Parametric Study Of Design Parameters And Thermal Comfort In Primary Schools In Ho Chi Minh City, Vietnam

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Abstract. *Overheating of premises is a typical thermal discomfort issue in naturally ventilated primary schools in Ho Chi Minh City, Vietnam. Several design parameters were shown to affect the indoor thermal environment. A parametric study was conducted and based on several building performance simulations to investigate the influences of the individual design parameters on indoor air temperatures and the prevalence of overheating in primary schools. The sensitivity analysis indicated that the material of building envelopes, the openings, and the solar controls, in descending order, affected overheating occurrence. The findings could assist the architect in choosing which parameters should be prioritised in the design stage, which is particularly useful in renovation and retrofit projects.*

INTRODUCTION

Thermal performance is an aspect of significant concern when considering indoor environmental quality. The current trend is to install energy-intensive air conditioning systems in primary schools, or better still, to use ceiling fans as a supplementary ventilation method during school time to maintain indoor thermal comfort. Because of the vast quantity of energy required for cooling via the installation of air-conditioning systems, it is not recommended in public schools. In naturally ventilated primary schools in Vietnam, there is a high risk of the occurrence of overheating due to the hot and humid climate. Several design parameters, in some way, were shown to affect the indoor thermal environment.

The main aim of this paper was to investigate the influences of these design parameters on indoor air temperatures and the prevalence of overheating in primary schools. A design guideline to avoid overheating was then proposed. The parametric study was conducted to assess the effects of each individual parameter on the indoor air temperature and the overheating hours. In this simulation work the temperature threshold of 33ºC was used to assess the overheating problem in primary schools.

LITERATURE REVIEW

The evaluations of the thermal conditions in naturally ventilated classrooms in the three primary schools which were studied by the author in previous work [1-3], showed that the differences in the thermal environment between these schools were based on many factors relating to occupants, outdoor conditions and building design. Among several factors affecting the indoor thermal environment, Teli, Jentsch [4] indicated that the building-related characteristics could significantly impact on occupants' perceptions through determining the indoor thermal conditions. Szokolay [5] stated that the thermal performance of a building is greatly influenced by several building design variables such as shape, fabric, fenestration, and ventilation. Figure 1 summarises the building elements, based on the four categories of the building-related factors, which had influences on the indoor thermal conditions from previous work [1-3].

The advantage of high floor-to-ceiling height is that the natural ventilation is enhanced which consequently improves the indoor thermal conditions and air quality. The warm air and contaminants rise above the occupied zone in the room towards the high ceiling. The air is exhausted through the openings above the doors, and the fresher outdoor air is introduced at the occupied level through the windows and doors [6]. Another parameter in Shape category, the orientation of the building, has influences on the indoor thermal conditions. The Vietnamese Standard [7] recommended that the building should avoid intensive solar radiation from the west.

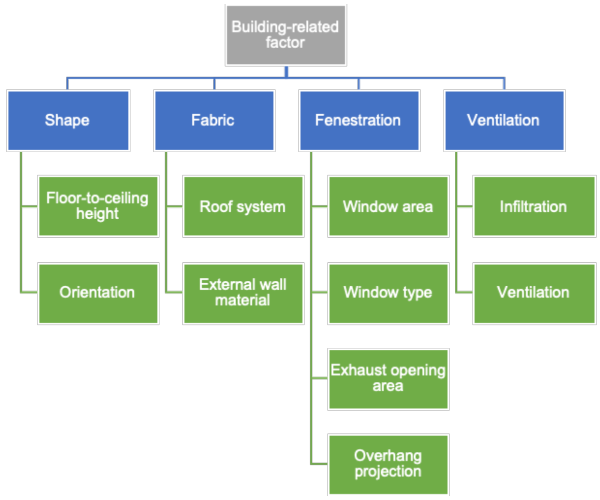


Figure 1. Design parameters that influenced the thermal conditions in Vietnamese primary schools

Public schools in Ho Chi Minh City are built and managed by the local department of education. Thus, careful consideration is generally given to the financial investment in the construction of schools. Schools are built using the most common local materials. Single and double brick walls are widely used for buildings up to three storeys in Ho Chi Minh City. Schools, which were built more than 10 years ago, are usually covered by external walls with a single layer of brick. Recently a double layer of brick has been used in renovated or new schools. Furthermore, public schools have either one of two typical forms of roof – pitched roof or flat roof.

Naturally ventilated buildings with exhaust openings are very popular in Vietnam. In the National Technical Regulation on Energy Efficiency Buildings [8], it is recommended that exhaust openings should be placed on the ceiling or on the opposite wall of the main ventilation inlet in order to enhance natural ventilation. Besides the exhaust opening, window design is one of the most critical factors affecting the natural ventilation of the building. In order to establish the window area for the purpose of the daylight design either the window-to-wall ratio [6] or the window-to-floor ratio [7] should be considered. Currently, Vietnamese standards do not provide recommendations for the size of window area or related criteria for thermal design. There are two very popular window types in primary schools in Ho Chi Minh City. The first window type, casement window, has side-hung clear glazed shutters with a fixed steel protection frame. In the second type, the windows have clear glazed movable louvres in a fixed steel frame and are generally used for schools in the city centre, which do not have enough space to operate casement windows. Furthermore, shading devices over the windows are essential to control direct solar radiation and thus reduce the solar heat gain. Concrete horizontal overhangs are generally used in Vietnamese schools, as they are affordable and durable.

These design parameters, in some way, were shown to affect the indoor thermal environment and therefore were investigated further in this paper. The work focused more on the building elements so the infiltration and add-in ventilation were not included in this study.

MATERIALS AND METHODS

Simulation Basis

Dynamic simulation modelling is suitable for simulating thermal performance as the parameters vary with time and the results show the building performance during the chosen period. CIBSE Guide A [9] recommends using dynamic thermal modelling to assess the risk of overheating. Dynamic simulation modelling software assumes that the temperature in a space is uniform no matter how large the space is. Moreover, based on his field study, Tran [10] stated that the difference in temperature between several measured points in the classroom is identical due to the natural ventilation and the small area of typical classrooms in Vietnam. Therefore, dynamic simulation modelling is suitable to use for simulating the thermal performance of classrooms in primary schools.

Among the wide range of simulation programs, IES VE is widely used in the building industry by architects and in academia by researchers. IES VE is one of the most appropriate building performance simulation software which provides the accurate thermal analysis [11]. IES VE 2018 is a dynamic simulation modelling software including an integrated set of building performance analysis tools such as ModelIT, SunCast, Apache, MacroFlo and VistaPro and so on. The IES package also contains Parametric Tool for parametric study, but the tool does not consider all the parameters, which are included in this study, such as the floor-to-ceiling height, the window area, and the orientation. Thus, the parametric study presented in this paper was conducted manually without support from Parametric Tool.

