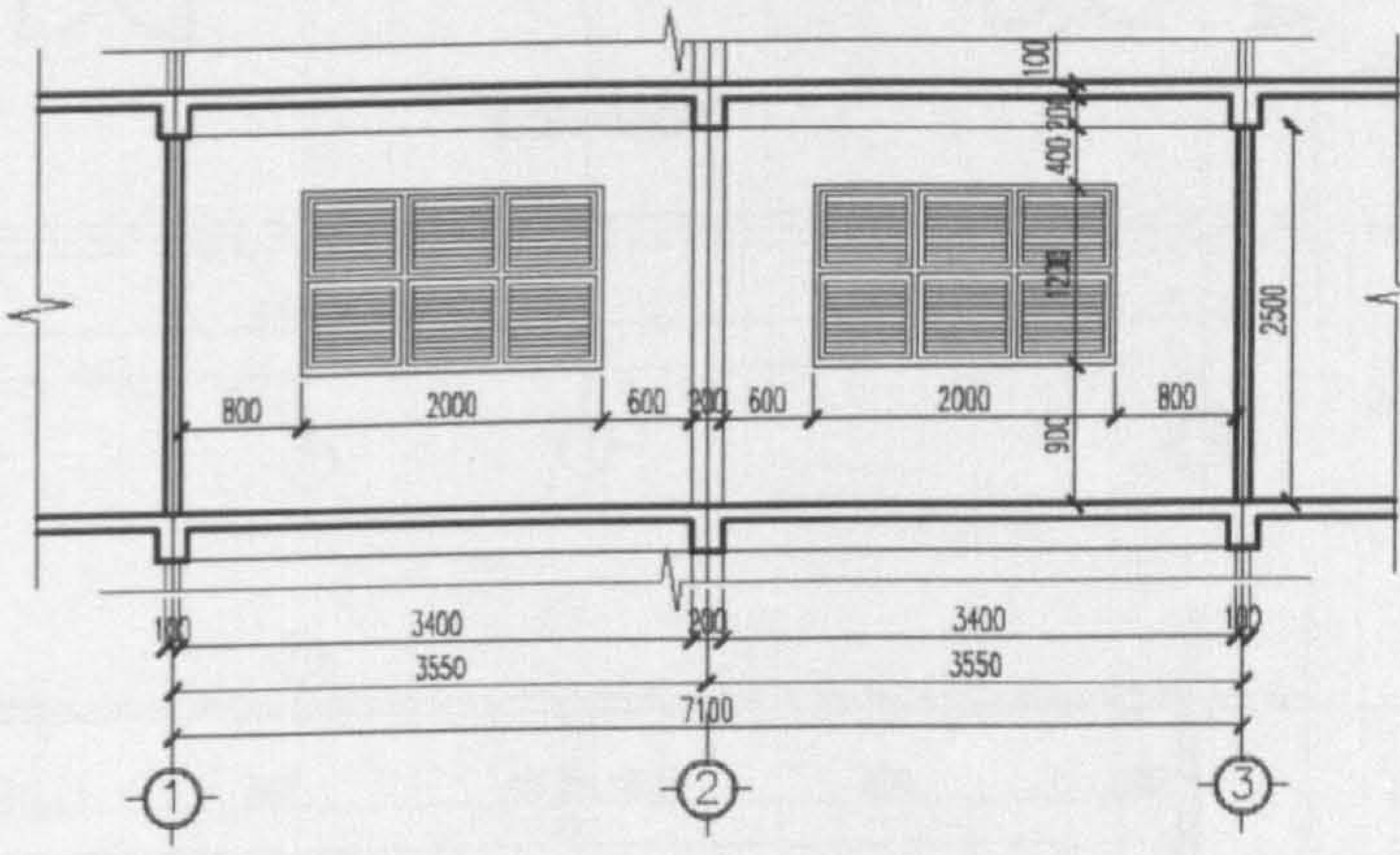

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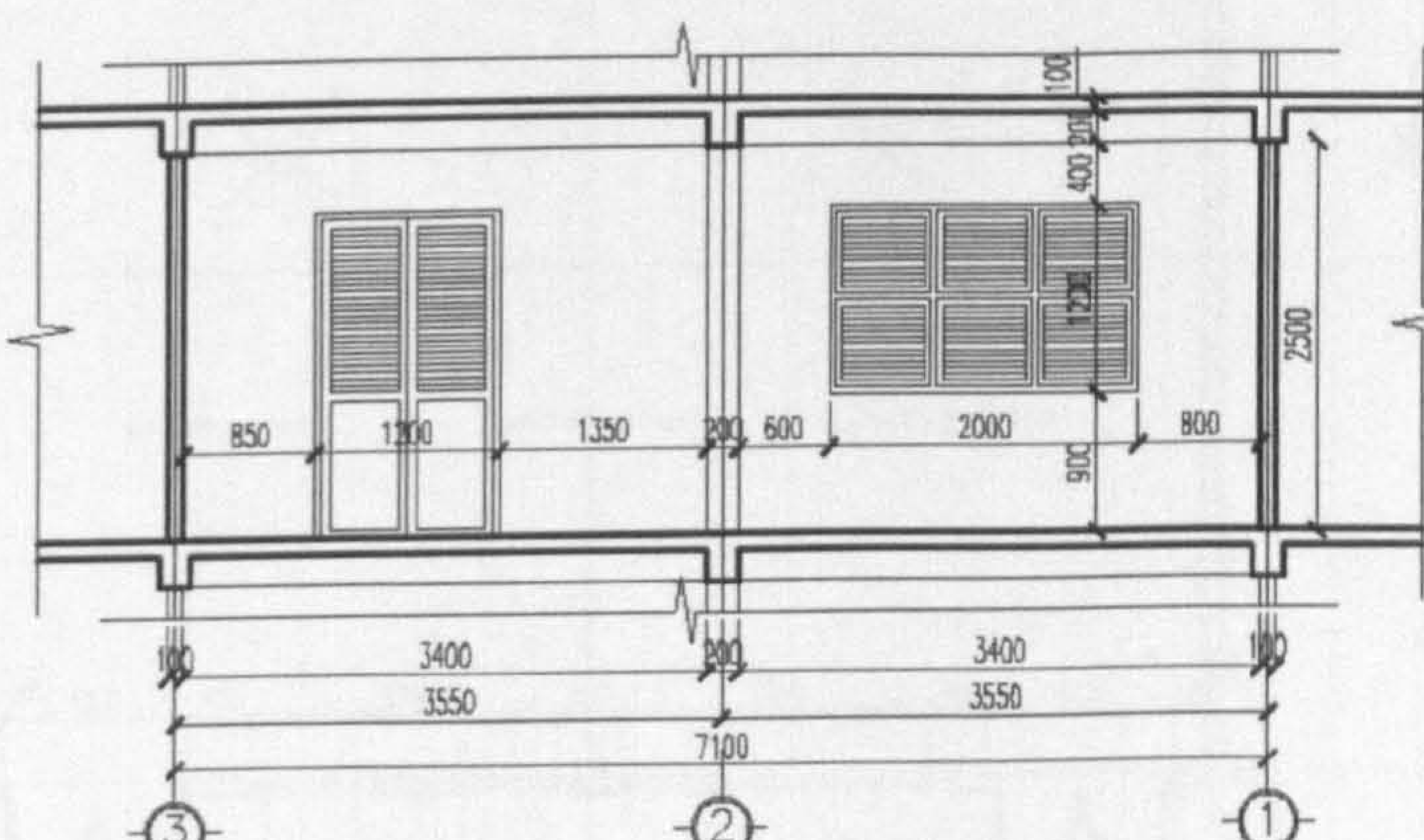

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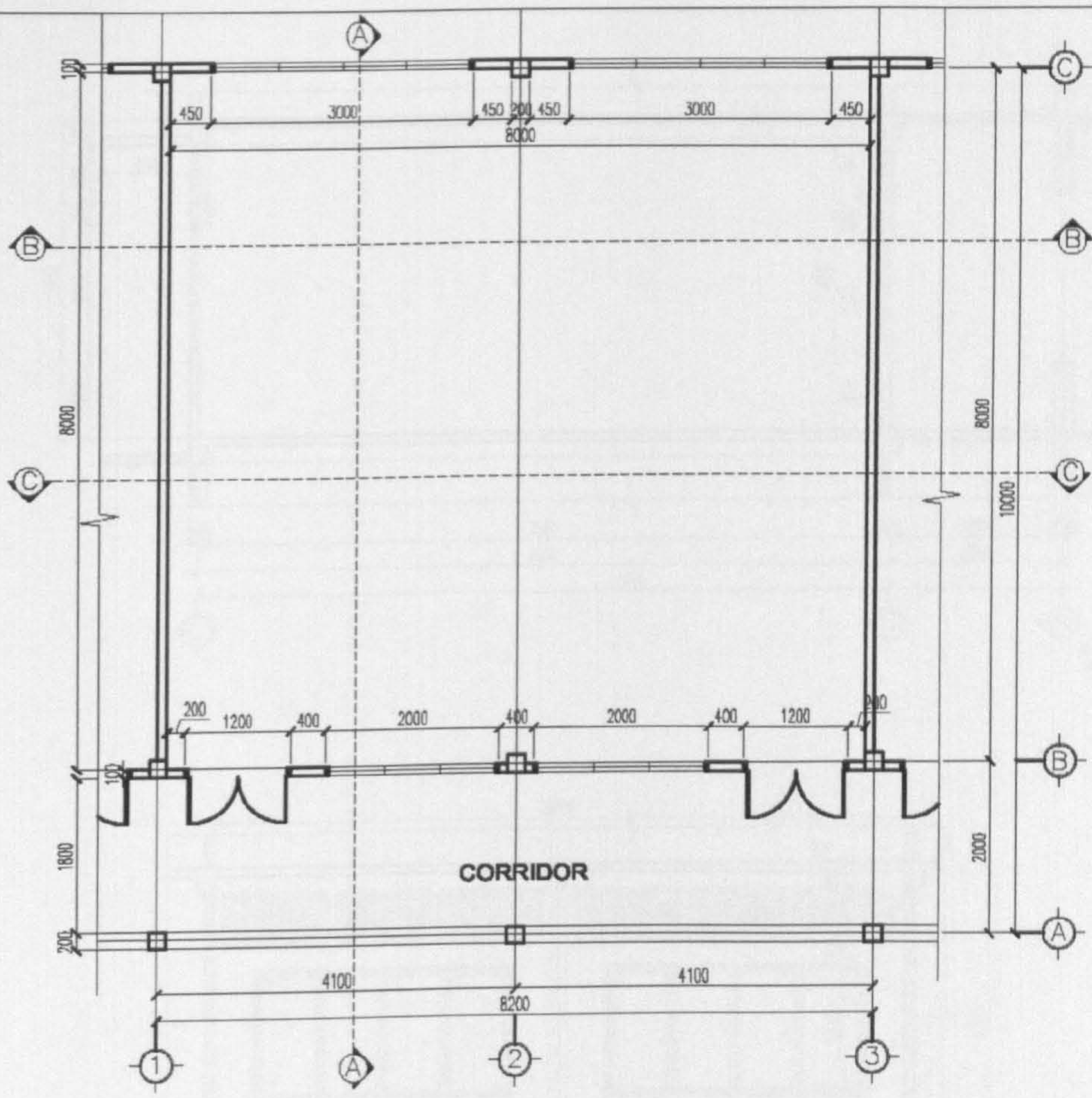
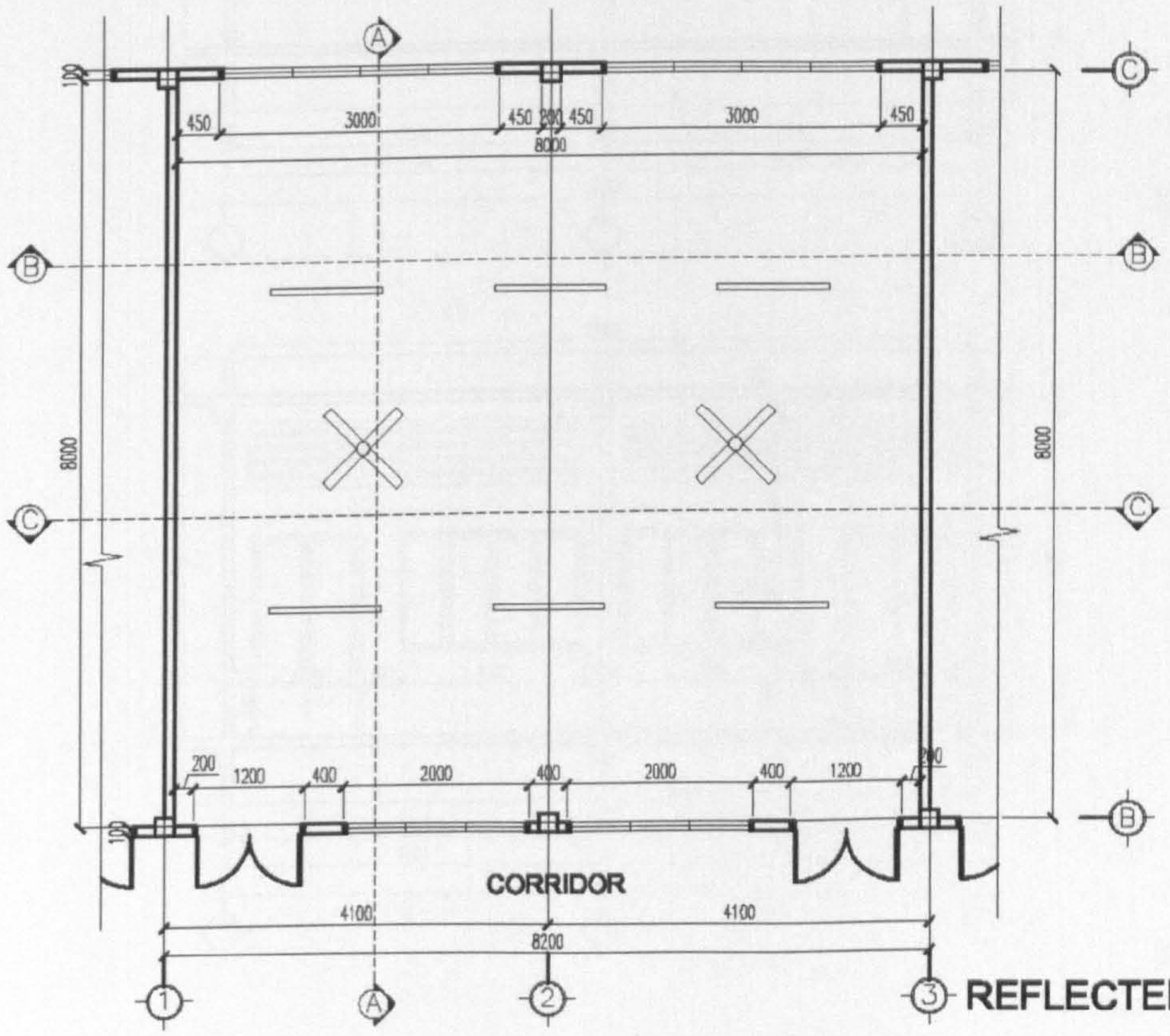
HA HUY TAP SCHOOL