Weather Data File

The weather data file presented here will be used in all further simulations in this paper. The trustworthy data for Ho Chi Minh City is from Tan Son Hoa weather station, which is located on latitude 10.82°N, longitude 106.67°E and elevation 5m. The weather data file in IWEC2 format was developed for ASHRAE by White Box Technologies. The file was based on data with at least 12 years of records up to 25 years. This is the only typical year weather file, which is official and reliable for Ho Chi Minh City centre. As the summer weather data are not available, the typical year weather file was used to provide a long-term assessment of overheating problems. Figure 2 shows the monthly mean temperatures of Ho Chi Minh City based on the IWEC2 weather file.

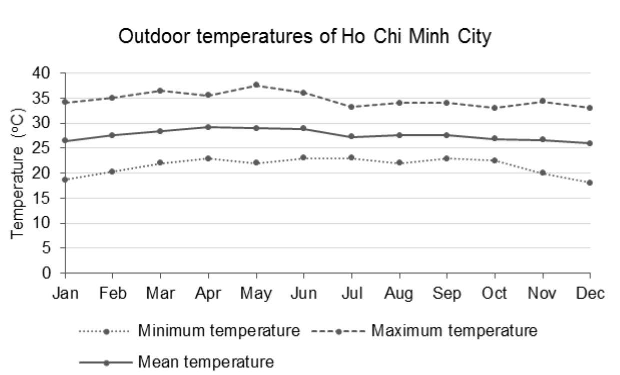


Figure 2. The monthly mean temperatures (extracted from the ASHRAE weather data)

Base Case

The Base Case was established and based on a selected primary school to increase the reliability of the model. The reason for choosing this case study is that the building design is close to the Vietnamese Standard and this particular study aims to develop design criteria from a standard level. It should be noted that the parameters in the base case were not the worst values as is usually expected.

The number of occupants in a classroom was set at 36 people including a teacher, as mentioned in the design requirements for primary schools [7]. ASHRAE [6] indicated that the heat gain from a child is 75% of that for an adult. Therefore, the average sensible gain of 57W and the average latent gain of 42W were inputted for a child. An input of 75W sensible gain and 55W latent gain was allocated to the teacher having 'moderately active office work'. The sensible heat gain of fluorescent lighting in classrooms was set at 12W/m^2 [9].

The input schedule was 07:00–10:30 for the morning session and 13:00–16:30 for the afternoon session. During a lunch break from 10:30 to 13:00, the children stayed in the classroom. The classroom was usually opened and occupied from around 06:30 and closed when all the children go home around 17:00. Therefore, to simplify the simulation model and reduce the computation time, the daily school time, which is defined for further analysis, was from 06:30 to 17:00. The academic calendar is from the middle of August to the end of May, excluding weekends. To simplify the simulation, the study did not exclude holidays as Vietnamese holidays are mainly based on the lunar calendar.

Bobenhausen [12] and Kiamba [13] indicated an infiltration rate of 1-2 air change per hour (ACH) for loose envelope construction in residential buildings. Buildings in Ho Chi Minh City can be considered loose buildings as the building's envelopes tend to be uninsulated and unsealed. In this study, the infiltration rate was set at 1ACH for schools in order to simplify the simulation process.

Although the Base Case was carefully established and validated, some details could not be measured properly and thus do not have accurate values. For that reason, the assumptions and estimations presented in Table 1 are included in the simulations.

Table 1. General assumptions for Base Case model

Fixed Parameters	
Climate	Station: VNM Tan Son Hoa 489000. Latitude 10.82ºN, Longitude 106.67ºE, Elevation 5m
Schedule	Academic year: 15 August to 31 May, Monday to Friday. School time: 06:30–17:00
Occupants	35 students and a teacher
Ventilation	Natural ventilation by all openings during school time. No additional ventilation
Infiltration	1 air change per hour (ACH)
Internal heat gains	Children: sensible gain 57W/person, latent gain 42W/person Teacher: sensible gain 75W/person, latent 55W/person Fluorescent Lighting: 12W/m^2
Doors	Two doors of 2.4m high and 1.4m wide
Varied Parameters	
Floor-to-ceiling height	3.4m
Window area	6.72m^2 (two windows of 1.4m high and 2.4m wide)
Exhaust opening area	1.28m^2 (two openings of 0.2m high and 3.2m wide)
Overhang projection	0.8m (fin offset 0.2m)
Orientation	Windows face 15o from south to west
Window type	Windows with side-hung glazed shutters and fixed steel protection frame
External wall material	Double layers of brick. U-value: 1.74 W/m^2K. Thickness: 250mm
Roof system	Ceiling with steel frame and insulation layer (U-value 1.54 W/m^2K, thickness: 30mm) Pitched concrete roof (U-value 3.62 W/m^2K, thickness: 155mm)

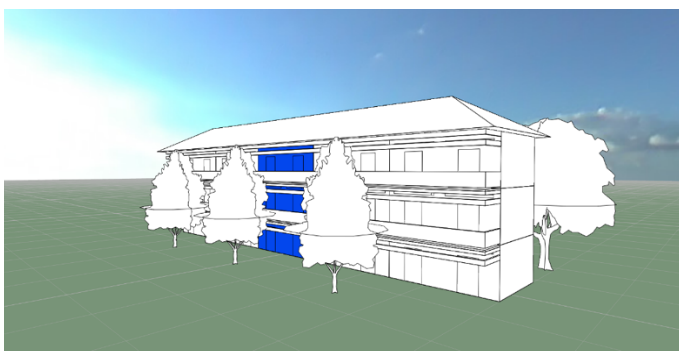


Figure 3. The position of three investigated classrooms in further simulations

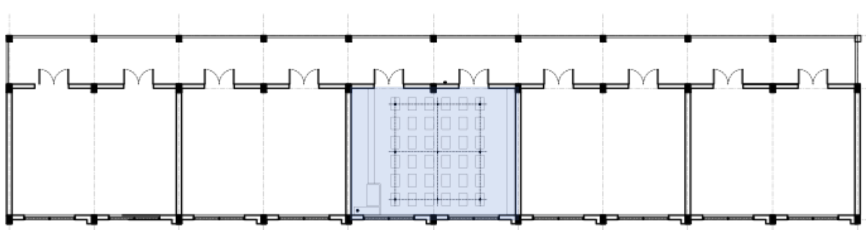


Figure 4. Typical plan of Base Case model

The classrooms, which are highlighted in Figure 3 and Figure 4, are investigated for the assessment of overheating throughout this paper. The classrooms are named as follows: Classroom A on the ground floor, Classroom B on the first floor and Classroom C on the second floor.

The average air temperatures in the three classrooms during school time, as shown in Figure 5 and Table 2, were around 2ºC higher than the outdoor conditions. The remarkable result is that the outdoor temperatures were over 33ºC for 8.3% of the school time, equivalent to 188 hours. The number of overheating hours (over 33ºC) in the classrooms, as shown in Figure 5, is far higher than the recommendation by the DfE [14] in assessing the risk of overheating in European summertime. Therefore, this performance standard cannot be applied to the case of schools in Ho Chi Minh City, Vietnam.

Table 2. The temperatures of the outdoor and indoor conditions of the Base Case during school time

	Temperature (ºC)		
	Min	Max	Average
Outdoor environment	18.4	37.6	29.46
Classroom A (ground floor)	25.08	37.38	31.41
Classroom B (first floor)	25.18	37.40	31.48
Classroom C (second floor)	25.07	37.60	31.53

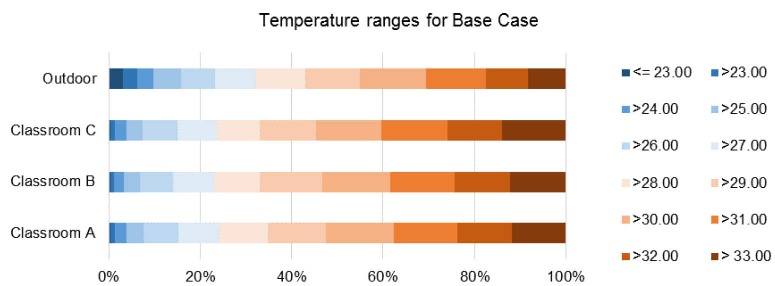


Figure 5. Indoor temperature ranges for investigated classrooms in the Base Case and outdoor temperature range

Among the three investigated classrooms, Classroom C had the worst performance where the percentage of overheating hours was 14% of school time with an average temperature of 31.53ºC. The best performance was in Classroom A where the temperature exceeded the overheating threshold of 33ºC during 11.8% of the occupied time. The average temperature of 31.41ºC in Classroom A was the lowest among the classrooms being investigated. The overheating occurred in the three classrooms for a total of 864 hours, equivalent to 12.6% of school time on average for the classrooms. The results from the Base Case are the baseline for the parametric studies.

RESULTS

The parametric study is necessary to understand the influences of the individual design parameters on thermal performance in primary schools. Classrooms are considered to be overheated when the temperature exceeds 33ºC, as studied by the author [3]. For assessment, the overheating hours are extracted from the results of simulations. The assessment is based on the average indoor air temperature and overheating hours.

The parametric study presented here is based on the local method in which the inputs are sampled one by one [15]. Thus, the outputs may show narrow changes and these distributions are based on the assumed input boundaries. Furthermore, it should be noted that in naturally ventilated buildings, the indoor thermal environment has been driven mainly by outside conditions, which may cause a very small improvement in the results.

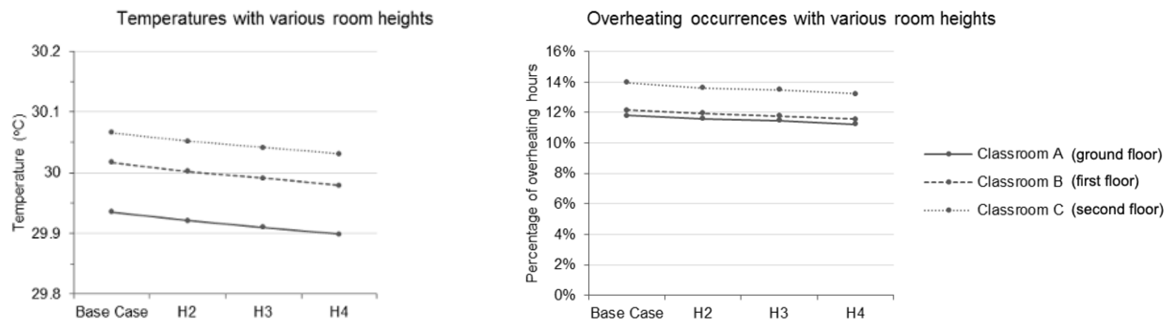
Floor-To-Ceiling Height

The variations of floor-to-ceiling height are investigated to learn to what extent this may contribute to the improvement of indoor thermal conditions, in terms of reducing the risk of overheating. The floor-to-ceiling height varies from 3.4m to 4.0m at 0.2m intervals. Recently built primary schools are usually around 3.3m to 3.6m high. A floor-to-ceiling height of 3.8m to 4.0m is usually found in French-style schools in Ho Chi Minh City, but this is not common in schools built after the Vietnam War. Table 3 shows the floor-to-ceiling height for each simulation case.

Table 3. Variations of floor-to-ceiling height

Case	Floor-to-ceiling height (m)
Base Case	3.4
H2	3.6
H3	3.8
H4	4.0

The average indoor air temperatures for all cases in all classrooms ranged from 29.9ºC to 30.1ºC during school time (Figure 6a). When varying the room height from 3.4m to 4.0m, the average air temperatures in classrooms decreased slightly (less than 0.1ºC). Among the three investigated classrooms, Classroom C had the worst performance with the highest average indoor temperature, while Classroom A performed well. Although the improvement in the average indoor air temperature was insignificant, this result showed that an increase in floor-to-ceiling height has a positive effect on indoor thermal conditions in classrooms.



(a) (b)

Figure 6. Average indoor air temperature (a) and the percentage of overheating hours (b) during school time when varying the floor-to-ceiling height

For each 0.2m change in the floor-to-ceiling height (Figure 6b), the overheating hours decreased by up to five hours in Classroom A and Classroom B, and up to eight hours in Classroom C. The percentage of overheating hours in occupied periods decreased by 0.6% (14 hours) in Classrooms A and B, and by 0.7% (17 hours) in Classroom C when the floor-to-ceiling height was changed from 3.4m to 4.0m. The results show that the higher floor-to-ceiling height helps buildings perform better in terms of reducing overheating hours. The floor-to-ceiling height contributed positively to the indoor thermal conditions and the reduction of overheating occurrence. Although design requirements for primary schools [7] recommend that floor-to-ceiling height is from 3.3m to 3.6m for classrooms, the simulation results show that the building has less overheating occurrence if the ceiling height is extended to 3.8m or 4.0m. The choice of building dimensions, particularly the floor-to-ceiling height, needs to be studied further in conjunction with other design issues such as aesthetics, construction costs or urban planning, which is out of the scope of this study.