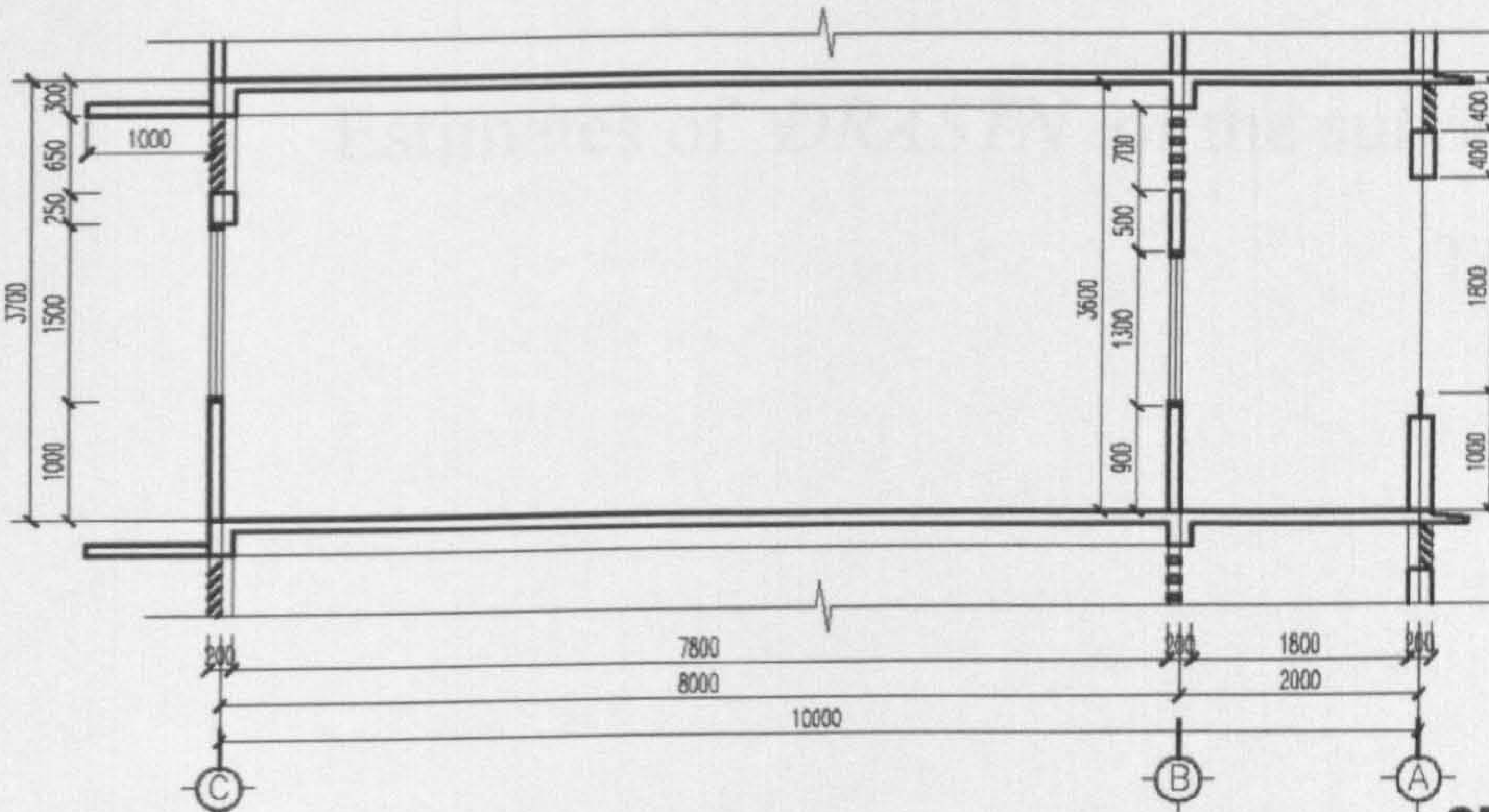


FLOOR PLAN
SCALE 1:100



REFLECTED CEILING PLAN
SCALE 1:100

LAM SON SCHOOL



SECTION A - A
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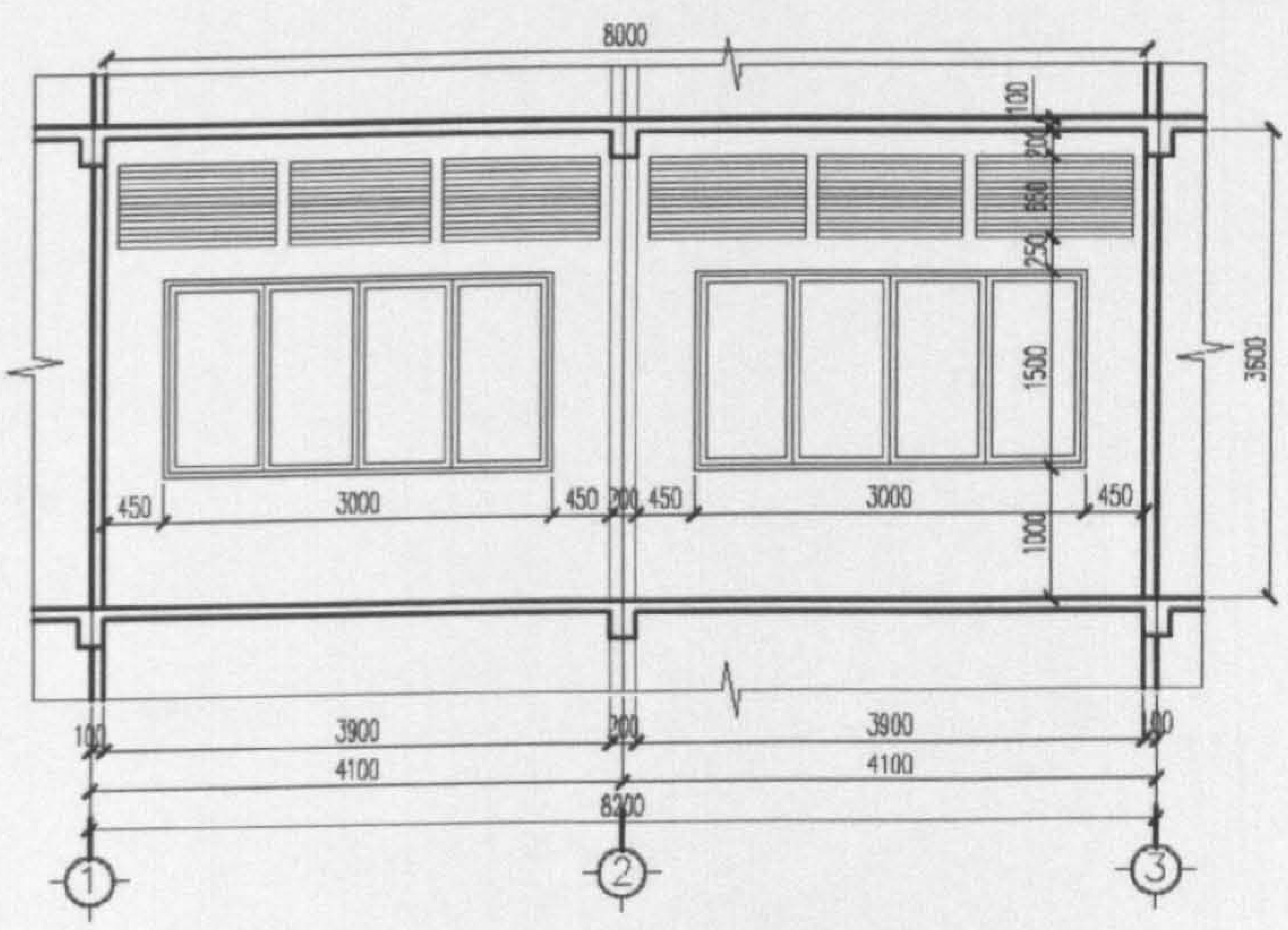

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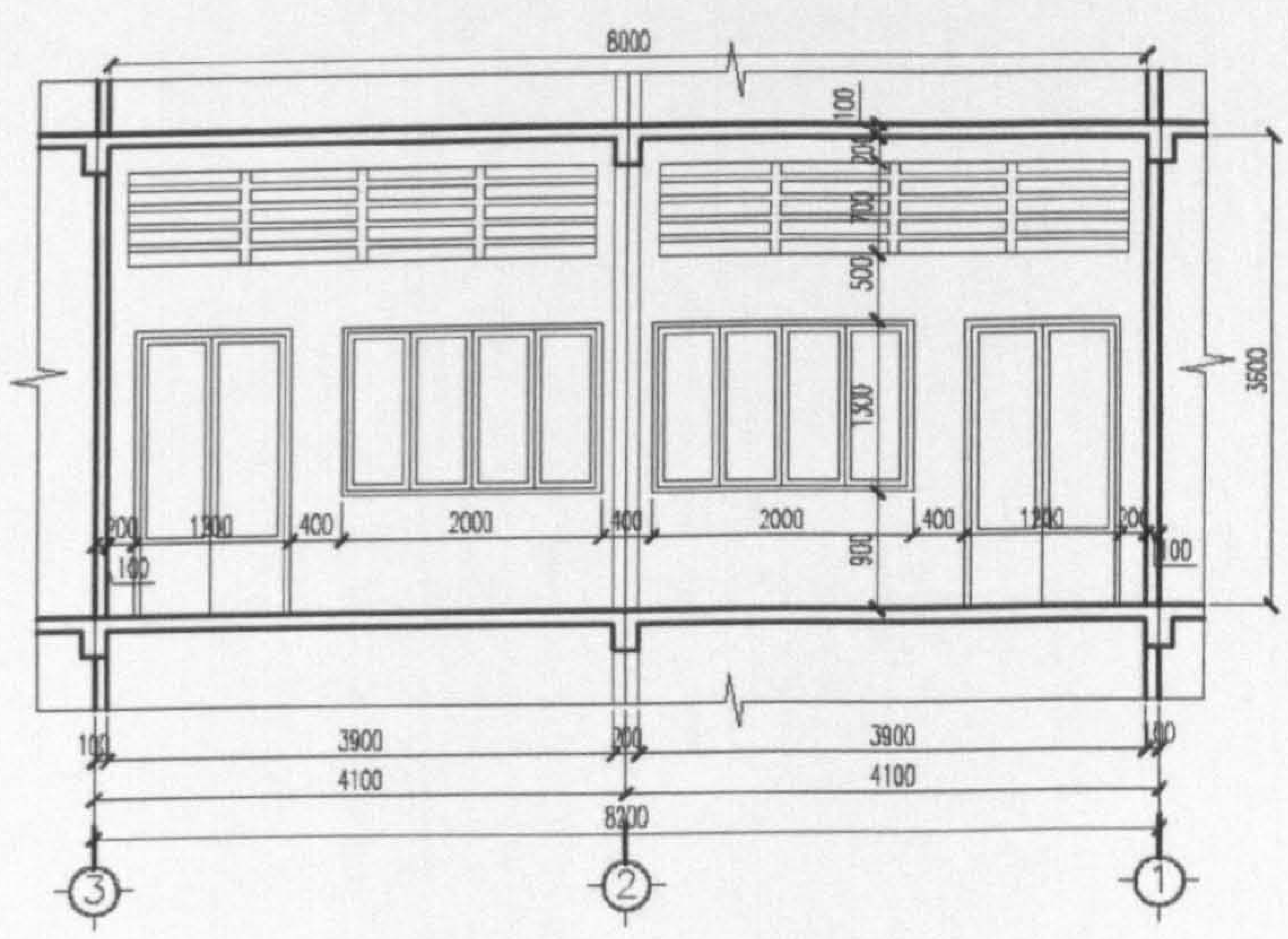


SECTION C - C
SCALE 1:100

LAM SON SCHOOL

Appendix D

Estimates of *ĐRASTN* of the surveyed classrooms

TCVN:29 (1991)

Table D.1 Estimates of *DRASTN* of window 1 and window 2 by equation.

Position	Symbol	Descriptions	School			
			Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
WALL 1 WINDOW 1	S_{cs1}	Total window 1 area (m^2)	3.15	3.22	2.40	4.50
	h_1	Distance from the head of window to working plane(m)	1.60	1.70	1.40	1.70
	τ_1	Glazing transmittance index	0.83	0.78	1.00	0.80
	τ_2	Window frame index	0.85	0.85	0.75	0.85
	τ_3	Roof structural index	1.00	1.00	1.00	1.00
	τ_4	Shading device index	0.80 *(Solid overhang, 0.8m width, 30°)*	0.80 *(Solid overhang, 0.8m width, 30°)*	0.32 *(Tilted window, 45°, and solid overhang,0.8m, 30°)*	0.85 *(Solid overhang, 0.8m width, 23°)*
	τ_5	Protection screen for roof windows	0.90	0.90	0.90	0.90
	τ_{cs1}	Window transmittance index	0.50	0.47	0.22	0.52
	K	Maintenance factor	1.20	1.20	1.20	1.20
	η_{cs}	Room-Windows index	18.00	16.00	17.00	19.00
	$\frac{B}{h_1}$	Calculating reference	4.38	3.53	4.29	4.71
	$\frac{L_1}{B}$	Calculating reference	0.50	0.50	0.50	0.50
	$\frac{L}{B}$	Calculating reference	1.11	1.33	1.17	1.00
	r_1	Reflectance correction factor	2.90	1.45	2.90	2.90
DRASTN$_1$	$DRASTN = \frac{S_{cs}.\tau_{cs}.r_1}{S_s.K.\eta_{cs}}.100$		0.39	0.24	0.18	0.47

Position	Symbol	Descriptions	School			
			Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
WALL 1 WINDOW 2	S_{cs2}	Total window 1 area (m^2)	3.15	3.22	2.40	4.50
	h_1	Distance from the head of window to working plane(m),	1.60	1.70	1.40	1.70
	τ_1	Glazing transmittance index	0.83	0.78	1.00	0.80
	τ_2	Window frame index	0.85	0.85	0.75	0.85
	τ_3	Roof structural index	1.00	1.00	1.00	1.00
	τ_4	Shading device index	0.80 *(Solid overhang, 0.8m width, 30°)*	0.80 *(Solid overhang, 0.8m width, 30°)*	0.32 *(Tilted window, 45°, and solid overhang,0.8m, 30°)*	0.85 *(Solid overhang, 0.8m width, 23°)*
	τ_5	Protection screen for roof windows	0.90	0.90	0.90	0.90
	τ_{cs2}	Window transmittance index	0.50	0.47	0.22	0.52
	K	Maintenance factor	1.20	1.20	1.20	1.20
	η_{cs}	Room-Windows index	18.00	16.00	17.00	19.00
	$\frac{B}{h_1}$	Calculating reference	4.38	3.53	4.29	4.71
	$\frac{L_1}{B}$	Calculating reference	0.50	0.50	0.50	0.50
	$\frac{L}{B}$	Calculating reference	1.11	1.33	1.17	1.00
	r_1	Reflectance correction factor	2.90	1.45	2.90	2.90
DRASTN$_2$	$DRASTN = \frac{S_{cs}.\tau_{cs}.r_1}{S_s.K.\eta_{cs}}.100$		0.39	0.24	0.18	0.47

Table D.2 Estimates of *DRASTN* of window 3 and window 4 (entrance) by equation.

Position	Symbol	Descriptions	School			
			Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
WALL 2 WINDOW 3	S_{cs2}	Total window 1 area (m²)	3.15	3.22	2.40	5.20
	h_1	Distance from the head of window to working plane (m)	1.60	1.70	1.40	1.40
	τ_1	Glazing transmittance index	0.83	0.78	1.00	0.80
	τ_2	Window frame index	0.85	0.85	0.75	0.85
	τ_3	Roof structural index	1.00	1.00	1.00	1.00
	τ_4	Shading device index	0.64 *(Solid overhang, 2.0 m width, 46 °)*	0.76 *(Solid overhang, 2.5 m width, 34 °)*	0.24 *(Tilted window, 45°, and solid overhang,1.6m, 50°)*	0.66 *(Solid overhang, 2.0 m width, 44 °)*
	τ_5	Protection screen for roof windows	0.90	0.90	0.90	0.90
	τ_{cs3}	Window transmittance index	0.40	0.45	0.16	0.40
	K	Maintenance factor	1.20	1.20	1.20	1.20
	η_{cs}	Room-Windows index	18.00	16.00	17.00	19.00
	$\frac{B}{h_1}$	Calculating reference	4.38	3.53	4.29	5.71
	$\frac{L_1}{B}$	Calculating reference	0.50	0.50	0.50	0.50
	$\frac{L}{B}$	Calculating reference	1.11	1.33	1.17	1.00
	r_1	Reflectance correction factor	2.90	1.45	2.90	2.90
	$DRASTN_3$	$DRASTN = \frac{S_{cs}.\tau_{cs}.r_1}{S_s.K.\eta_{cs}}.100$	0.31	0.23	0.13	0.42

Position	Symbol	Descriptions	School			
			Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
WALL 2 ENTRANCE	S_{cs4}	Total window 1 area (m²)	2.24	2.21	1.56	3.36
	h_1	Distance from the head of window to working plane (m)	1.70	1.70	1.40	1.40
	τ_1	Glazing transmittance index	1.00	1.00	1.00	1.00
	τ_2	Window frame index	0.85	0.85	0.75	0.85
	τ_3	Roof structural index	1.00	1.00	1.00	1.00
	τ_4	Shading device index	0.74 *(Solid overhang, 2.0 m width, 36 °)*	0.62 *(Solid overhang, 2.5 m width, 48 °)*	0.49 *(Solid overhang, 2.5 m width, 61 °)*	0.55 *(Solid overhang, 2.0 m width, 55 °)*
	τ_5	Protection screen for roof windows	0.90	0.90	0.90	0.90
	τ_{cs4}	Window transmittance index	0.57	0.47	0.33	0.42
	K	Maintenance factor	1.20	1.20	1.20	1.20
	η_{cs}	Room-Windows index	18.00	16.00	17.00	19.00
	$\frac{B}{h_1}$	Calculating reference	4.38	3.53	4.29	5.71
	$\frac{L_1}{B}$	Calculating reference	0.50	0.50	0.50	0.50
	$\frac{L}{B}$	Calculating reference	1.11	1.33	1.17	1.00
	r_1	Reflectance correction factor	2.90	1.45	2.90	2.90
	$DRASTN_4$	$DRASTN = \frac{S_{cs}.\tau_{cs}.r_1}{S_s.K.\eta_{cs}}.100$	0.31	0.16	0.17	0.28

Table D.3 Estimates of $DRASTN_{D1}$ of window 1 by Danhiluc chart.

Position	Symbol	Descriptions	School			
			Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
WINDOW 1	S_{cs1}	Total window 1 area (m^2)	3.15	3.22	2.40	4.50
	h_1	Distance from the head of window to working plane(m)	1.60	1.70	1.40	1.70
	τ_1	Glazing transmittance index	0.83	0.78	1.00	0.80
	τ_2	Window frame index	0.85	0.85	0.75	0.85
	τ_3	Roof structural index	1.00	1.00	1.00	1.00
	τ_4	Shading device index	0.80 *(Solid overhang, 0.8m width, 30°)*	0.80 *(Solid overhang, 0.8m width, 30°)*	0.32 *(Tilted window, 45°, and solid overhang,0.8m, 30°)*	0.85 *(Solid overhang, 0.8m width, 23°)*
	τ_5	Protection screen for roof windows	0.90	0.90	0.90	0.90
	τ_{cs}	Window transmittance index	0.50	0.47	0.22	0.52
	K	Maintenance factor	1.20	1.20	1.20	1.20
	η_{cs}	Room-Windows index	18.00	16.00	17.00	19.00
	$\frac{B}{h}$	Calculating reference	4.12	3.53	4.29	5.71
	$\frac{L_1}{B}$	Calculating reference	0.50	0.50	0.50	0.50
	$\frac{L}{B}$	Calculating reference	1.11	1.33	1.17	1.00
	r_1	Reflectance correction factor	2.90	1.45	2.90	2.90
	β	Height angle	14.00	19.00	14.00	13.00
	q	Sky luminance coefficient	0.64	0.73	0.64	0.64
	n_{1o}	Visible beam in section, no overhang impact	5.00	6.50	4.00	3.70
	n_1	Visible beam in section, with overhang impact	3.00	4.00	0.00	3.00
	n_2	Visible beam in plan	19.00	18.00	21.00	22.00
	ε_b	Direct daylight component	0.36	0.53	0.00	0.42
	L_{ob}	Length of obstruction	-	-	7.10	24.00
	H_{ob}	Height of obstruction	-	-	6.00	12.00
	a	Window width	-	-	2.00	3.00
	P	Distance from window surface to obtruction	-	-	7.30	0.00
	Z_1	Obstructing building index calculated in plan	-	-	1.48	14.12
	Z_2	Obstructing building index calculated in section	-	-	1.25	7.06
	R	External obstruction index	-	-	0.35	0.08
	n_r	Obstructing beam in section	-	-	3.00	3.70
	n_{z}	Obstructing beam in plan	-	-	23.00	5.00
	ε_{ch}	External reflected daylight component by obstructions	0.00	0.00	0.24	0.01
	$DRASTN_{D1}$	$DRASTN = (\varepsilon_b + \varepsilon_{ch}).r_1.\frac{\tau_{cs}}{K}$	0.45	0.30	0.13	0.55

Table D.4 Estimates of $DRASTN_{D2}$ of window 2 by Danhiluc chart.

Position	Symbol	Descriptions	School			
			Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
WINDOW 2	S_{cs1}	Total window 1 area (m^2)	3.15	3.22	2.40	4.50
	h_1	Distance from the head of window to working plane(m)	1.60	1.70	1.40	1.70
	τ_1	Glazing transmittance index	0.83	0.78	1.00	0.80
	τ_2	Window frame index	0.85	0.85	0.75	0.85
	τ_3	Roof structural index	1.00	1.00	1.00	1.00
	τ_4	Shading device index	0.80 *(Solid overhang, 0.8m width, 30°)*	0.80 *(Solid overhang, 0.8m width, 30°)*	0.32 *(Tilted window, 45°, and solid overhang, 0.8m, 30°)*	0.85 *(Solid overhang, 0.8m width, 23°)*
	τ_5	Protection screen for roof windows	0.90	0.90	0.90	0.90
	τ_{cs}	Window transmittance index	0.50	0.47	0.22	0.52
	K	Maintenance factor	1.20	1.20	1.20	1.20
	η_{cs}	Room-Windows index	18.00	16.00	17.00	19.00
	$\frac{B}{h_1}$	Calculating reference	4.12	3.53	4.29	5.71
	$\frac{L_1}{B}$	Calculating reference	0.50	0.50	0.50	0.50
	$\frac{L}{B}$	Calculating reference	1.11	1.33	1.17	1.00
	r_1	Reflectance correction factor	2.90	1.45	2.90	2.90
	β	Height angle	14.00	19.00	14.00	13.00
	q	Sky luminance coefficient	0.64	0.73	0.64	0.64
	n_{1o}	Visible beam in section, no overhang impact	5.00	6.50	4.00	0.00
	n_1	Visible beam in section, with overhang impact	3.00	4.00	2.30	0.00
	n_2	Visible beam in plan	19.00	18.00	21.00	0.00
	ε_b	Direct daylight component	0.36	0.53	0.31	0.00
	L_{ob}	Length of obstruction	-	-	7.10	34.00
	H_{ob}	Height of obstruction	-	-	3.00	3.00
	a	Window width	-	-	2.00	3.00
	P	Distance from window surface to obtruction	-	-	10.20	0.00
	Z_1	Obstructing building index calculated in plan	-	-	1.15	20.00
	Z_2	Obstructing building index calculated in section	-	-	0.49	1.76
	R	External obstruction index	-	-	0.36	0.25
	$n_{1'}$	Obstructing beam in section	-	-	0.30	3.70
	$n_{2'}$	Obstructing beam in plan	-	-	23.00	27.00
	ε_{cb}	External reflected daylight component by obstructions	0.00	0.00	0.02	0.25
	$DRASTN_{D2}$	$DRASTN = (\varepsilon_b + \varepsilon_{cb}).r_1 \frac{\tau_{cs}}{K}$	**0.45**	**0.30**	**0.17**	**0.31**

Table D.5 Estimates of $DRASTN_{D3}$ of window 3 by Danhiluc chart.