Window Area

The variations of the window areas defined in Table 4 were used in this parametric study. The window area varied from 6.72m^2 to 10.92m^2 by increasing the width of the windows while the sill height of 1.0m and the window height of 1.4m kept unchanged.

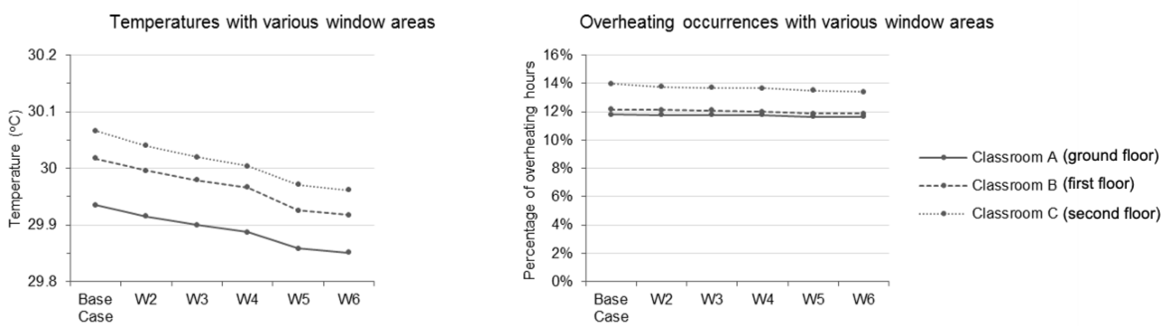
Table 4. Variations of window area

Case	Window area (m^2)	Dimension*	Window-to-floor ratio (%)
Base Case	6.72	2x1.4x2.4	14
W2	7.56	2x1.4x2.7	15.75
W3	8.4	2x1.4x3.0	17.5
W4	9.24	2x1.4x3.3	19.25
W5	10.08	2x1.4x3.6	21
W6	10.92	1x1.4x7.8	22.75

*number of shutters x height x width

There was a decrease in the average indoor air temperatures throughout the simulation cases as shown in Figure 7a. In all three investigated classrooms, the average indoor air temperature reduced by up to 1°C when the window area increased from 6.72m^2 to 10.92m^2. Therefore, within the defined parameter range, the areas with bigger openings helped the indoor environment become cooler.

As shown in Figure 7b, the percentage of overheating hours decreased from Base Case to Case W6. When changing the window area from 6.72m^2 to 10.92m^2, the overheating hours reduced by 0.7% (from 14% to 13.3%) of the total occupied period in Classroom C. The reductions for Classroom B and Classroom A respectively were only 0.3% and 0.1% of the total occupied period. Therefore, within the defined range, the wider the openings in the higher classrooms were, the further the reduction of overheating hours under indoor conditions was. The possible explanation is that the wind-driven cross-ventilation in Classroom C effectively removes the hot air indoors and replaces it with the cooler outside air while, at the lower storeys, the wind is interrupted by the surrounding buildings, particularly in the city centre.



(a) (b)

Figure 7. Average indoor air temperature (a) and the percentage of overheating hours (b) during school time when varying the window area

Nguyen [16] proposed that glazed window areas should be minimised on building façades in Vietnamese houses which are naturally ventilated. This differs from the findings presented here that a bigger window area could improve the indoor thermal conditions. This is because the windows are open during the occupied period, which allows the air exchange between outdoors and indoors to cool down the indoor thermal conditions. It also should be noted that the above findings are based on a defined range of window area. Out of the defined range, classrooms with larger windows may have a higher number of overheating hours because of the greater exposure to solar radiation. The window design is related to natural ventilation as well as the solar control of buildings. For that reason, there are complicated interactions between this parameter and others, such as room height, other openings, shading devices, and orientation of the room. Thus, to decide about the size of window areas, architects need to consider other building characteristics carefully.

Window Type

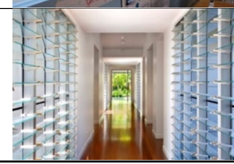
Simulations with the most popular window types were conducted to understand how these different window types affect the indoor air temperature and overheating (Table 5). The glazing types of windows have a profound effect on indoor thermal conditions in air-conditioned rooms. However, in naturally ventilated classrooms, the windows and the doors are open during school time. The glazing types, therefore, have a very limited effect on indoor thermal conditions during the occupied time; thus, the glazing type was not varied for simulations in this study. Both window types, which were investigated, have 6mm clear glazing with U-value of 5.69 W/m^{2}K. In both cases, the openings were maximised.

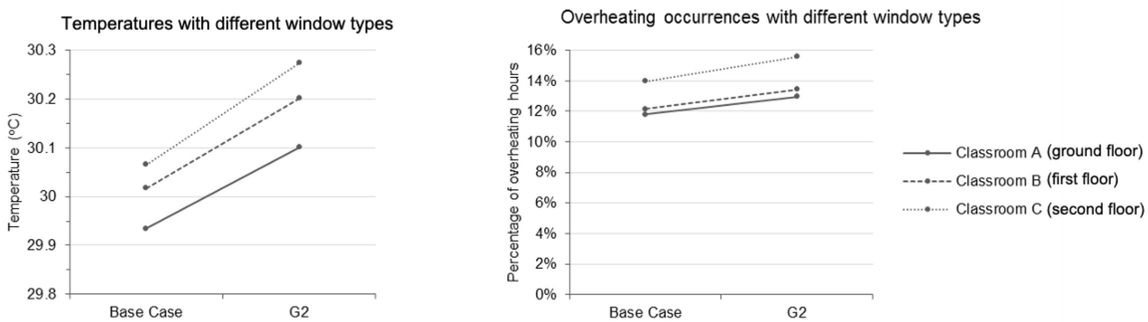
In Figure 8, it is apparent that the classrooms in Base Case were warmer than those in Case G2. The difference in the average indoor air temperature was nearly 0.2oC in each classroom between the two cases. Therefore, the casement windows provided better thermal performance than the louvres did during school time.

In terms of overheating, the classrooms in Base Case were found to have fewer overheating hours than in Case G2, as shown in Figure 8. The differences between the two cases during school time were significantly high: 1.1% for

Classroom A (26 hours), 1.3% for Classroom B (29 hours), and 1.6% for Classroom C (37 hours). This dissimilarity can be explained by the orifice area of each window type. The casement window with the safety frame provided around 90% of the gross opening area while the fixed louvre, because of its structure, only had an equivalent orifice area around 60% of the gross area. Therefore, the reduced inlet area in Case G2 caused a shortfall of natural ventilation and, consequently, worse thermal conditions and overheating problem in the classrooms.

Table 5. Variations of window type

Case	Window type	Note
Base Case	Casement window	
G2	Louvre window	



(a) (b)

Figure 8. Average indoor air temperature (a) and the percentage of overheating hours (b) during school time with different window types

These findings should help architects decide which window types would be most suitable in different circumstances. It is recommended that, wherever possible, the first window type is used. However, in some difficult circumstances, particularly for buildings in the city centre, although the second type is more suitable for use, alternative arrangements will need to be made to enhance the thermal environment.

Exhaust Opening Area

The exhaust opening areas, varying up to 1.92m^2 with 0.64m^2 intervals, were investigated. The distance between the exhaust opening and the ceiling was kept the same at 0.4m. Only the heights of the holes were varied. Table 6 summarises the details of exhaust openings in each case for simulations.

Table 6. Variations of exhaust opening area

Case	Exhaust opening area (m^2)	Dimension*
E1	0	-
E2	0.64	2x0.1x3.2
Base Case	1.28	2x0.2x3.2
E4	1.92	2x0.3x3.2

*number of exhaust openings x height x width

The simulation results presented in Figure 9 show that the average indoor air temperatures reduced when the exhaust opening area increased from Case E1 to Case E4. Among the classrooms, the most improved thermal condition was in Classroom C with a reduction of 2^{o}C. This result shows that exhaust openings enhance thermal performance. The percentage of overheating hours was highest when there were no exhaust openings in the classrooms (Case E1). When each opening area was reduced by 0.64m^2, the percentage of the overheating hours reduced by up to 0.3% during school time, as shown in Figure 9. Within a reasonable range, the larger the exhaust opening areas are, the lower the percentage of overheating hours experienced in the classrooms.

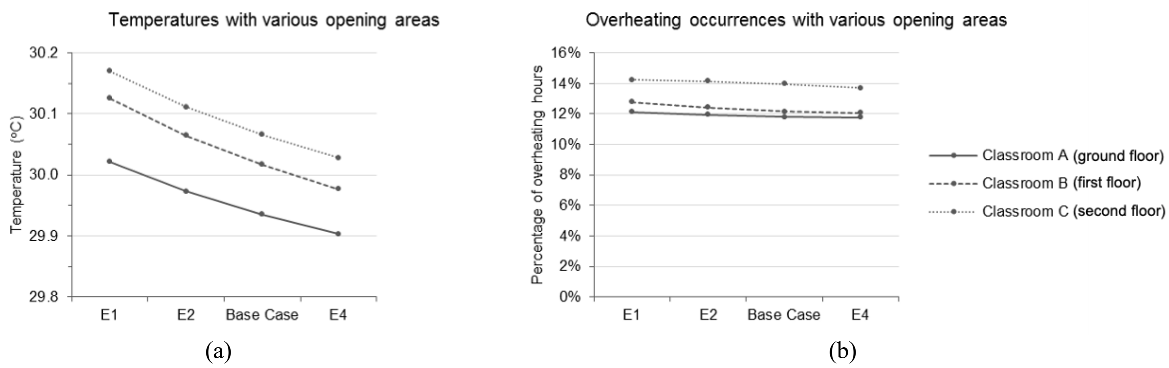


Figure 9. Average indoor air temperature (a) and the percentage of overheating hours (b) during school time when varying the exhaust opening area

During school time, the presence of the exhaust openings helped to improve the air changes in classrooms by the stack effect. The heated indoor air was released through those openings; therefore, the thermal environment was enhanced, and the risk of overheating was reduced. The exhaust openings also provided single cross-ventilation at night time. These openings have very limited effects from direct solar radiation because the extended corridor or roof provides shade; thus, exhaust openings are highly recommended in the design of schools.

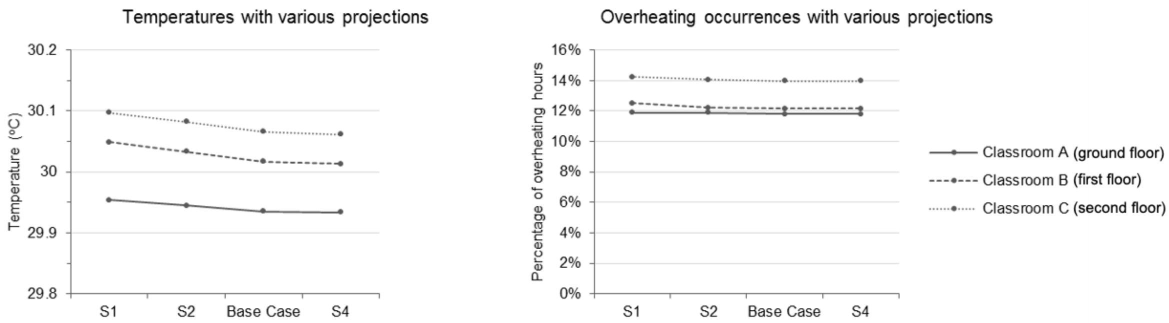
Overhang Projection

In this section, the overhang projection is investigated to learn how far this parameter contributes to the thermal performance of schools. The overhang projections were varied from 0.4m to 1m to produce the simulation cases shown in Table 7.

Table 7. Variations of the overhang projection

Case	Overhang projection (m)
S1	0.4
S2	0.6
Base Case	0.8
S4	1

As seen in Figure 10, the indoor temperatures reduced slightly (up to 0.05oC) from Case S1 to Case S4. For each 0.2m extension of the overhang projection from 0.4m to 0.8m, the percentage of overheating hours reduced insignificantly, up to 0.1%. The overheating hours, as well as the temperature, remain similar in Base Case and Case S4. Thus, within the assumed input boundary, the results showed the weak contribution of the overhang projection on the indoor thermal performance and the overheating. Only the horizontal overhang was investigated in this paper. Further study on the different types of shading for primary schools is recommended.



(a) (b)

Figure 10. Average indoor air temperature (a) and the percentage of overheating hours (b) during school time when varying the overhang projection

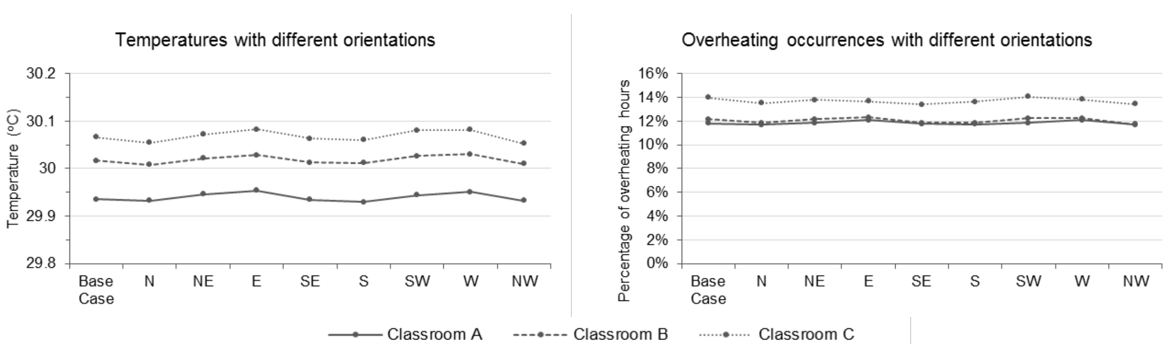
Orientation

This parametric study is to establish the influences of the building orientation on the thermal performance and overheating problem. The term ‘orientation’ refers to the direction of the windows. The orientation of Base Case is 15^{o} from south to west. The eight investigated directions can be seen in Table 8.