Position	Symbol	Descriptions	School			
			Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
WINDOW 3	S_{cs}	Total window 1 area (m2)	3.15	3.22	2.40	5.20
	h_1	Distance from the head of window to working plane(m)	1.60	1.70	1.40	1.40
	τ_1	Glazing transmittance index	0.83	0.78	1.00	0.80
	τ_2	Window frame index	0.85	0.85	0.75	0.85
	τ_3	Roof structural index	1.00	1.00	1.00	1.00
	τ_4	Shading device index	0.64 *(Solid overhang, 2.0 m width, 46 °)*	0.76 *(Solid overhang, 2.5 m width, 34 °)*	0.24 *(Tilted window, 45°, and solid overhang,1.6m, 50°)*	0.66 *(Solid overhang, 2.0 m width, 44 °)*
	τ_5	Protection screen for roof windows	0.90	0.90	0.90	0.90
	τ_{cs}	Window transmittance index	0.40	0.45	0.16	0.40
	K	Maintenance factor	1.20	1.20	1.20	1.20
	η_{cs}	Room-Windows index	18.00	16.00	17.00	19.00
	$\frac{B}{h'}$	Calculating reference	4.12	3.53	4.29	5.71
	$\frac{L'}{B}$	Calculating reference	0.50	0.50	0.50	0.50
	$\frac{L}{B}$	Calculating reference	1.11	1.33	1.17	1.00
	r_1	Reflectance correction factor	2.90	1.45	2.90	2.90
	β	Height angle	14.00	19.00	14.00	11.00
	q	Sky luminance coefficient	0.64	0.73	0.64	0.60
	n_{1o}	Visible beam in section, no overhang impact	5.00	6.50	4.00	1.00
	n_1	Visible beam in section, with overhang impact	2.00	1.00	4.00	1.00
	n_2	Visible beam in plan	21.00	19.00	21.00	6.00
	ε_b	Direct daylight component	0.27	0.14	0.54	0.04
	L_{ob}	Length of obstruction	-	20.20	-	27.00
	H_{ob}	Height of obstruction	-	9.00	-	9.00
	a	Window width	-	2.30	-	3.50
	P	Distance from window surface to obtruction	-	22.60	-	0.00
	Z_1	Obstructing building index calculated in plan	-	1.03	-	7.71
	Z_2	Obstructing building index calculated in section	-	0.62	-	6.43
	R	External obstruction index	-	0.45	-	0.12
	n_{r}	Obstructing beam in section	-	0.50	-	2.80
	$n_{2'}$	Obstructing beam in plan	-	24.00	0.00	23.00
	ε_{cb}	External reflected daylight component by obstructions	0.00	0.05	0.00	0.08
	$DRASTN_{D3}$	$DRASTN = (\varepsilon_b + \varepsilon_{cb}).r_1 \frac{\tau_{cs}}{K}$	0.26	0.10	0.21	0.11

Table D.6 Estimates of $DRASTN_{D4}$ of window 4 by Danhiluc chart.

Position	Symbol	Descriptions	School			
			Le Van Tam	Truong Cong Dinh	Ha Huy Tap	Lam Son
ENTRANCE	S_{cs}	Total window 1 area (m^2)	2.24	2.21	1.56	3.36
	h_1	Distance from the head of window to working plane(m)	1.70	1.70	1.40	1.40
	τ_1	Glazing transmittance index	1.00	1.00	1.00	1.00
	τ_2	Window frame index	0.85	0.85	0.75	0.85
	τ_3	Roof structural index	1.00	1.00	1.00	1.00
	τ_4	Shading device index	0.74 *(Solid overhang, 2.0 m width, 36°)*	0.62 *(Solid overhang, 2.5 m width, 48°)*	0.49 *(Solid overhang, 2.5 m width, 61°)*	0.55 *(Solid overhang, 2.0 m width, 55°)*
	τ_5	Protection screen for roof windows	0.90	0.90	0.90	0.90
	τ_{cs}	Window transmittance index	0.57	0.47	0.33	0.42
	K	Maintenance factor	1.20	1.20	1.20	1.20
	η_{cs}	Room-Windows index	18.00	16.00	17.00	19.00
	$\frac{B}{h_1}$	Calculating reference	4.12	3.53	4.29	5.71
	$\frac{L_1}{B}$	Calculating reference	0.50	0.50	0.50	0.50
	$\frac{L}{B}$	Calculating reference	1.11	1.33	1.17	1.00
	r_1	Reflectance correction factor	2.90	1.45	2.90	2.90
	β	Height angle	14.00	19.00	14.00	11.00
	q	Sky luminance coefficient	0.64	0.73	0.64	0.60
	n_{1o}	Visible beam in section, no overhang impact	5.00	6.50	4.00	1.00
	n_1	Visible beam in section, with overhang impact	2.00	1.00	0.00	1.50
	n_2	Visible beam in plan	11.00	11.00	0.00	31.00
	ε_b	Direct daylight component	0.14	0.08	0.00	0.28
	L_{ob}	Length of obstruction	-	9.70	-	28.00
	H_{ob}	Height of obstruction	-	9.00	-	4.50
	a	Window width	-	1.20	-	3.50
	P	Distance from window surface to obtruction	-	22.60	-	29.00
	Z_1	Obstructing building index calculated in plan	-	0.95	-	0.97
	Z_2	Obstructing building index calculated in section	-	0.62	-	0.39
	R	External obstruction index	-	0.45	-	0.30
	$n_{1'}$	Obstructing beam in section	-	0.50	-	1.40
	$n_{2'}$	Obstructing beam in plan	-	13.00	-	37.00
	ε_{ch}	External reflected daylight component by obstructions	0.00	0.03	0.00	0.16
	$DRASTN_{D4}$	$DRASTN = (\varepsilon_b + \varepsilon_{ch}).r_1 \frac{\tau_{cs}}{K}$	0.19	0.06	0.00	0.44

Appendix E

Results from the Waldram diagram plotting

This appendix provides further details of the horizontal Waldram diagram plotting from position P1 and position P3. The descriptions and illustrations of the plotting are presented in chapter 5.

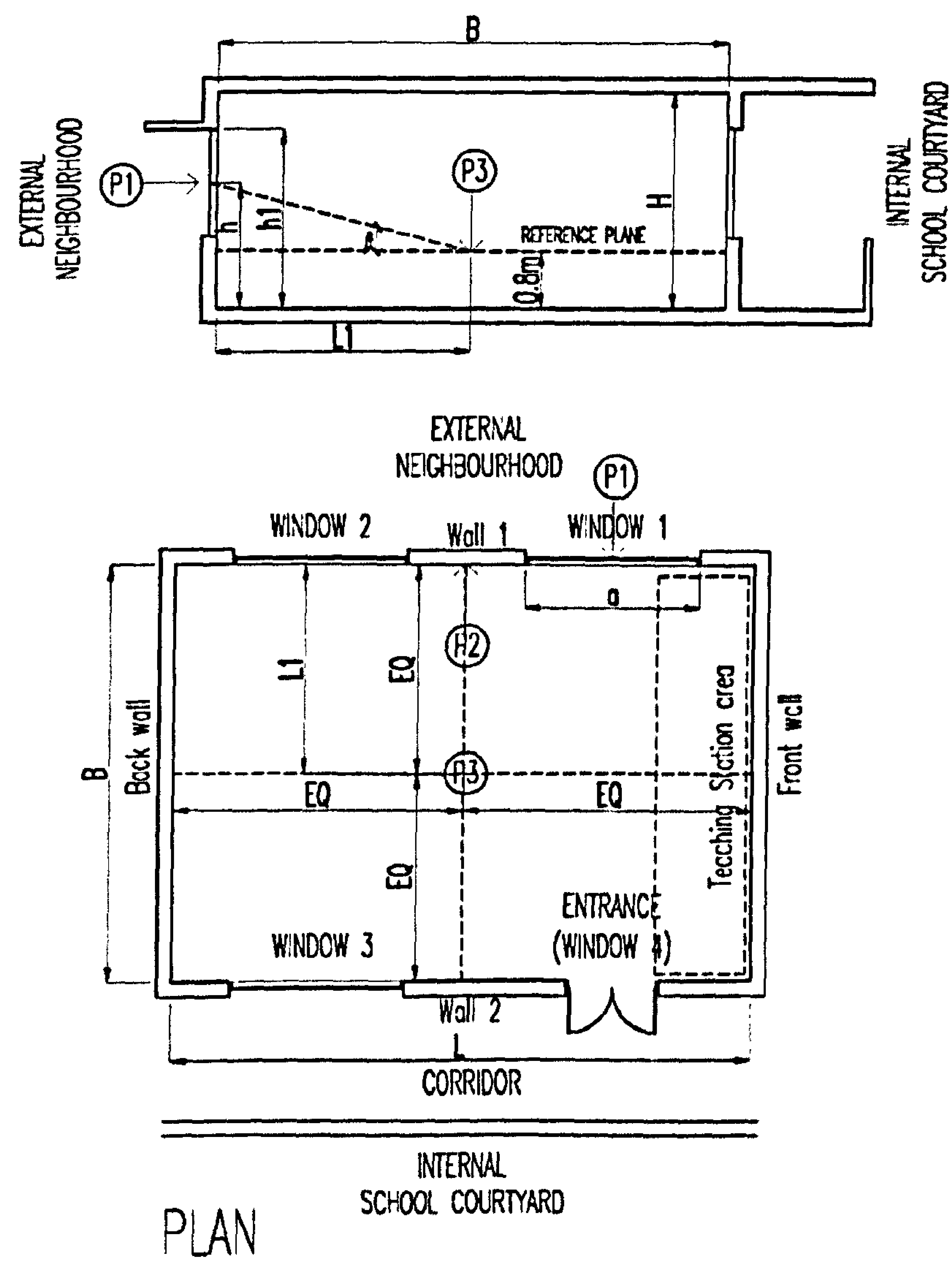


Figure E.1 Definitions of room geometry and positions of the reference points.

E1. Vertical plotting from P1

Table E.1 Estimates of direct vertical sky factor [%] from position P1.

DESCRIPTIONS	LE VAN TAM		TRUONG CONG DINH		HA HUY TAP		LAM SON	
	% Window area	Equivalent Sky factor	% Window area	Equivalent Sky factor	% Window area	Equivalent Sky factor	% Window area	Equivalent Sky factor
AREA OBSTRUCTED BY SHADINGS	31.75%	15.88%	31.75%	15.88%	38.02%	19.01%	15.35%	7.68%
AREA OBSTRUCTED BY EXTERNAL BUILDING	0.00%	0.00%	0.00%	0.00%	26.86%	13.43%	8.67%	4.33%
AREA OBSTRUCTED BY BLINDS	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
AREA OBSTRUCTED BY TREES	0.00%	0.00%	51.23%	25.61%	0.00%	0.00%	0.00%	0.00%
UNOBSTRUCTED AREA	68.25%	34.12%	17.02%	8.51%	35.12%	17.56%	75.98%	37.99%

Table E.2 Estimates of external reflected vertical sky factor [%] from position P1.

DESCRIPTIONS	LE VAN TAM SCHOOL	TRUONG CONG DINH SCHOOL	HA HUY TAP SCHOOL	LAM SON SCHOOL
	Equivalent Sky factor	Equivalent Sky factor	Equivalent Sky factor	Equivalent Sky factor
REFLECTED BY SHADINGS	0.00%	0.00%	0.00%	0.00%
REFLECTED BY EXTERNAL BUILDING	0.00%	0.00%	13.43%	4.33%
TRANSMITTED BY EXTERNAL BLINDS	0.00%	0.00%	0.00%	0.00%
TRANSMITTED& REFLECTED BY TREES	0.00%	10.25%	0.00%	0.00%
TOTAL	0.00%	10.25%	13.43%	4.33%

Table E.3 Estimates of vertical sky factor [%], as seen vertically from point P1 of window 1 plotted in *Waldram diagrams*.

	DESCRIPTIONS	School							
		LE VAN TAM		TRUONG CONG DINH		HA HUY TAP		LAM SON	
		% of window area (*)	SF (**)	% of window area (*)	SF (**)	% of window area (*)	SF (**)	% of window area (*)	SF (**)
DIRECT COMPONENTS	Area obstructed by shadings	31.75%	15.88%	31.75%	15.88%	38.02%	19.01%	15.35%	7.68%
	Area obstructed by external buildings	0%	0%	0%	0%	26.86%	13.43%	8.67%	4.33%
	Area obstructed by external blinds	0%	0%	0%	0%	0%	0%	0%	0%
	Area obstructed by trees	0%	0%	51.23%	25.61%	0%	0%	0%	0%
	Unobstructed area	68.25%	34.12%	17.02%	8.51%	35.12%	17.56%	75.98%	37.99%
EXTERNAL REFLECTED COMPONENTS	Reflected by shadings		0%		0%		0%		0.00%
	Reflected by external buildings		0%		0%		13.43%		4.33%
	Reflected by external blinds	N/A	0%	N/A	0%	N/A	0%	N/A	0.00%
	Transmitted & reflected by trees		0%		10.25%		0%		0.00%
	Total		0%		10.25%		13.43%		4.33%
TOTAL	(Direct + External Reflected)		34.12%		18.75%		30.99%		42.32%

(*) as percentage of obstructed area to the total window area

(**) SF: sky factor, as fraction of the whole sky. The total area of a Waldram diagram represents half a sky dome.

E2. Horizontal plotting from P3

Table E.4 Estimates of direct horizontal sky factor [%] contributed from each window, seen from P3.

ESTIMATES OF DIRECT SKY FACTOR CONTRIBUTED BY EACH WINDOW

	DESCRIPTIONS	School							
		LE VAN TAM		TRUONG CONG DINH		HA HUY TAP		LAM SON	
		% of window area (*)	SF (**)	% of window area (*)	SF (**)	% of window area (*)	SF (**)	% of window area (*)	SF (**)
WINDOW 1	Total window area plotted in the diagram	100.00%	1.06%	100.00%	1.79%	100.00%	1.19%	100.00%	1.15%
	Area obstructed by shadings	34.08%	0.36%	39.34%	0.71%	36.17%	0.43%	0%	0%
	Area obstructed by external buildings	0%	0%	0%	0%	0%	0%	3.76%	0.04%
	Area obstructed by external blinds	0%	0%	0%	0%	0%	0%	0%	0%
	Area obstructed by trees	0%	0%	49.71%	0.89%	0%	0%	0%	0%
	Unobstructed area	65.92%	0.70%	10.95%	0.20%	63.83%	0.76%	96.24%	1.11%
WINDOW 2	Total window area plotted in the diagram	100.00%	1.06%	100.00%	1.79%	100.00%	1.19%	100.00%	1.15%
	Area obstructed by shadings	34.08%	0.36%	39.34%	0.71%	36.17%	0.43%	0%	0%
	Area obstructed by external buildings	0%	0%	0%	0%	20.86%	0.25%	2.88%	0.03%
	Area obstructed by external blinds	0%	0%	0%	0%	0%	0%	0%	0%
	Area obstructed by trees	0%	0%	49.71%	0.89%	0%	0%	0%	0%
	Unobstructed area	65.92%	0.70%	10.95%	0.20%	42.98%	0.51%	97.12%	1.12%
WINDOW 3	Total window area plotted in the diagram	100.00%	1.04%	100.00%	1.79%	100.00%	1.19%	100.00%	1.00%
	Area obstructed by shadings	62.84%	0.65%	64.19%	1.15%	5.53%	0.07%	7.00%	0.07%
	Area obstructed by external buildings	0%	0%	0.0%	0.0%	0%	0%	21.13%	0.21%
	Area obstructed by external blinds	0%	0%	16.50%	0.30%	0%	0%	60.31%	0.60%
	Area obstructed by trees	0%	0%	6.61%	0.12%	0%	0%	0%	0%
	Unobstructed area	37.16%	0.39%	12.70%	0.23%	94.47%	1.13%	11.56%	0.12%
WINDOW 4	Total window area plotted in the diagram	100.00%	0.64%	100.00%	0.99%	100.00%	0.60%	100.00%	1.00%
	Area obstructed by shadings	60.73%	0.39%	58.69%	0.58%	6.23%	0.04%	7.00%	0.07%
	Area obstructed by external buildings	0%	0%	0%	0%	93.76%	0.57%	17.64%	0.18%
	Area obstructed by external blinds	0%	0%	14.73%	0.15%	0%	0%	65.06%	0.65%
	Area obstructed by trees	0%	0%	0%	0%	0%	0%	0%	0%
	Unobstructed area	39.27%	0.25%	26.58%	0.26%	0.01%	0%	10.29%	0.10%

(*) as percentage of obstructed area to the total window area.

(**) SF: sky factor, as fraction of the whole sky. The total area of a Waldram diagram represents half a sky dome.

Table E.5 Estimates of direct horizontal sky factor [%] contributed from each side, seen from P3.

ESTIMATES OF DIRECT SKY FACTOR CONTRIBUTED FROM EACH SIDE

	DESCRIPTIONS	School							
		LE VAN TAM		TRUONG CONG DINH		HA HUY TAP		LAM SON	
		% of window area (*)	SF (**)	% of window area (*)	SF (**)	% of window area (*)	SF (**)	% of window area (*)	SF (**)
WALL 1 (WINDOW 1 AND WINDOW 2)	Total window area plotted in the diagram	100.00%	2.12%	100.00%	3.59%	100.00%	2.39%	100.00%	2.31%
	Area obstructed by shadings	34.08%	0.72%	39.34%	1.41%	36.17%	0.86%	0%	0%
	Area obstructed by external buildings	0%	0%	0%	0%	10.43%	0.25%	3.32%	0.08%
	Area obstructed by external blinds	0%	0%	0%	0%	0%	0%	0%	0%
	Area obstructed by trees	0%	0%	49.71%	1.78%	0%	0%	0%	0%
	Unobstructed area	**65.92%**	**1.40%**	**10.95%**	**0.39%**	**53.40%**	**1.27%**	96.68%	2.23%
WALL 2 (WINDOW 3 AND WINDOW 4)	Total window area plotted in the diagram	100.00%	1.68%	100.00%	2.78%	100.00%	1.80%	100.00%	2.00%
	Area obstructed by shadings	62.03%	1.04%	62.23%	1.73%	5.77%	0.10%	7.00%	0.14%
	Area obstructed by external buildings	0%	0%	0%	0%	31.49%	0.57%	19.38%	0.39%
	Area obstructed by external blinds	0%	0%	15.86%	0.44%	0%	0%	62.69%	1.26%
	Area obstructed by trees	0%	0%	4.25%	0.12%	0%	0%	0%	0%
	Unobstructed area	37.97%	0.64%	17.66%	0.49%	62.75%	1.13%	10.92%	0.22%
TOTAL (SUM OF ALL WINDOWS)	Total window area plotted in the diagram	100.00%	3.81%	100.00%	6.37%	100.00%	4.18%	100.00%	4.31%
	Area obstructed by shadings	46.43%	1.77%	49.34%	3.14%	23.11%	0.97%	3.26%	0.14%
	Area obstructed by external buildings	0%	0%	0%	0%	19.47%	0.81%	10.78%	0.46%
	Area obstructed by external blinds	0%	0%	6.93%	0.44%	0%	0%	29.13%	1.26%
	Area obstructed by trees	0%	0%	29.86%	1.90%	0%	0%	0%	0%
	Unobstructed area	**53.57%**	**2.04%**	**13.88%**	**0.88%**	**57.42%**	**2.40%**	**56.83%**	**2.45%**

(*) as percentage of obstructed area to the total window area

(**) SF: sky factor, as fraction of the whole sky. The total area of a Waldram diagram represents half a sky dome.

Table E.6 Estimates of external reflected sky factor [%] contributed from each window, seen from P3.

ESTIMATES OF EXTERNAL REFLECTED SKY FACTOR CONTRIBUTED BY EACH WINDOW

	DESCRIPTIONS	LE VAN TAM SF (**)	TRUONG CONG SF (**)	HA HUY TAP SF (**)	LAM SON SF (**)
WINDOW 1	Reflected by shadings	0%	0%	0%	0%
	Reflected by external buildings	0%	0%	0%	0.01%
	Reflected by external blinds	0%	0%	0%	0%
	Transmitted & reflected by trees	0%	0.36%	0%	0%
	Total	0%	0.36%	0%	0.01%
WINDOW 2	Reflected by shadings	0%	0%	0%	0%
	Reflected by external buildings	0%	0%	0.05%	0.01%
	Reflected by external blinds	0%	0%	0%	0%
	Transmitted & reflected by trees	0%	0.36%	0%	0%
	Total	0%	0.36%	0.05%	0.01%
WINDOW 3	Reflected by shadings	0%	0%	0%	0%
	Reflected by external buildings	0%	0%	0%	0.04%
	Reflected by external blinds	0%	0.09%	0%	0.18%
	Transmitted & reflected by trees	0%	0.05%	0%	0%
	Total	0%	0.14%	0%	0.22%
WINDOW 4	Reflected by shadings	0%	0%	0%	0%
	Reflected by external buildings	0%	0%	0.11%	0.04%
	Reflected by external blinds	0%	0.04%	0%	0.20%
	Transmitted & reflected by trees	0%	0%	0%	0%
	Total	0%	0.04%	0.11%	0.23%

(**) SF: sky factor, as fraction of the whole sky. The total area of a Waldram diagram represents half a sky dome.

Table E.7 Estimates of external reflected sky factor [%] contributed from each side, seen from P3.

ESTIMATES OF EXTERNAL REFLECTED SKY FACTOR CONTRIBUTED BY EACH SIDE

	DESCRIPTIONS	School			
		LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON
		SF (**)	SF (**)	SF (**)	SF (**)
WALL 1 (WINDOW 1 + WINDOW 2)	Reflected by shadings	0%	0%	0%	0%
	Reflected by external buildings	0%	0%	0.05%	0.02%
	Reflected by external blinds	0%	0%	0%	0%
	Transmitted & reflected by trees	0%	0.71%	0%	0%
	Total	0%	0.71%	0.05%	0.02%
WALL 2 (WINDOW 3 + WINDOW 4)	Reflected by shadings	0%	0%	0%	0%
	Reflected by external buildings	0%	0%	0.11%	0.08%
	Reflected by external blinds	0%	0.13%	0%	0.38%
	Transmitted & reflected by trees	0%	0.05%	0%	0%
	Total	0%	0.18%	0.11%	0.45%
TOTAL (SUM OF ALL WINDOWS)	Reflected by shadings	0%	0%	0%	0%
	Reflected by external buildings	0%	0%	0.16%	0.09%
	Reflected by external blinds	0%	0.13%	0%	0.38%
	Transmitted & reflected by trees	0%	0.76%	0%	0%
	Total	0%	0.89%	0.16%	0.47%

(**) SF: sky factor, as fraction of the whole sky. The total area of a Waldram diagram represents half a sky dome.

Table E.8 Estimates of total sky factor [%] contributed from each side, seen from P3.

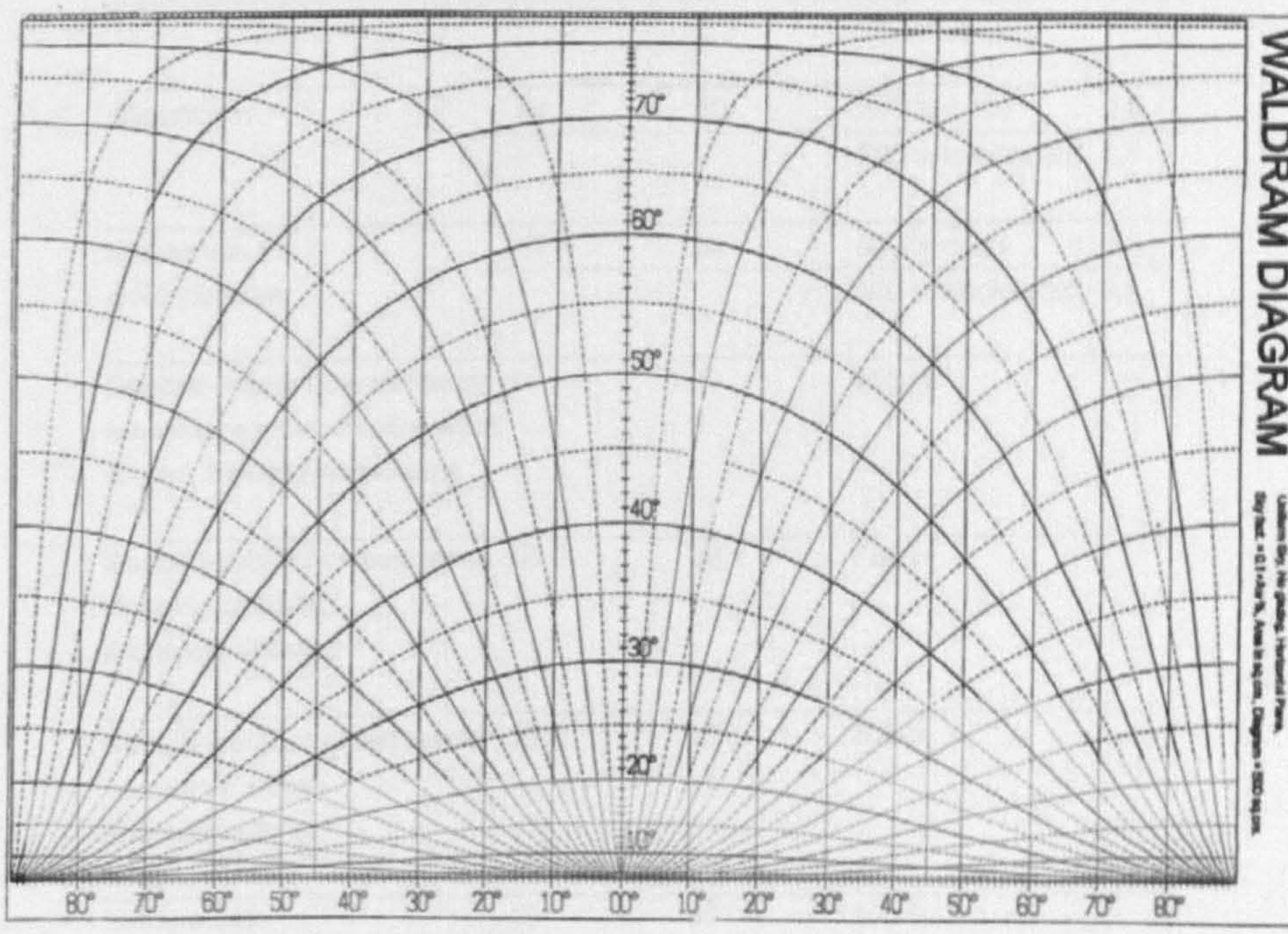
DESCRIPTIONS	POSTION	School			
		LE VAN TAM	TRUONG CONG DINH	HA HUY TAP	LAM SON
DIRECT AND EXTERNAL REFLECTED COMPONENTS	WINDOW 1	0.70%	0.55%	0.76%	1.12%
	WINDOW 2	0.70%	0.55%	0.56%	1.13%
	Windows on wall 1	***1.40%***	***1.11%***	***1.32%***	***2.25%***
	WINDOW 3	0.39%	0.36%	1.13%	0.34%
	WINDOW 4	0.25%	0.31%	0.11%	0.33%
	Windows on wall 2	***0.64%***	***0.67%***	***1.24%***	***0.67%***
	TOTAL	**2.04%**	**1.78%**	**2.57%**	**2.92%**

Appendix F

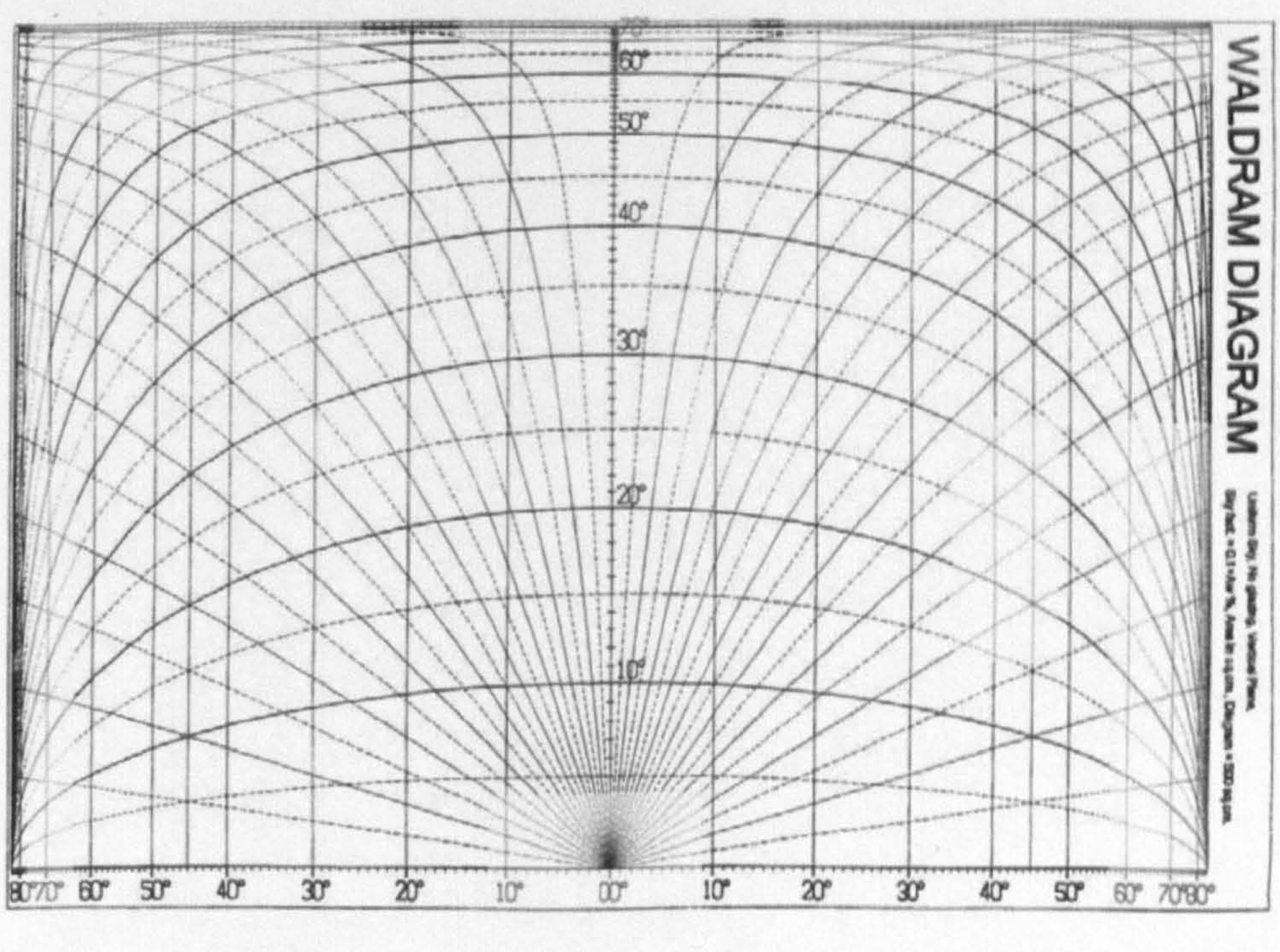
Waldram Diagrams for windows with no glazing, and under uniform sky

(Wilkinson, 2008)

Horizontal diagram



Vertical diagram



Appendix G

Recommendations for Classroom illuminance

Table G.1 Classroom illuminance, excerpt from European code EN 12464-1. (Zumtobel, 2009)

	UGR	Ra	Em	g_1
Classroom	19	80	300 lx room	0,5
			500 lx blackboard	0,7
Classroom for adult classes	19	80	500 lx room	0,5
			500 lx blackboard	0,7
Special-subject classrooms: laboratories, productive work rooms, training workshops	19	80	500 lx	
Special-subject classrooms: drawing classes, technical drawing	16	80	750 lx	
Special-subject classrooms: computer rooms Requirements for a DSE workstation	19	80	300 lx	
Lecture hall	19	80	500 lx	

Table G.2 Classroom illuminance in UK lighting codes. (CIBSE, 2002)

Educational buildings

	Maintained illuminance (lux)	Limiting glare rating	Minimum colour rendering (R_a)	Notes
Classrooms, tutorial rooms	300	19	80	1
Classrooms for evening classes and adult education	500	19	80	1
Lecture hall	500	19	80	1
Blackboard	500	19	80	2
Demonstration table	500	19	80	3
Art rooms	500	19	80	
Art rooms in art schools	750	19	90	4
Technical drawing rooms	750	16	80	
Practical rooms and laboratories	500	19	80	
Handicraft rooms	500	19	80	
Teaching workshops	500	19	80	
Music practice rooms	300	19	80	
Computer practice rooms	300	19	80	5
Language laboratory	300	19	80	
Preparation rooms and workshops	500	22	80	
Entrance halls	200	22	80	
Circulation areas, corridors	100	25	80	
Stairs	150	25	80	
Student common rooms and assembly halls	200	22	80	
Teachers' rooms	300	19	80	
Stock rooms for teaching materials	100	25	80	
Sports halls, gymnasiums, swimming pools	300	22	80	6
School canteens	200	22	80	
Kitchen	500	22	80	

Table G.3 Classroom illuminance in US Code: ANSI-IESNA-RP3-00, categoried by activities. Classroom illuminance are classfied as either D or E (ANSI/IESNA:RP3, 2000).

Orientation and simple visual tasks. Visual performance is largely unimportant. These tasks are found in public spaces where reading and visual inspection are only occasionally performed. Higher levels are recommended for tasks where visual performance is occasionally important		
A	Public spaces	30 lux (3 fc)
B	Simple orientation for short visits	50 lux (5 fc)
C	Working spaces where simple visual tasks are performed	100 lux (10 fc)
Common visual tasks. Visual performance is important. These tasks are found in commercial, industrial and residential applications. Recommended illuminance levels differ because of the characteristics of the visual task being illuminated Higher levels are recommended for visual tasks with critical elements of low contrast or small size.		
D	Performance of visual tasks of high contrast and large size	300 lux (30 fc)
E	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size	500 lux (50 fc)
F	Performance of visual tasks of low contrast and small size	1000 lux (100 fc)
Special visual tasks. Visual performance is of critical importance. These tasks are very specialized, including those with very small or very low contrast critical elements. Recommended illuminance levels should be achieved with supplementary task lighting. Higher recommended levels are often achieved by moving the light source closer to the task.		
G	Performance of visual tasks near threshold	3000-10,000 lux (300-1000 fc)

Table G.4. Classroom illuminance, excerpt from Australian/New Zealand codes AUS/NZS 1680.2.3: Interior Lighting – Education and training facilities. (Pries, 2008).

Source: AS1680.2.3 (Interior lighting, Part 2.3: Educational and training facilities)

Type of interior or activity		Illuminance lux
Classrooms:	General use classrooms	240
	Laboratories, Music Rooms	320
Libraries:	Audio listening areas	160
	Audio visual areas, Book Stacks	240
Circulation & Amenity Areas:	Toilets, change rooms, locker rooms, cleaners rooms	80
	Corridors, passage ways, ramps	40
	Stairs	Internal: 80 External: 20
	Entrance halls, lobbies, foyers, waiting rooms	160
	Enquiry desks	320
Administration areas:	General tasks involving typing, reading, writing	320
	Background/environment	160
	Meeting rooms	320
	Training rooms, seminar rooms	240
	Photocopying	Intermittent: 160 Sustained: 240
First Aid Centres		Rest rooms: 40 Treatment rooms: 400
Cafeterias/ Kitchens		General: 160 Counters, food preparation, cooking, washing up: 240
Indoor Sports Facilities		Recreation & training: 300 Competition: 500

Appendix H

Summary of Recommendations for classroom lighting proposed by Vietnam Energy Efficient Public Lighting Project (VEEPL,2008)

VEEPL Proposed classroom lighting requirements		
Description	Value	Details
1. Maintained Illuminance ***Em:***		
- Working plan (desk)	≥ 300 lux	
- Teaching board (vertical)	≥ 300 lux	
2. Glare index	Minimal	
3. Uniformity		*(no specific detail given)*
- Working plan (desk)	> 0.7	
- Teaching board (vertical)	> 0.6	
- Lighting flickering	Minimal	using 20-30kHz ballast
- Colour Rendering Index	83	Using T8 fluorescent lamp 100% Triphosphor
- Light colour	Soft white	5500K -6500K
- Lighting Power Density (LPD)	LPD < $13W/m^2$	

Appendix I

General Characteristics of Popular Light Sources

Table I.1 Colour and Colour Rendering Characteristics of Common Light Sources.