Table 8. Variations of the window’s orientation

Case	Orientation
Base Case	15^{o} from south to west
N	North
NE	North-east
E	East
SE	South-east
S	South
SW	South-west
W	West
NW	North-west

As shown in Figure 11, the results show that the average temperatures slightly decreased (by less than 0.1^{o}C) while the percentage of overheating problems reduced by up to 0.7% of the occupied period in all classrooms when changing the orientation of the building. The overheating hours during school time reached a peak of 12.1% in Classroom A, 12.3% in Classroom B and 14.1% in Classroom C when the windows face the east and south-west. The results show that the classrooms with windows facing south-east or north or north-west had the least number of overheating hours (11.7% for Classrooms A and B, and 13.4% for Classroom C).



(a) (b)

Figure 11. Average indoor air temperature(a) and the percentage of overheating hours (b) during school time when changing the windows’ orientation

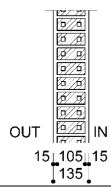
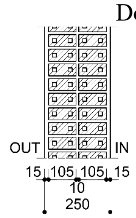
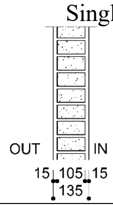
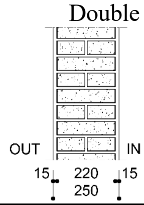
Among the three investigated cases, Classroom C suffered the most from the overheating problem. However, the indoor thermal condition in this classroom improved more than it did in Classroom A and Classroom B when the orientation was changed. In summary, the results suggest that the windows should face south-east or north-west to reduce the overheating problem. The building could be overheated more when facing south-west, west or north-east.

These findings are contrary to the recommendations of the Vietnamese Standard [7] which suggested that windows should face north or north-east. This research has found that facing north-west or south-east is a good solution for solving the overheating problem. The main reason why buildings that face south-east have fewer overheating problems is that the prevailing wind direction is from the south-east from March to May, the hottest period of the academic year. The orientation of the building affects the solar heat gain and natural ventilation as well as the daylighting in classrooms. This study examined thermal issues only, and a further study with more focus on the daylighting is therefore suggested.

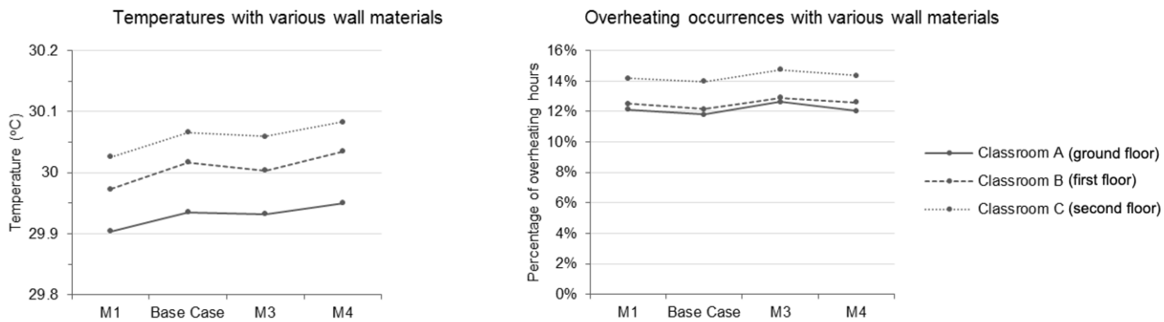
External Wall Material

Brick walls with single and double layers; and walls made of single and double concrete blocks were investigated in the simulation. These materials are recommended by the Ministry of Construction [8] because the R-value is higher than 0.56 m^2K/W and satisfies the requirement for energy-efficient building. The materials of external walls investigated here do not include an insulation layer because the use of thermal insulation for external walls had an insignificant impact on thermal performance and caused negative effects in some cases in Ho Chi Minh City [16].

Table 9. Variations of external wall materials

Case	External wall material	Properties	Value
M1	Single brick wall	Thickness (mm)	135
	 OUT	ISO U-value (W/m^2K)	2.61
	15mm Cement Plaster	CIBSE U-value (W/m^2K)	2.47
	105mm Hollow Brick	Admittance (W/m^2K)	3.95
	15mm Cement Plaster	Decrement factor	0.79
	IN	Time lag (hours)	4
Base Case	Double brick wall	Thickness (mm)	250
	 OUT	ISO U-value (W/m^2K)	1.74
	15mm Cement Plaster	CIBSE U-value (W/m^2K)	1.68
	105mm Hollow Brick	Admittance (W/m^2K)	4.25
	10mm Cement Plaster	Decrement factor	0.43
	105mm Hollow Brick	Time lag (hours)	8
	15mm Cement Plaster		
	IN		
M3	Single concrete block wall	Thickness (mm)	135
	 OUT	ISO U-value (W/m^2K)	2.09
	15mm Cement Plaster	CIBSE U-value (W/m^2K)	2.00
	105mm Concrete Block	Admittance (W/m^2K)	2.97
	15mm Cement Plaster	Decrement factor	0.91
	IN	Time lag (hours)	3
M4	Double concrete block wall	Thickness (mm)	250
	 OUT	ISO U-value (W/m^2K)	1.28
	15mm Cement Plaster	CIBSE U-value (W/m^2K)	1.25
	220mm Concrete Block	Admittance (W/m^2K)	3.29
	15mm Cement Plaster	Decrement factor	0.68
	IN	Time lag (hours)	5

As shown in Figure 12, in terms of the average indoor air temperature, Case M1 shows the best performance while the worst is Case M4. In general, the brick walls in Case M1 and Base Case resulted in lower temperatures than the concrete block walls in Case M3 and Case M4 did. The schools with single-layer walls (Case M1 and Case M3) performed better than those with double layer walls (Base Case and Case M4). Although the differences in average temperatures between cases are minimal (less than 0.1ºC), this may result in a large difference in overheating hours.