(IESNA, 2000)

Lamp	x	y	CCT (K)	R_a	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}	R_{13}	R_{14}
Fluorescent																		
CIE F1, Daylight	0.313	0.337	6430	76	69	84	92	73	74	80	62	53	−47	61	67	75	73	95
CIE F2, Cool white	0.372	0.375	4230	64	56	77	90	57	59	67	74	33	−84	45	40	54	60	94
CIE F3, White	0.409	0.394	3450	57	48	72	90	46	49	59	68	21	−102	36	31	38	52	94
CIE F4, Warm white	0.440	0.403	2940	51	42	70	90	38	41	54	65	11	−111	31	18	26	47	94
CIE F5	0.314	0.345	6350	72	83	80	91	67	68	75	81	48	−68	54	61	58	67	94
CIE F6	0.378	0.388	4150	59	49	72	88	51	52	60	73	27	−105	35	38	42	54	93
CIE F7, Broad-band	0.313	0.329	6500	90	89	92	91	91	90	89	93	87	61	78	89	87	90	94
CIE F8, Broad-band	0.346	0.359	5000	95	87	96	91	97	96	83	90	97	90	63	95	80	97	95
CIE F9, Broad-band	0.374	0.373	4150	90	80	93	90	90	89	88	94	89	70	79	67	93	80	94
CIE F10, 3 narrow bands	0.346	0.359	5000	81	93	90	53	86	83	74	89	80	27	42	66	51	63	69
CIE F11, 3 narrow bands	0.380	0.377	4000	83	98	93	50	88	87	77	88	79	25	47	72	53	97	67
CIE F12, 3 narrow bands	0.437	0.404	3000	83	99	95	54	89	88	83	89	68	1	63	77	53	98	68
Cool white deluxe	0.375	0.367	4080	89	92	91	84	89	90	86	89	89	73	74	90	78	90	90
Warm white deluxe	0.440	0.403	2940	73	72	80	81	71	69	67	83	86	16	43	60	43	73	88
Triphosphor, 3000 K	0.440	0.403	3000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Triphosphor, 3500 K	0.413	0.393	3500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Triphosphor, 4100 K	0.376	0.387	4100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Triphosphor, 6500 K	0.313	0.337	6500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Triphosphor, deluxe 2700 K	0.463	0.415	2700	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Triphosphor, deluxe 3000 K	0.437	0.402	3000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Triphosphor, deluxe 3600 K	0.413	0.303	3600	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Triphosphor, deluxe 4100 K	0.376	0.387	4100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Triphosphor, deluxe 5000 K	0.346	0.359	5000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
HID																		
Metal halide	0.374	0.383	4220	67	59	84	88	63	67	84	67	21	−113	69	60	78	67	92
Metal halide, coated	0.388	0.379	3800	70	64	88	86	66	71	80	67	26	−88	73	67	84	72	91
Mercury, clear	0.308	0.377	6410	18	−0	32	51	7	8	8	47	−4	−200	−53	−17	−21	1	70
Mercury, coated	0.405	0.402	3600	49	44	60	59	45	40	35	68	41	−66	−5	20	−8	40	75
High pressure sodium	0.519	0.417	2100	24	15	56	56	−5	14	56	37	−45	−197	45	−29	34	21	71
Xenon	0.324	0.324	5920	94	94	91	90	96	95	92	95	96	81	81	97	93	92	95
Other																		
Low pressure sodium	0.569	0.421	1740	−44	−68	44	−2	−101	−67	29	−23	−165	−492	20	−128	−21	−39	31
Tungsten halogen	0.424	0.399	3190	100	100	100	100	100	100	99	100	100	100	99	100	100	100	100

Table I.2 Properties of Common Light Sources. (IESNA, 2000)

Source Type and Correlated Color Temperature	Lamp Watts	Initial Lumens	Efficacy (LPW)[1]	Lumen Maintenance[2]	Life (Hours)	CRI	Starting and Warmup Time[3] (Minutes)	Dimming Range (Percent Light Output)
Standard incandescent filament 2700 K	100	1690	17	85	750	100	0	100–0
Tungsten-halogen (linear), 2950 K	300	6000	20	95	2000	100	0	100–0
Tungsten-halogen (reflector), 2850 K	90	1280[5]	14	95	2500	100	0	100–0
Tungsten-halogen (low voltage reflector), 3000 K–3200 K	50	900[5]	18	95	4000	100	0	100–0
Fluorescent T-5 4 ft,[7] 3000 K–4100 K	28	2900[8]	104	95	20,000	85	0	100–1
High output fluorescent T-5 4 ft,[7] 3000 K–4000 K	54	5000[8]	93	95	20,000	85	0	100–1
Fluorescent T-8 4 ft, 3000 K–4100 K	32	2800	88	85	20,000	75	0	100–1
Reduced wattage T-12 4 ft, 3500 K	34	2800	82	85	20,000	73	0	N/A[9]
Slimline reduced wattage 8 ft 3000 K–5000 K	60	6900	96	80	12,000	85	0	N/A[9]
High output reduced wattage 8 ft, 4100 K	95	8000	84	75	12,000	62	0	100–1
Compact fluorescent (long twin), 3000 K–4100 K	38	3300	87	85	20,000	82	1	100–5
Compact fluorescent (double), 2700 K–4100 K	26	1800	70	85	10,000	82	1	100–5[6]
Mercury vapor, 6800 K	175	7900	45	60	24,000	20	< 10	100-10
Metal halide, low wattage, 3200 K	100	8075	81	85	10,000	70	< 5	100–50[6]
Metal halide, high wattage, 4000 K	400	36,000	90	80	20,000	65	< 10	100–50[6]
HPS, low wattage, 2100 K	70	6300	90	90	24,000	21	< 5	100–50[6]
HPS, high wattage (diffuse), 2100 K	250	26,000	104	90	24,000	21	< 5	100–50[6]

* See manufacturers' catalogs for specific data.

1. Efficacy for lamp is shown. Ballasting is required for all lamps except standard incandescent and tungsten-halogen.
2. Percent of initial lumens for illuminance calculations.
3. Time interval to reach usable light output.
4. Four-pin lamp required.
5. The important performance parameters for reflector lamps are beam angle and maximum center beam intensity.
6. Dimming below the lower value results in significant color shift.
7. Exact lamp length = 1149 mm.
8. Lumen output measured at 35°C (95°F) ambient.
9. Dimming ballasts are currently not available for this lamp.

Appendix J

TCVN: 29 (1991): *ĐRASTN Method*

The process comprises of two steps:

- STEP 1: Defining the window area to fulfil minimum *ĐRASTN*, by using the equations provided by the code
- STEP 2: Verifying the *ĐRASTN* by using *Danhiluc chart*

STEP 1:

For a side lit room, the window area S_c is obtained by

$$100.\frac{S_{cs}}{S_s} = \frac{ĐRASTN.K.\eta_{cs}}{\tau_{cs}.r_1} \quad (J.1)$$

Where:

	S_{cs}:	Total window area [m^2]
	S_s:	Total floor area [m^2]
	K:	Maintenance factor (by dirt, cleaning frequency), expressed as a decimal, often taking K=1.2
	η_{cs}:	Window-Room index, expressed as a decimal, obtained from table J.1
	τ_{cs}:	Window transmittance index: $\tau_{cs} = \tau_1 . \tau_2 . \tau_3 . \tau_4 . \tau_5$
	τ_1:	Glazing transmittance index, expressed as a decimal, obtained from table J.2
	τ_2:	Window frame index, expressed as a decimal, obtained from table J.3
	τ_3:	Roof structural index for roof windows; for side windows the value is given as $\tau_3 = 1$

τ_4: Shading device index, expressed as a decimal, from table J.5

τ_5: Protection screen index for roof windows, expressed as a decimal, for side window $\tau_5 = 0.9$

r_1: Reflectance correction factor by internal reflected light and external reflected light from ground, expressed as a decimal, obtained from table J.6.

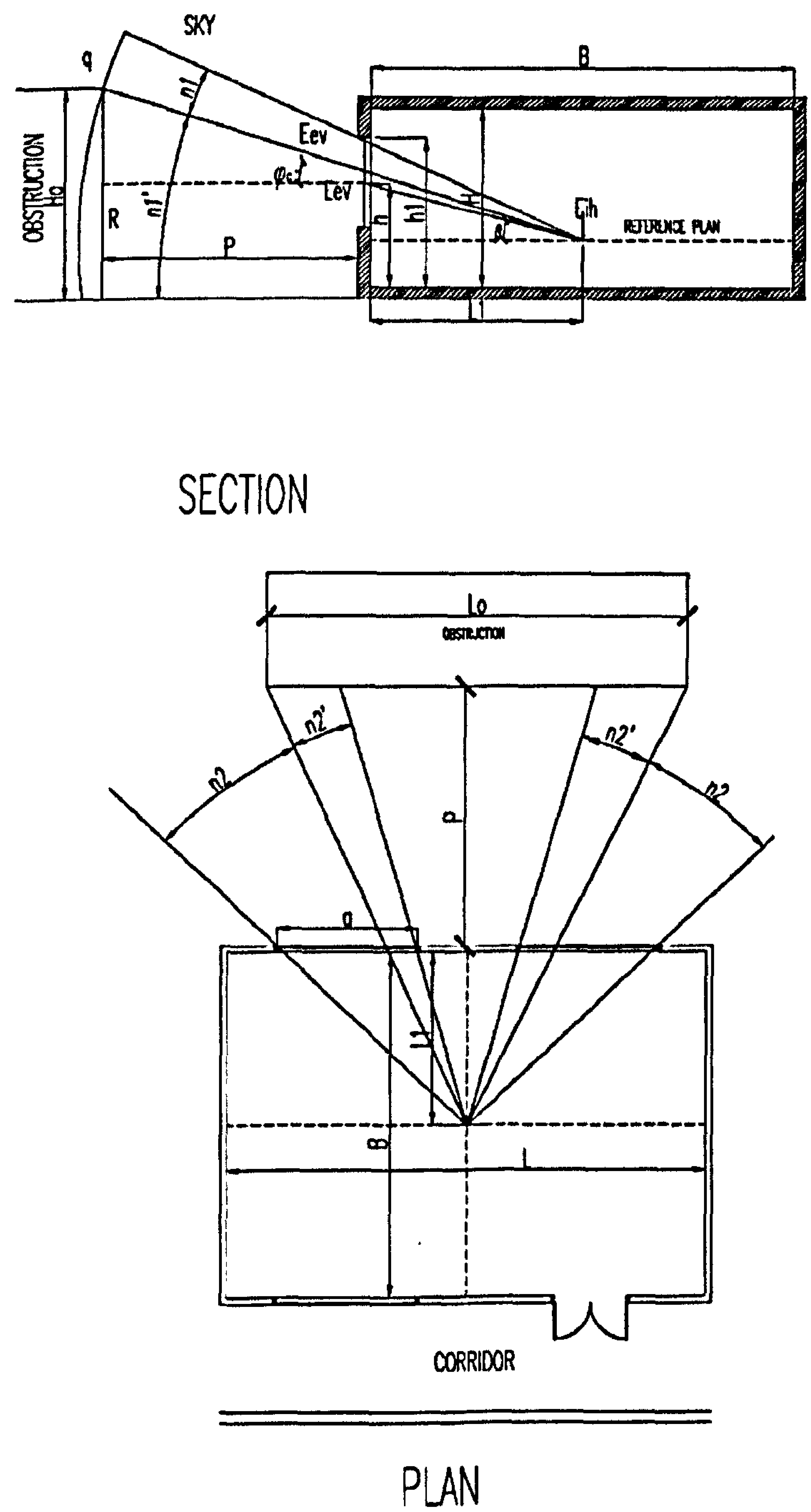


Figure J.1 Room geometry indices.

Table J.1 Window-room index ηcs. L: room length, B: room width, h_1: distance from window head to working plan.

$\frac{L}{B}$	Window index ηcs as per $\frac{B}{h1}$							
	1	1.5	2	3	4	5	7.5	10
Over 4	6.5	7	7.5	8	9	10	11	12.5
3	7.5	8	8.5	9.5	10	11	12.5	14
2	8.5	9	9.5	10,5	11.5	13	15	17
1.5	9.5	10.5	13	15	17	19	21	23
	11	15	16	18	21	20	26.5	29
	18	23	31	37	45	54	66	-

Table J.2 Glazing transmittance index τ_1

Material	τ1
- Single glazing	0.9
- 6mm-8mm glazing	0.8
- Glazing with net	0.6
- Fritted glazing	0.65
- Organic glazing	
+ Transparent	0.9
+ Milky	0.6
- Hollow glass structure	
+ Diffusing	0.5
+ Transparent	0.55

Table J.3 Window frame index τ_2 .

Window frame type	τ2
- Wooden frame	
+ Single door	0.8
+ Double door	0.75
- Metal frame (aluminium or steel)	
+ Single	0.9
+ Double door	0.85
- Concrete – Hollow glass structure	0.85

Table J.4 Structural obstruction index τ_3.

Construction Structure	τ4
- Steel truss	0.9
- Concrete or wood truss	0.8
- Onsite constructed slab and beam framing type:	
+ Section height > 50 cm	0.8
+ Section height < 50 cm	0.9

Table J.5 Shading device index τ_4.

Shading type and feature	τ_5
- No shading device	1
- Solid overhang 15^0- Solid overhang 30^0	0.95
- Louvered overhang 15^0	0.8
- Louvered overhang 30^0	0.95
- Flip windows, shading angle 45^0	0.82
- Horizontal Fin 15^0	0.4
- Horizontal Fin 30^0	0.95
- Horizontal Fin 45^0	0.85
- Louvered window with 1cm louver thickness, 10cm spacing, louvers tilt angle 15^0	0.7
- Louvered window with 1cm louver thickness, 10cm spacing, louvers tilt angle 30^0	0.6
- Improved louvered window with 1cm louver thickness, 10cm spacing, louvers tilt angle 15^0	0.61
- Improved louvered window with 1cm louver thickness, 10cm spacing, louvers tilt angle 30^0	0.5

Table J.6 Reflectance correction factor r_1

$\frac{B}{h1}$	$\frac{L1}{B}$	r_1 for side lighting, rtb 0,5, $\frac{L1}{B}$ = 0.5	0,5: 1	0,5: >2	0,3: 0.5	0,3: 1	0,3: >2
From 1 to 1.5	0.1	1.05	1.05	1.05	1.05	1	1
	0.5	1.4	1.3	1.2	1.15	1.1	1.1
	1	2.1	1.9	1.5	1.4	1.3	1.2
From 1.5 to 2.5	0	1.05	1.05	1.05	1.05	1	1
	0.3	1.3	1.2	1.1	1.15	1.1	1.05
	0.5	1.85	1.6	1.3	1.3	1.2	1.1
	0.7	2.45	2.15	1.7	1.55	1.4	1.25
	1	3.8	3.3	2.4	2	1.8	1.5
From 2.5 to 3.5	0.1	1.1	1	1.05	1	1	1
	0.2	1.15	1.1	1.05	1.05	1.05	1.05
	0.3	1.2	1.15	1.1	1.1	1.1	1.05
	0.4	1.35	1.25	1.2	1.15	1.1	1.1
	0.5	1.6	1.45	1.3	1.25	1.15	1.1
	0.6	2	1.75	1.45	1.4	1.3	1.2
	0.7	2.6	2.2	1.7	1.6	1.5	1,3
	0.8	3.6	3.1	2.4	1.9	1.7	1.4
	0.9	5.3	4.2	3	2.2	1.85	1.5
	1	7.2	5.4	4.3	2.6	2.2	1.7
Above 3.5	0.1	1.2	1.15	1.1	1.05	1.05	1
	0.2	1.4	1.3	1.2	1.1	1.05	1.05
	0.3	1.75	1.5	1.3	1.25	1.1	1.1
	0.4	2.4	2.1	1.8	1.4	1.2	1.2
	0.5	3.4	2.9	2.5	1.7	1.3	1.3
	0.6	4.6	3.8	3.1	2	1.5	1.5
	0.7	6	4.7	3.7	2.3	1.7	1.7
	0.8	7.4	5.8	4.7	2.6	1.9	1.9
	0.9	9	7.1	5.6	3	2.1	2.1
	1	10	7.3	5.7	3.5	2.5	2.5

Where: (1) L1: distance from the calculation point to the partial wall.

(2) ρ_{tb}: mean reflectance factor, to be calculated as follows:

$$S_{tb} = \frac{r_{tr}.S_{tr} + \rho_{tư}.S_{tư} + \rho_s.S_s}{S_{tr} + S_{tư} + S_s} \qquad (B.3)$$

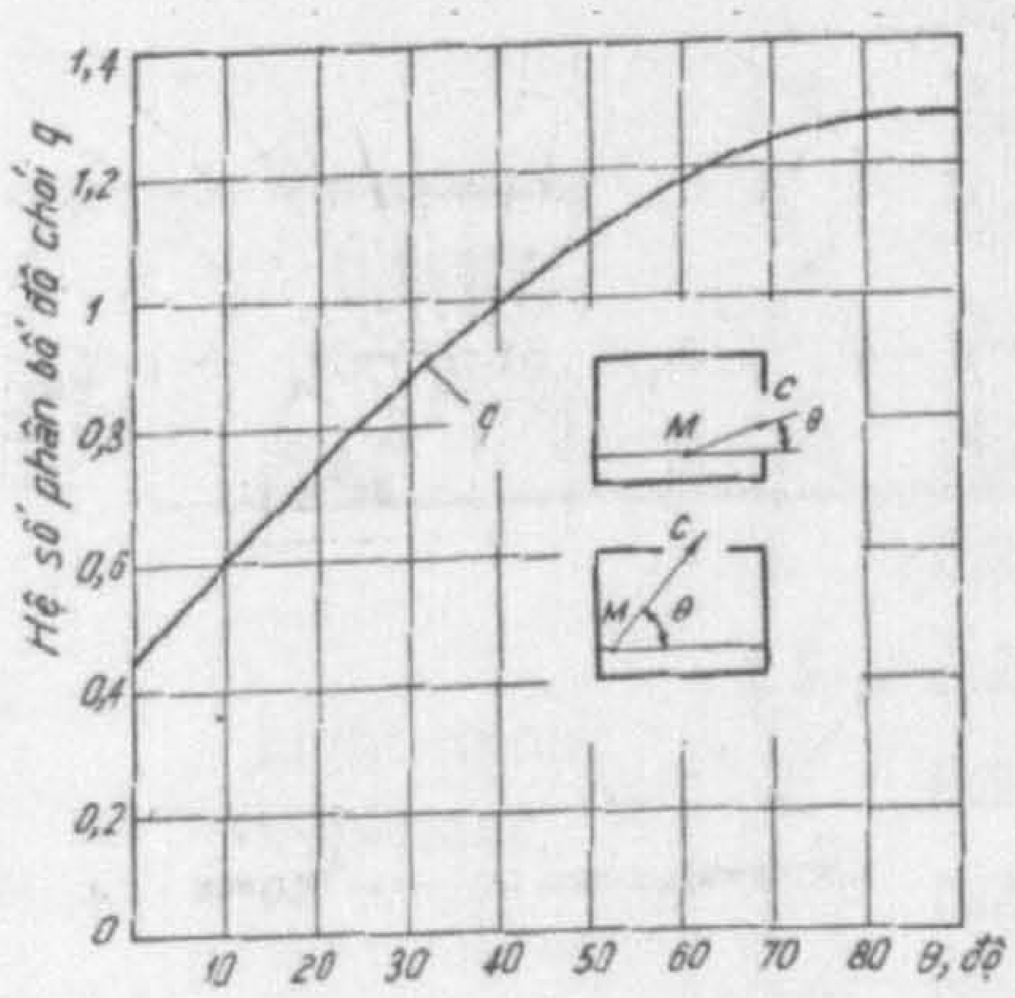
ρ_{tr}; ρ_t; ρ_s: ceiling, wall, floor reflectance value

S_{tr},$S_{tư}$,S_s: ceiling, wall floor area (m2)

(3) When ρ_{tb}=0.4, r1 value can be interpolated.

Where: (1) H_{cm}: Distance from the lowest point of the window glazing to the working plan.

(2) L_2: Aperture width.



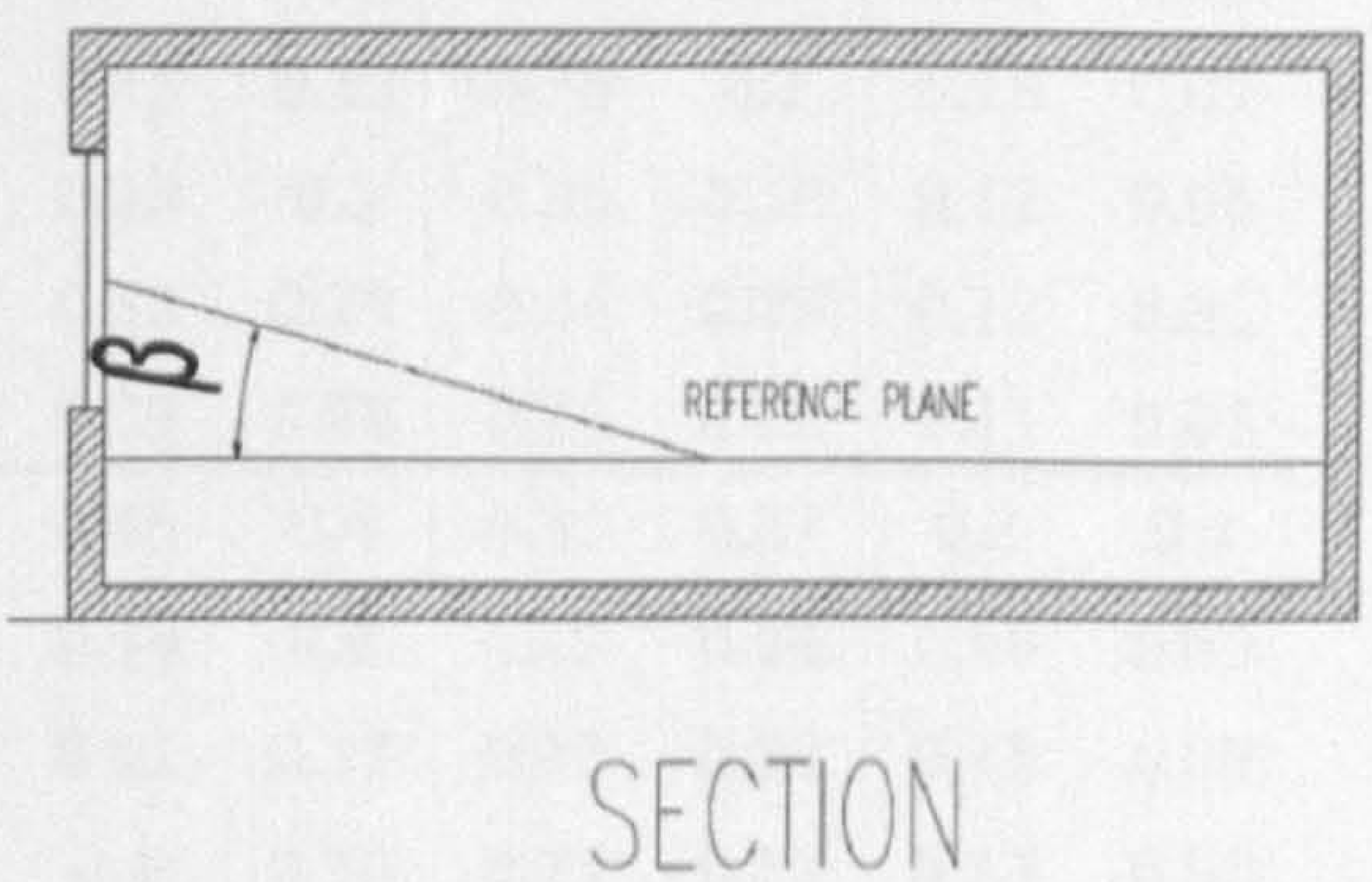


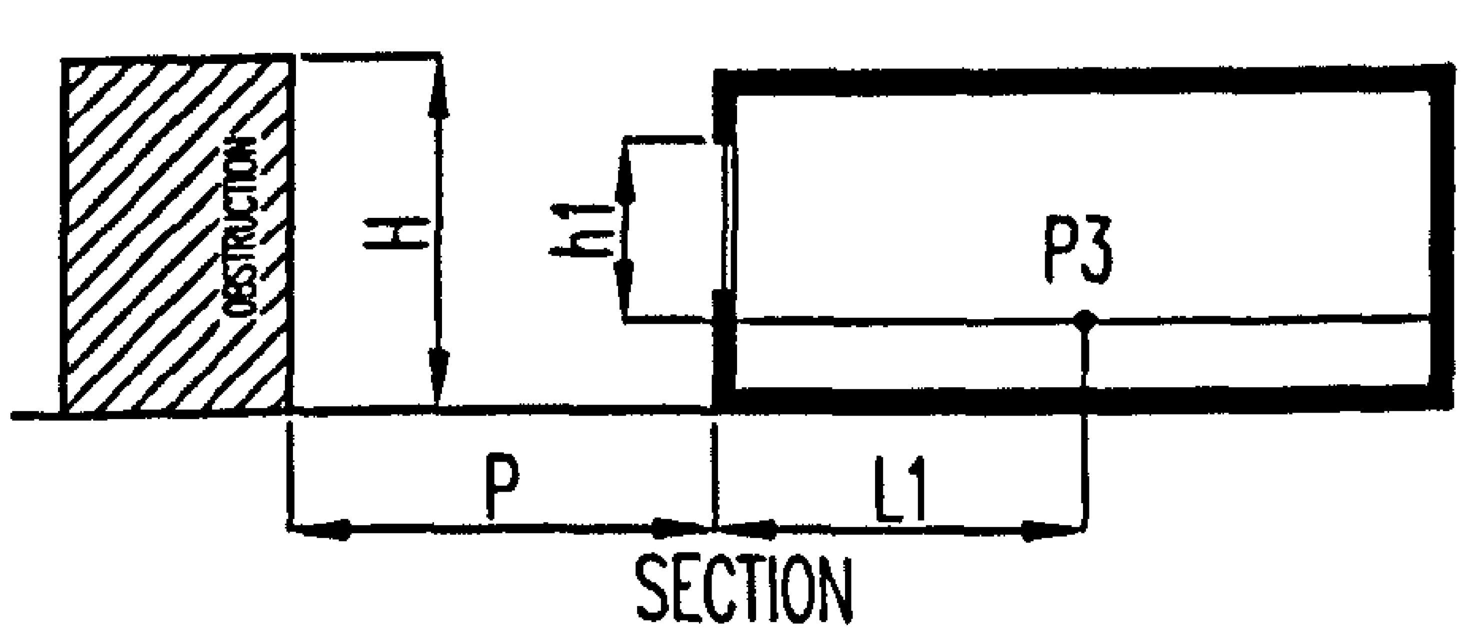
Table J.7 The angle subtended by the visible sky *β* and sky luminance coefficient *q*

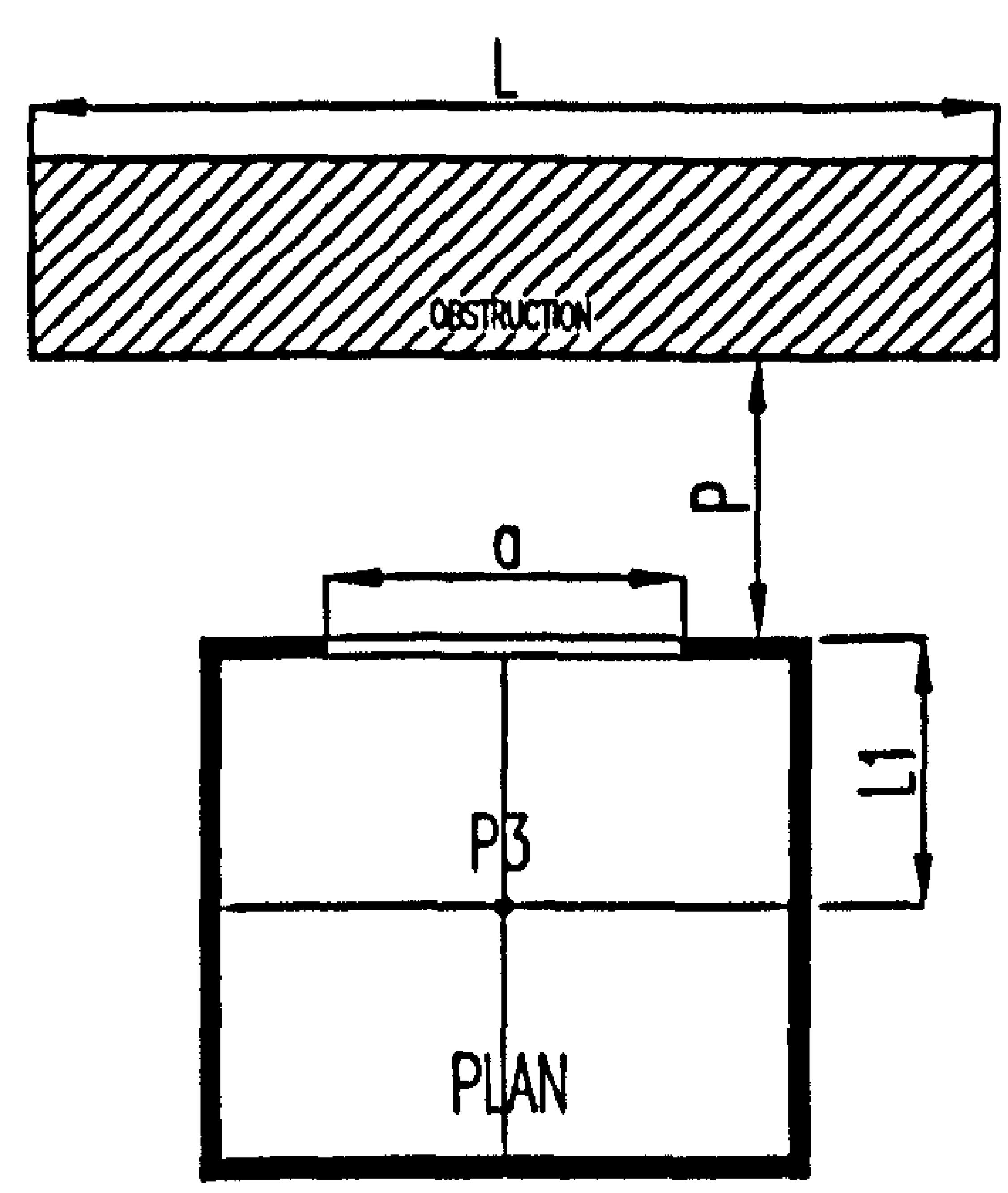
The sky luminance coefficient q			
β	**q**	**β**	**q**
2	0.46	50	1.08
6	0.52	54	1.12
10	0.58	58	1.16
14	0.64	62	1.18
18	0.69	66	1.21
22	0.75	70	1.23
26	0.80	74	1.25
30	0.86	78	1.27

Table J. 8 External obstruction index *R*.

Obstructions reflectance	Z_1 index	R							
		Z_2 index							
		0.1	0.5	1	1.5	2	3	4	>5
Brick or concrete cladding	1	0.14	1.25	0.26	0.23	0.2	0.15	0.11	0.06
	1.5	0.14	0.23	0.25	0.22	0.19	0.14	0.1	0.05
	3	0.14	0.21	0.23	0.2	0.2	0.12	0.08	0.04
	6	0.14	0.2	0.22	0.2	0.17	0.12	0.08	0.04
	>10	0.14	0.18	0.2	0.18	0.16	0.11	0.08	0.04
Ceramic cladding	1	0.16	0.3	0.3	0.26	0.23	0.17	0.13	0.07
	1.5	0.16	0.26	0.28	0.25	0.22	0.16	0.12	0.06
	3	0.18	0.24	0.26	0.24	0.2	0.14	0.1	0.05
	6	0.16	0.23	0.25	0.23	0.2	0.13	0.09	0.05
	>10	0.16	0.21	0.23	0.21	0.18	0.12	0.09	0.04
Dark colour plaster	1	0.2	0.36	0.37	0.33	0.29	0.21	0.16	0.08
	1.5	0.2	0.33	0.35	0.32	0.28	0.2	0.15	0.07
	3	0.2	0.3	0.33	0.3	0.25	0.18	0.12	0.06
	6	0.2	0.29	0.32	0.29	0.24	0.17	0.12	0.05
	>10	0.2	0.26	0.29	0.26	0.23	0.16	0.11	0.05
Light colour plaster	1	0.25	0.45	0.46	0.4	0.37	0.27	0.2	0.1
	1.5	0.25	0.42	0.44	0.4	0.35	0.24	0.19	0.09
	3	0.25	0.38	0.41	0.37	0.32	0.22	0.15	0.08
	6	0.25	0.37	0.4	0.36	0.31	0.21	0.15	0.08
	>10	0.25	0.33	0.36	0.32	0.28	0.19	0.14	0.07

$$Z_1 = \frac{L_{ob}.L_1}{(P+L_1).a} \qquad Z_2 = \frac{H_{ob}.L_1}{(P+L_1).h_1}$$





Appendix K

Average Daylight Factor

(Lynes,1979)

The original concept of Average Daylight Factor is derived from works of J.A. Lynes (1979). The below section is excerpt from review made by L.Brotas (2004) and Tregenza & Wilson (2010).

By definition, the daylight factor on the outside face of the window is obtained by:

$$D_{w=}\frac{E_w}{E_{dh}}\times 100$$

Where: E_w Vertical illuminance on the outside face of the window [lux]

E_{dh} Horizontal unobstructed illuminance [lux]

If the ground and the obstructions have about one tenth of the mean sky luminance, then the average daylight factor on the vertical outside window surface is approximately given by:

$$D_w \approx \frac{\theta}{2}$$

Where: θ angle of visible sky measured in section through the window, in degrees

Then:

$$E_{w=}\frac{\theta.Edh}{200}$$

The flux entering the room is obtained by: $\Phi = Ew.Aw.\tau = \frac{\theta.Edh.Aw.\tau}{200}$

Where: A_w Total window net glazed area, excluding frames and glazing bars [m^2]

τ Diffused light transmittance of the glazing, including effects of dirt, expressed as a decimal

The interior daylight illuminance is found by multiplying the illuminance on the window by the window area, then dividing it by the interior surface area. So if all of the light falling on the window passes through the glazing onto the room surfaces, the average daylight factor $\bar{D}$ on these surfaces would be:

$$\bar{D} = D_w \frac{A_w}{A_r}$$

Where: A_r The total room surface area, walls, ceiling and floor [m^2]

Some of the light is lost because the glazing and the dirt on it absorbs some of the light. Secondly, there is inter-reflection within the room, which increases the amount of light energy falling on the surfaces. Therefore, the average daylight factor becomes:

$$\bar{D} = D_w \frac{A_w . \tau}{A_r .(1-\rho)}$$

Where: ρ the mean reflectance of the enclosed room surfaces – ceiling, walls (including windows) and floor, expressed as a decimal

Therefore: $$\bar{D} = \frac{\theta . A_w . \tau}{2A_r .(1-\rho)}$$

This is a popular average daylight factor formula, also known as *Lynes's* average daylight factor formula (Lynes, 1979). Based on this approach and the split-flux theory, the British Building Research Establishment (BRE) has developed another formula to estimate the average daylight factor on a reference plan, obtained by:

$$\bar{D}_{BRE} = \frac{\theta . \tau . A_w}{A_r .(1-\rho^2)}$$

This formula is used extensively in the UK in daylighting regulations and codes of practice.