(a) (b)

Figure 12. Average indoor air temperature (a) and the percentage of overheating hours (b) during school time when changing the external materials

By varying the wall materials and wall thickness, the overheating hours increased in all cases in comparison to Base Case (Figure 12). The Base Case with a double brick wall achieved the best thermal performance in term of overheating in all classrooms (average percentage of overheating hours = 12.6% of school time). Case M3 with a single layer concrete block performed the worst among the cases as the overheating hours reached a peak of 13.4% of school time on average for all classrooms. The notable result is that with regard to avoiding overheating, the classrooms with brick walls (Case M1 and Base Case) performed better than those with concrete walls (Case M3 and Case M4) and the double layer walls achieved better results than the single-layer walls. Among the classrooms, Classroom C, which was overheated more than 14% of school time in all cases, achieves the worst thermal performance.

The results showed that brick wall buildings had better thermal performance than concrete block ones. Schools with single-layer walls had an insignificantly lower average temperature but more overheating hours than those with double layer walls during school time. In terms of the overheating hours, the double brick wall of the Base Case had the best performance. Although the double concrete block wall recommended by the Ministry of Construction [8] has a higher R-value, the overheating problem is more serious with the double concrete block material than with the double brick material. This is because of the lower decrement factor and higher time lag of the double brick wall, which results in better performance.

This finding implies that the current popular material of double brick wall works well to help reduce overheating in schools. Furthermore, concrete block costs more than traditional materials such as brick, so it is not recommended for public schools with limited funds. The finding is contrary to popular opinion, which believes that concrete blocks perform better than traditional hollow bricks. The study only focused on materials that are popular, local sources and recommended by the Vietnamese standard; therefore, a further study with a wider range of materials is recommended.

Roof System

In Ho Chi Minh City, newly built public schools have either one of two typical forms of roof – pitched roof or flat roof, as shown in Table 10 and Table 11. Construction of a pitched roof can be divided into three types: the first (as with the Base Case) is where a concrete pitched roof covered with dark tiles is used together with a steel frame insulated ceiling. The second type is a concrete pitched roof covered by dark tiles with a flat concrete slab as the internal floor. This type of roof is ventilated and can be seen in renovated schools where the concrete pitched roof has been added at the renovation stage. The third and final type of pitched roof is one on which there is a tiling layer on the steel frame with a flat concrete slab. This roof type is also ventilated. This section also investigated two flat roofs, one with hollow brick and the other with insulation foam.

Table 10. Variations of the pitched roof system

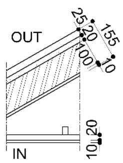
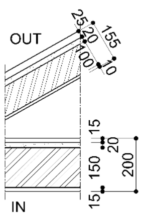
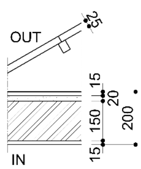
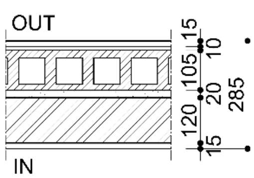
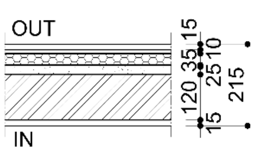
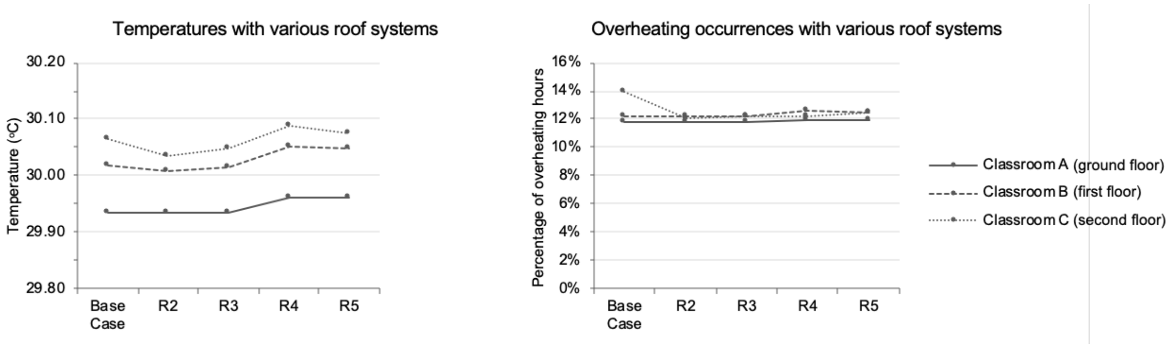
Case	Roof system			
Base Case 	OUT 25mm Clay Roof Tile 20mm Cement Plaster 100mm Concrete Deck 10mm Cement Plaster VOID Steel frame 20mm Roof Insulation 10mm Plasterboard IN		Normal ceiling	Concrete Roof
		Thickness (mm)	30	155
		ISO U-value (W/m^{2}K)	1.54	3.62
		CIBSE U-value (W/m^{2}K)	1.54	3.62
		Admittance (W/m^{2}K)	1.57	6.21
		Decrement factor	1.00	0.64
		Time lag (hours)	0	5
R2 	OUT 25mm Clay Roof Tile 20mm Cement Plaster 100mm Concrete Deck 10mm Cement Plaster VOID 15mm Clay Tile 20mm Screed 150mm Reinforced Concrete 15mm Cement Plaster IN		Concrete slab	Concrete Roof
		Thickness (mm)	200	155
		ISO U-value (W/m^{2}K)	2.43	3.62
		CIBSE U-value (W/m^{2}K)	2.43	3.62
		Admittance (W/m^{2}K)	5.36	6.21
		Decrement factor	0.39	0.64
		Time lag (hours)	6	5
R3 	OUT 25mm Clay Roof Tile Steel frame VOID 15mm Clay Tile 20mm Screed 150mm Reinforced Concrete 15mm Cement Plaster IN		Concrete slab	Tiling Roof
		Thickness (mm)	200	25
		ISO U-value (W/m^{2}K)	2.43	5.84
		CIBSE U-value (W/m^{2}K)	2.43	5.82
		Admittance (W/m^{2}K)	5.36	5.86
		Decrement factor	0.39	1.00
		Time lag (hours)	6	0

Table 11. Variations of the flat roof system

Case	Roof system		
R4 	OUT 15mm Clay Tile 10mm Cement Plaster 105mm Hollow Brick 20mm Cement Plaster 120mm Reinforced Concrete 15mm Cement Plaster IN	Flat roof with hollow brick	
		Thickness (mm)	285
		ISO U-value (W/m^{2}K)	1.24
		CIBSE U-value (W/m^{2}K)	1.23
		Admittance (W/m^{2}K)	6.47
		Decrement factor	0.22
		Time lag (hours)	11
R5 	OUT 15mm Clay Tile 10mm Cement Plaster 35mm Polystyrene 25mm Cement Plaster 120mm Reinforced Concrete 15mm Cement Plaster IN	Flat roof with insulation foam	
		Thickness (mm)	215
		ISO U-value (W/m^{2}K)	0.87
		CIBSE U-value (W/m^{2}K)	0.87
		Admittance (W/m^{2}K)	6.65
		Decrement factor	0.34
		Time lag (hours)	7

The results in Figure 13 showed that the average indoor air temperature in Classroom C was strongly affected depending on which roof system was used. Classroom C in Cases R4 had the hottest condition, about 30.1^{o}C. Among five cases, the average temperatures in three classrooms in Case R2 reached the lowest value. However, the changes in the average indoor air temperatures between cases were minimal (up to 0.05ºC) to extrapolate conclusions about the indoor temperature.