Appendix L

Modification of the split-flux formulae for mean daylight factor and internal reflected component with large external obstructions

(Tregenza, 1989)

The mean daylight factor, DF_{mean}, is given by:

$$DF_{mean} = tW\left(\frac{C}{A_{fw}} + \frac{C\rho_{fw} + D\rho_{cw}\rho_g}{A(1-\rho)}\right)$$

The mean internal reflected component, IRC_{mean}, is given by

$$IRC_{mean} = t\left(\frac{W}{A}\frac{C\rho_{fw} + D\rho_{cw}\rho_g}{1-\rho}\right)$$

Where

t	Overall transmittance of the window system, taking into account diffuse glass transmittance, dirt, glazing bars, curtains and other obstructions, expressed as a decimal
W	Window area [m^2]
A	Total internal area: floor, walls, ceiling, windows [m^2]
A_{fw}	Area of the floor and wall surfaces below the centre height of the windows, excluding the window wall surfaces [m^2]
ρ_{fw}	Mean reflectance of the floor and wall surfaces below the centre-height of the windows, excluding the window wall surfaces, expressed as a decimal
ρ_{cw}	Mean reflectance of the floor and wall surfaces above the centre-height of the windows, excluding the window wall surfaces, expressed as a decimal
ρ	Mean reflectance: floor, walls, ceiling, windows, expressed as a decimal
ρ_g	Mean ground reflectance (The area of effective ground extend from the

building some 3 to 3.5 times the height of the ceiling above the ground), expressed as a decimal

C and *D* are coefficients which define the relative illuminance of the window by flux incident from above and from below the horizontal. The coefficient *C* is given by:

$$C = \frac{9}{7\pi} f\left(1 + \frac{\rho_b}{\pi(1-\rho_o)} g\right) x100\%$$

Where:

$$f = \left(\frac{1}{3}(\sin\phi_L + \sin\phi_R) x \left(\frac{\theta_H - \theta_L}{2} + \frac{\sin 2\theta_H - \sin 2\theta_L}{4} - \frac{2\cos^3\theta_H - 2\cos^3\theta_L}{3}\right)\right)$$

$$g = \left(\frac{\pi}{2} - (\sin\phi_L + \sin\phi_R) x \left(\frac{\phi_H - \phi_L}{2} + \frac{\sin 2\phi_H - \sin 2\theta_L}{4}\right)\right)$$

$$\rho_o = \frac{\rho_b + \rho_g}{4}$$

And θ_H, θ_L, Φ_R, Φ_L are the angle of visible sky, as defined in figure K.1 below

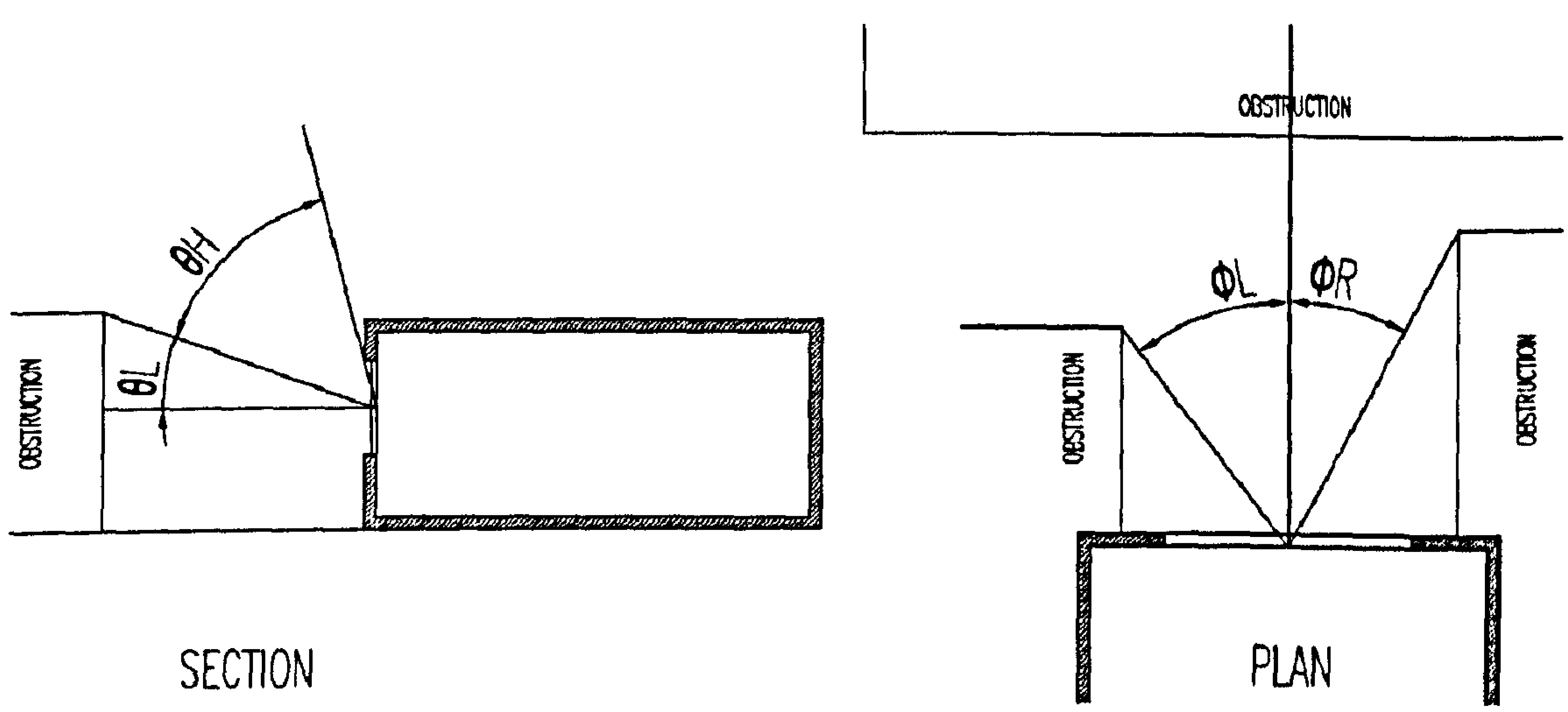


Figure L.1 The area of sky visible is defined by the area θ_H and θ_L in altitude, Φ_R and Φ_L in azimuth.

With the ground reflectance around 0.2, it is not worthwhile to calculate the fraction corresponding to the ground illuminance. It is appropriate to assume the *D*=25. The coefficient *C* can also be referred from table L.1

Table L.1 Values of the coefficient C and angle of visible sky

Values of $\frac{C}{2}$ *when there is no overhang canopy* (θ_H=90°), *mean reflectance of ground and obstructions is taken as 0.2.*

θ_L	ϕ_L or ϕ_R, half-sky angle in azimuth									C_o
	10°	20°	30°	40°	50°	60°	70°	80°	90°	
0°	3.8	7.3	10.5	13.2	15.6	17.4	18.7	19.5	19.8	39
10°	3.2	6.3	9.1	11.6	13.6	15.3	16.5	17.2	17.5	35
20°	2.6	5.1	7.4	9.4	11.1	12.5	13.5	14.1	14.3	31
30°	1.9	3.8	5.5	7.0	8.3	9.4	10.2	10.6	10.8	25
40°	1.3	2.5	3.7	4.7	5.6	6.3	6.8	7.1	7.2	20
50°	0.7	1.4	2.1	2.7	3.2	3.6	3.9	4.1	4.2	14
60°	0.3	0.7	1.0	1.2	1.5	1.7	1.8	1.9	1.9	10
70°	0.1	0.2	0.3	0.4	0.5	0.5	0.6	0.6	0.6	7
80°	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1	5

Values of $\frac{C}{2}$ *when there is overhang canopy* (θ_H=70°), *mean reflectance of ground and obstructions is taken as 0.2*

θ_L	ϕ_L or ϕ_R, half-sky angle in azimuth								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
0°	3.7	7.1	10.2	12.9	15.2	17.0	18.2	19.0	19.3
10°	3.1	6.1	8.8	11.2	13.2	14.8	16.0	16.7	16.9
20°	2.5	4.9	7.1	9.0	10.7	12.0	13.0	13.6	13.8
30°	1.8	3.6	5.2	6.7	7.9	8.9	9.6	10.1	10.2
40°	1.2	2.3	3.4	4.3	5.1	5.8	6.3	6.6	6.7
50°	0.6	1.2	1.8	2.3	2.8	3.1	3.4	3.5	3.6
60°	0.2	0.5	0.7	0.9	1.0	1.2	1.3	1.3	1.3

Values of $\frac{C}{2}$ *when there is overhang canopy* (θ_H=50°), *mean reflectance of ground and obstructions is taken as 0.2*

θ_L	ϕ_L or ϕ_R, half-sky angle in azimuth								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
0°	3.0	5.9	8.5	10.8	12.7	14.2	15.3	16.0	16.2
10°	2.5	4.9	7.1	9.1	10.7	12.0	13.0	13.5	13.7
20°	1.9	3.7	5.4	6.8	8.1	9.1	9.9	10.3	10.5
30°	1.2	2.4	3.4	4.4	5.2	5.9	6.4	6.7	6.8
40°	0.6	1.1	1.6	2.0	2.4	2.7	3.0	3.1	3.1

Appendix M

Summary of the method for evaluating daylight access and site layout planning

(Littlefair, 1991)

Littlefair's guideline is based on the assessment of external obstructions and the visible sky component from windows. As external buildings can impair the quality and quantity of daylight in the interior, external obstructions should be checked carefully at the layout design stage to ensure that there is adequate daylight accessibility. According to PJ Littlefair (1991), a building will have a potential of good diffused daylight if on all its main faces:

> *(a) No obstruction, measured in a vertical section perpendicular to the main face, from a point 2 m above ground level, subtends an angle of more than 25° to the horizontal..."*
>
> *or*
>
> *(b) if (a) is not satisfied, then all points on the main face on a line 2 m above ground level are within 4 m (measured sideways) of a point which has a vertical sky component of 27% or more.*

In the case of (a), a layout with no obstruction is defined by checking on the section plan of each main face. From the 2m height reference point, draw a 25° angle to the horizontal; if none of obstructing buildings is higher than this line, there is a potential for good daylight in the interior.

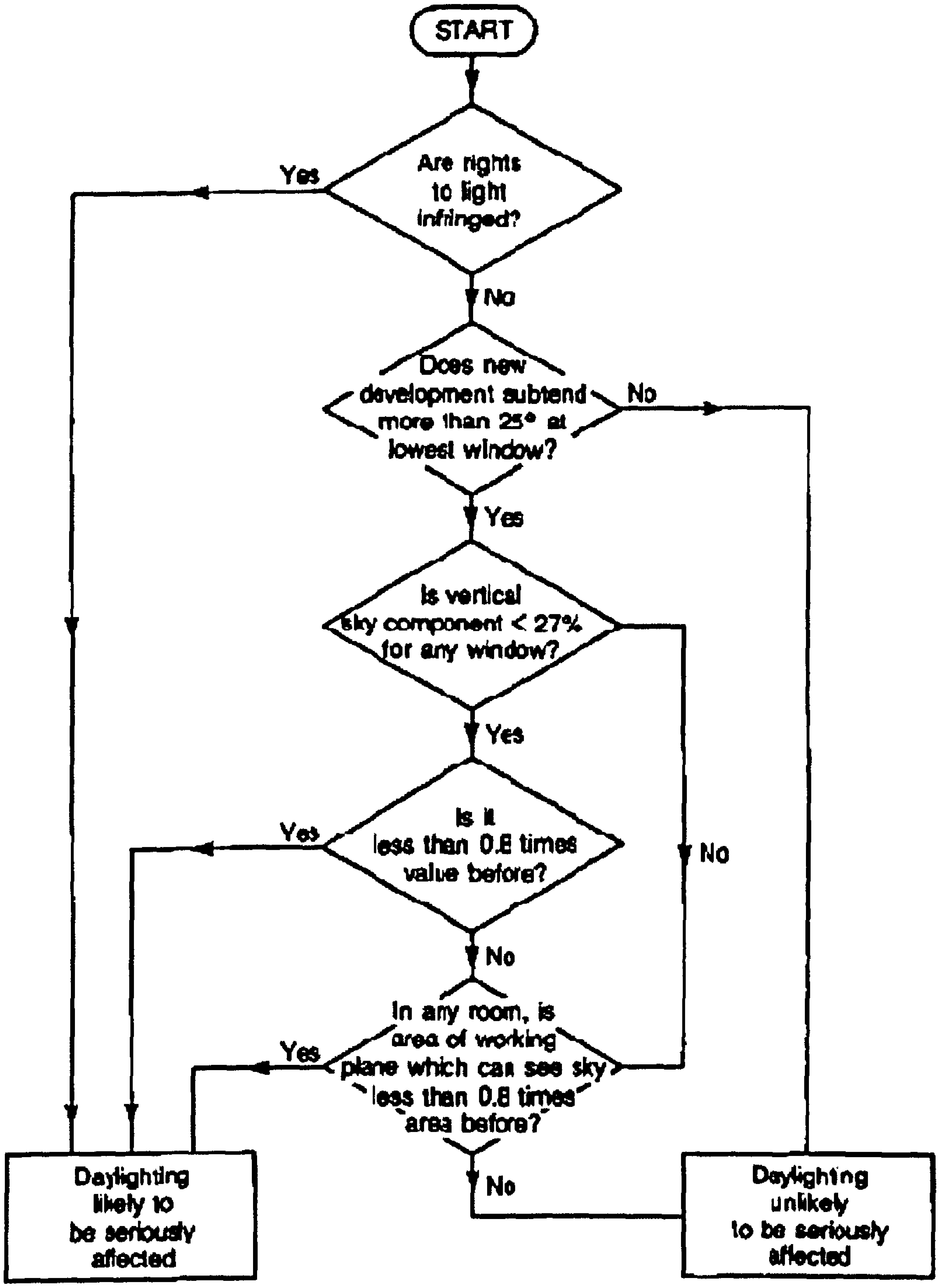


Figure M.1 Decision chart to verify impact of new development on diffuse daylight in existing buildings. (Littlefair, 1991)

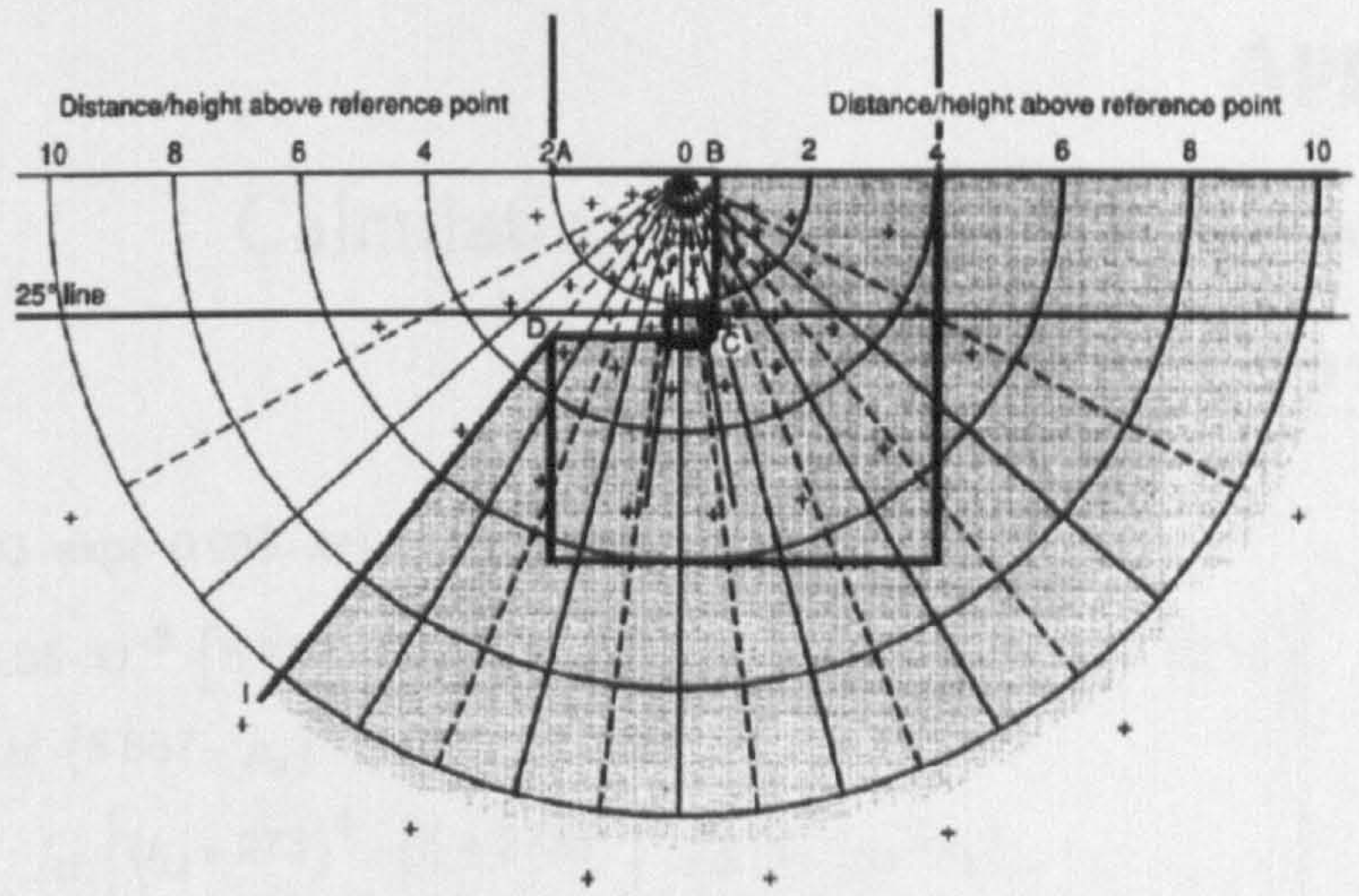


Figure M.2 Using sky indicator diagram to define vertical sky component for a reference point facing a courtyard (Littlefair, 1991)

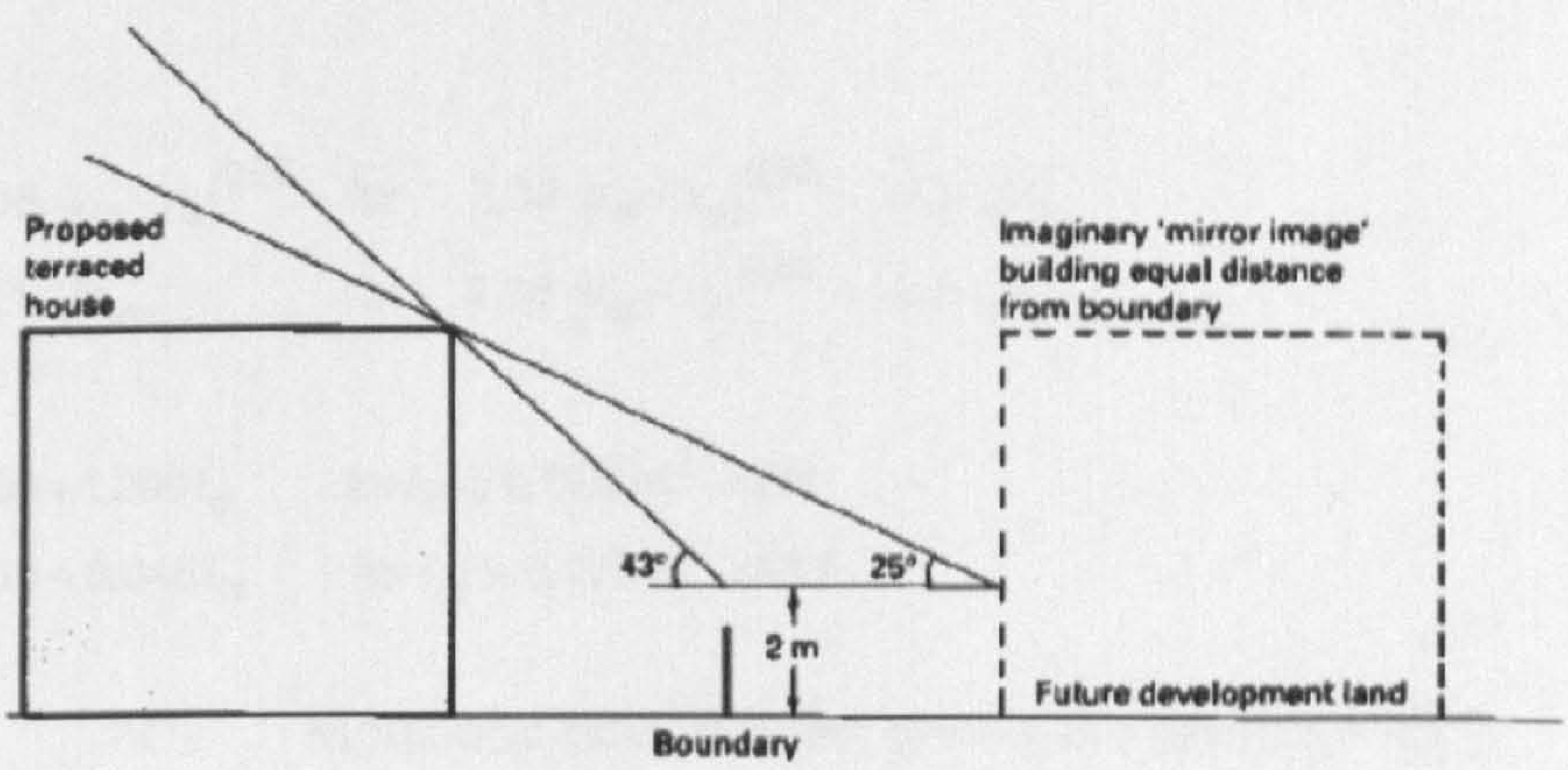


Figure M.3. Derivation of an angular boundary criterion to safeguard future development of adjoining land (Littlefair, 1991)

It is noted that if the vertical sky component, with the new development in place, is both less than 27% and less than 0.8 times its former value then the reduction of the amount of skylight will be noticed by the occupants of existing buildings . In case of adjoining development, it is recommended that the buildings should stand at a reasonable distance away from the boundary, to allow good access to daylight. P.J. Littlefair (1991) recommends the use of another diagram to check in this case, using the 43° checking line. If this is not satisfied, there can still be a potential for good daylight access if: *"every point 2m above the boundary line is within 4m of a point with a vertical component of 17% or more".*

Appendix N

Calculating *Predicted Mean Vote* (PMV)

(ISO:7730, 2005)

$$PMV = [0{,}303 \cdot \exp(-0{,}036 \cdot M) + 0{,}028] \cdot \begin{Bmatrix} (M-W) - 3{,}05 \cdot 10^{-3} \cdot [5\,733 - 6{,}99 \cdot (M-W) - p_a] - 0{,}42 \cdot [(M-W) - 58{,}15] \\ -1{,}7 \cdot 10^{-5} \cdot M \cdot (5\,867 - p_a) - 0{,}0014 \cdot M \cdot (34 - t_a) \\ -3{,}96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4\right] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{Bmatrix} \quad \text{(N.1)}$$

$$t_{cl} = 35{,}7 - 0{,}028 \cdot (M-W) - I_{cl} \cdot \left\{3{,}96 \cdot 10^{-8} \cdot f_{cl} \cdot \left[(t_{cl}+273)^4 - (\bar{t}_r + 273)^4\right] + f_{cl} \cdot h_c \cdot (t_{cl} - t_a)\right\} \quad \text{(N.2)}$$

$$h_c = \begin{cases} 2{,}38 \cdot |t_{cl} - t_a|^{0{,}25} & \text{for} \quad 2{,}38 \cdot |t_{cl} - t_a|^{0{,}25} > 12{,}1 \cdot \sqrt{v_{ar}} \\ 12{,}1 \cdot \sqrt{v_{ar}} & \text{for} \quad 2{,}38 \cdot |t_{cl} - t_a|^{0{,}25} < 12{,}1 \cdot \sqrt{v_{ar}} \end{cases} \quad \text{(N.3)}$$

$$f_{cl} = \begin{cases} 1{,}00 + 1{,}290\, I_{cl} & \text{for } I_{cl} \leqslant 0{,}078 \text{ m}^2 \cdot \text{K/W} \\ 1{,}05 + 0{,}645\, I_{cl} & \text{for } I_{cl} > 0{,}078 \text{ m}^2 \cdot \text{K/W} \end{cases} \quad \text{(N.4)}$$

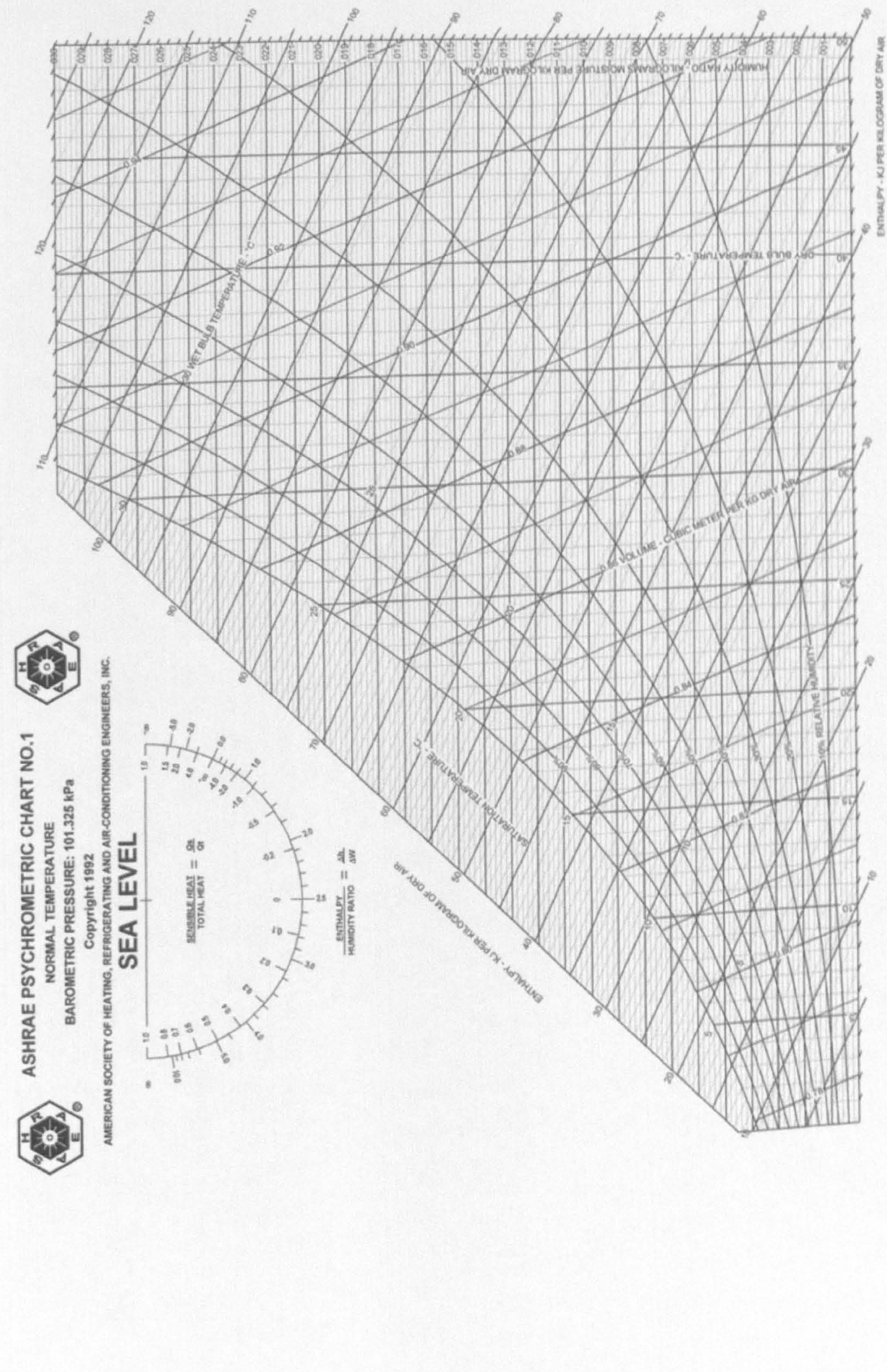
Where:

- M: Metabolic rate, in watts per square metre [W/m^2]
- W: Effective mechanical power, in watts per square metre
- I_{cl}: Clothing insulation, [square metres kelvin per watt]
- $f$cl: Clothing surface area factor
- t_a: Air temperature, in degrees Celsius [°C]
- t_r: Mean radiant temperature, in degrees Celsius [°C]
- v_{ar} Relative air velocity, in metres per second [m/s]
- p_a Water vapour partial pressure, in pascals [P_a];
- h_c Convective heat transfer coefficient [watts per square metre kelvin]
- t_{cl} Clothing surface temperature, in degrees Celsius [°C]

Appendix O

ASHRAE Psychrometric Chart

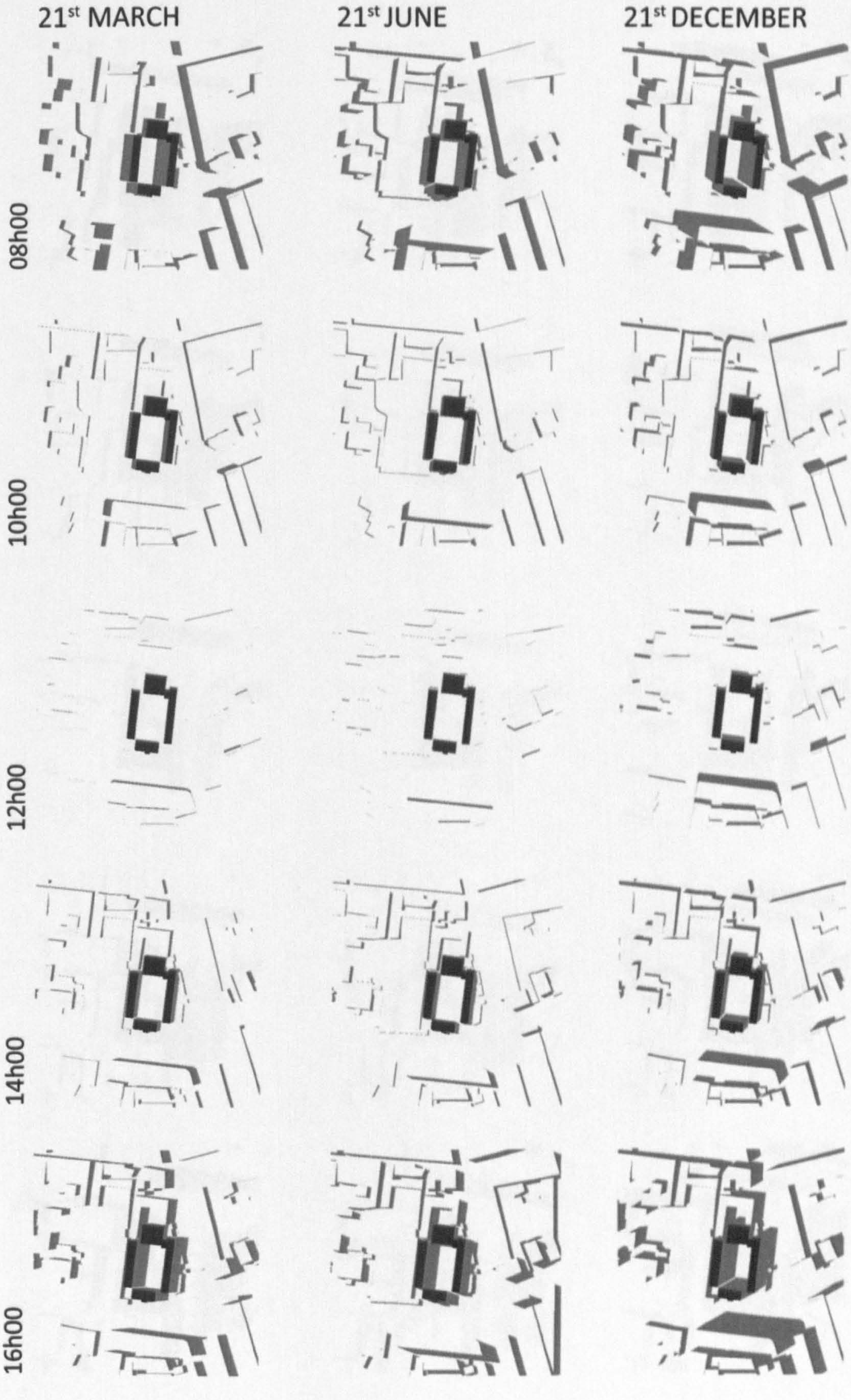
(ASHRAE, 2009)



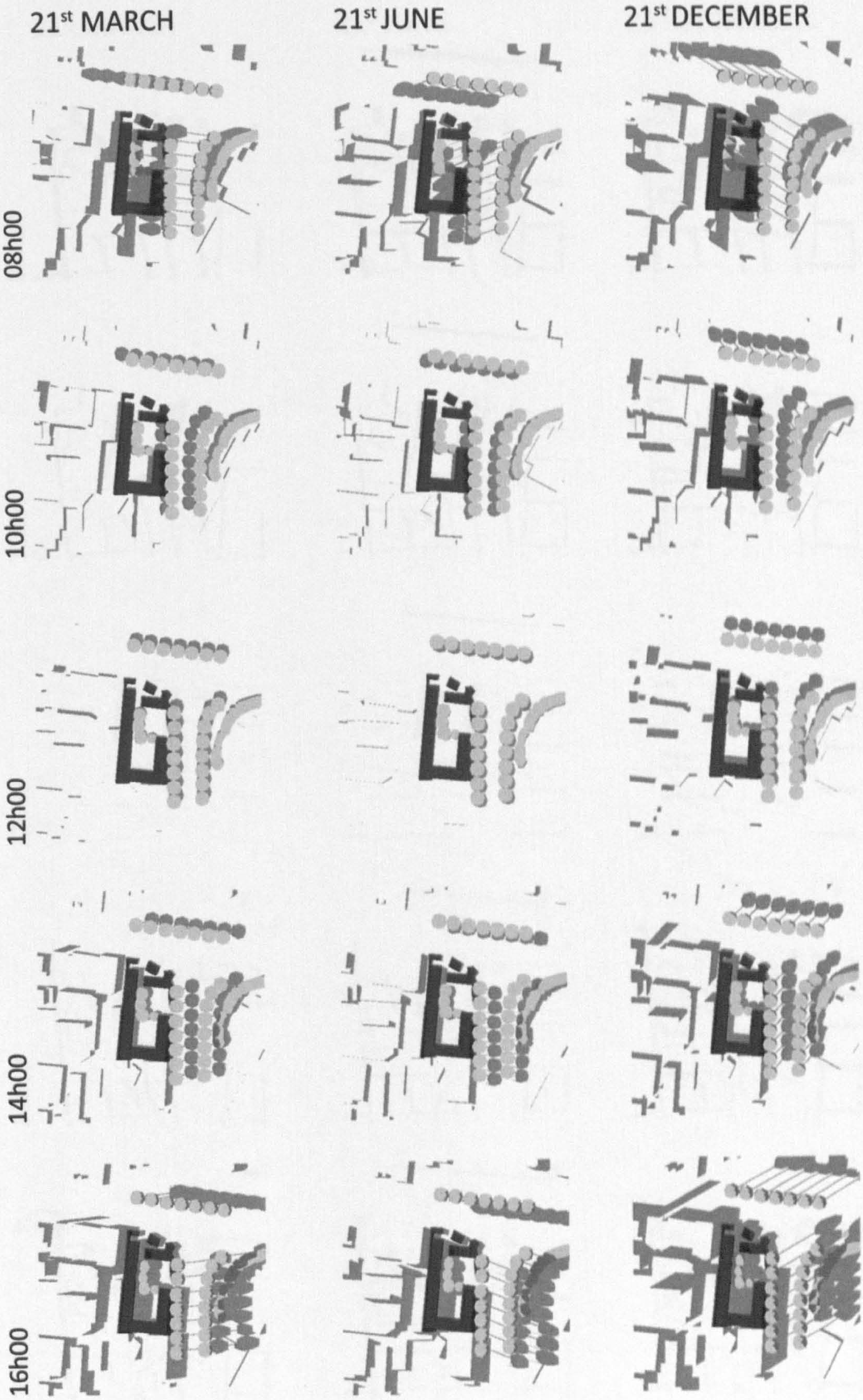
Appendix P

Site shadow plotting

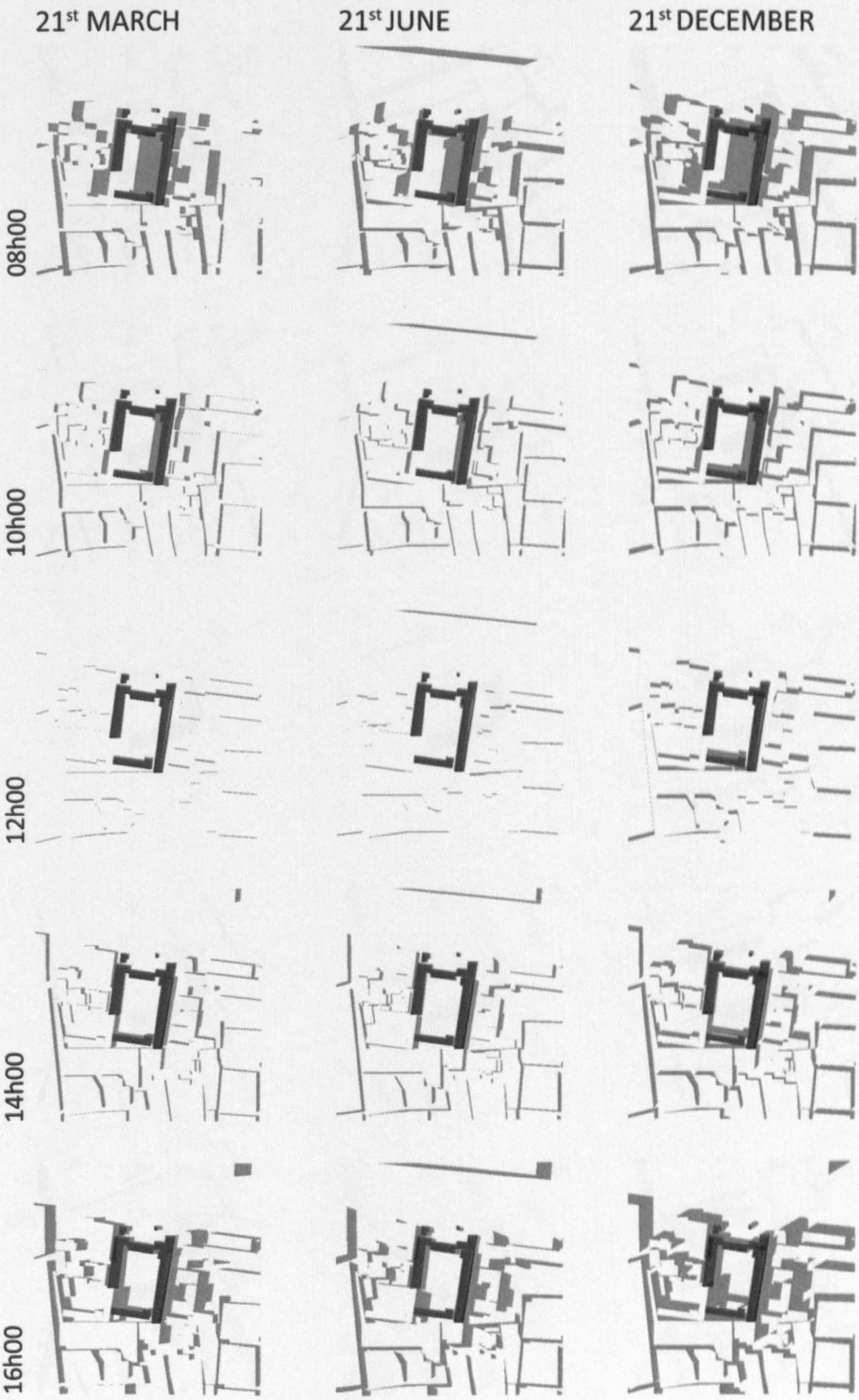
Le Van Tam School



Truong Cong Dinh School



Ha Huy Tap School



Lam Son School