(a) (b)

Figure 13. Average indoor air temperature (a) and the percentage of overheating hours (b) during school time when changing the roof system

As shown in Figure 13, there was a noticeable decrease of 43 overheating hours (equivalent to 1.8% of the occupied period) in Classroom C between Base Case and Case R2. This indicates that the roof of Case R2 brought benefit to the indoor thermal conditions in terms of indoor temperature and overheating problem, as expected when compared with Base Case. Furthermore, the thermal environment of Classroom C was also remarkably improved in the other cases. Although the differences in average indoor air temperatures between cases are minor, the overheating condition in Case R2 is lower than in the other cases. All roof systems, except in Base Case, provide better thermal performance and more stable indoor temperatures.

The study investigated the whole combination of the ceiling and the roof. According to the results, the pitched roof performed better than the flat roof did in Classroom C. This result supports to the choice of the pitched roof in tropical countries as it helps to reduce not only the overheating problems during the hottest season but also the risk of water pooling and leakage during the rainy season.

DISCUSSION

The percentage of changes in overheating hours of the worst and best cases in comparison with Base Case within the defined boundary of the design parameters, as shown in Figure 14.

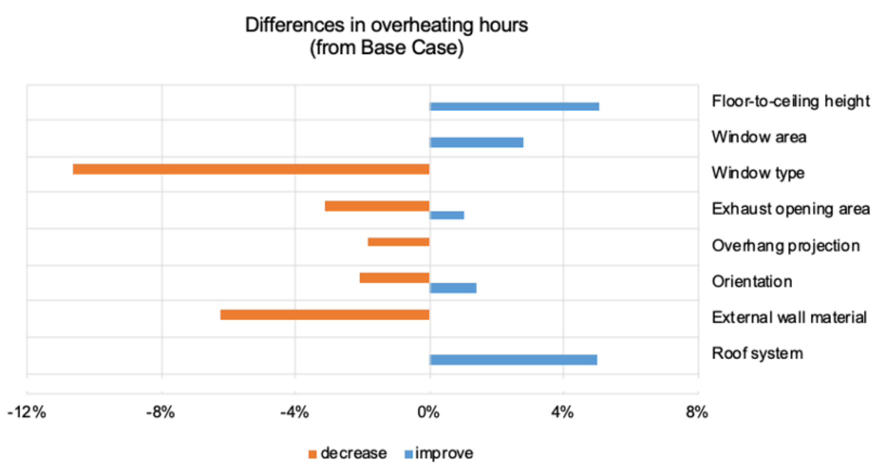


Figure 14. The differences of overheating hours in comparison with Base Case for each parameter

The results from the parametric study for each of the parameters showed that the changes in the overheating hours were less than 11% from Base Case. Changing the window type had the worst result – that is, the most negative impact (10.7% reduction from Base Case) on the thermal environment. The shading devices were found to have the least impact (1.9% difference to Base Case) on reducing overheating. It is apparent that Base Case was not always the worst or the best case in this parametric study. There is further potential to reduce more overheating hours in Base Case by adjusting the design parameters.

The sensitivity analysis, as shown in Table 12, was based on the minimum and maximum results of the total overheating hours in the three classrooms. The most sensitive parameter was found to be the type of window, where the casement window performed better than the louvre window (the overheating hours were reduced by 1.35% of school time). The parameters of external wall material came next in the ranking of the sensitivity analysis. Then in descending order, floor-to-ceiling height, roof system, exhaust opening area, orientation and the size of the window area had different effects on the indoor conditions. The shading device provided the least reduction in overheating hours among the parameters as the maximum reduction of the overheating hours was only 0.23% of school time.

Table 12. Ranking of the parameters' sensitivity based on overheating hours within the defined input range

Rank	Overheating hours
1	Window type
2	External wall material
3	Floor-to-ceiling height
4	Roof
5	Exhaust opening area
6	Orientation
7	Window area
8	Overhang projection

The parametric study could help architects make decisions for each design parameter. It is suitable for problem-solving in renovation or retrofit projects. In the early stages of the design process, the sensitivity analysis could help architects to choose the most important parameter to avoid overheating in primary schools. However, the parametric study does not show the interaction between these parameters, which may further boost the improvement of the indoor thermal conditions. Furthermore, it cannot provide an optimum solution for the whole building design. An optimisation study may be needed to provide an optimum solution for the whole building regarding the overheating threshold.

CONCLUSIONS

This paper focused on dynamic thermal simulations to seek a long-term prediction of the thermal environment, particularly overheating problems. The overheating threshold applied was 33ºC. The study investigated the design parameters that affect indoor temperature. The main model was built and validated based on a case study, the design of which is the closest to the requirements set out in the Vietnamese Standard. By varying the parameters, the parametric study was conducted to propose the design guidelines for naturally ventilated primary schools in term of avoiding the overheating in different design circumstances.

In the parametric study, the design parameters were varied one-at-a-time within the defined range to understand how each parameter affected the indoor thermal environment in terms of the overheating occurrence in the naturally ventilated primary schools. The parameters, which contribute to the natural ventilation in classrooms, are more sensitive to the indoor thermal performance than those which are related to solar radiation control. These findings suggest that in the design stage when choosing the parameters to improve thermal conditions in naturally ventilated classrooms, the architect should consider firstly the materials of building envelopes, secondly the parameters relating to ventilation, and finally the solar controls. These findings could assist the architect in choosing which parameters should be prioritised in the design stage, which is particularly useful in renovation and retrofit projects where only limited adjustments are considered, to improve the indoor thermal performance and reduce the overheating risk in primary schools. This paper investigated overheating in a primary school as this is the aspect of greatest concern. Further studies about daylight design and noise control are needed in order to complete the design guidelines for indoor environmental quality in primary schools in Ho Chi Minh City, Vietnam.

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