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# An analysis of thermal comfort in primary schools in Vietnam

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*There is a trend of installing air conditioning systems in public primary schools that are currently naturally ventilated in Vietnam. A previous study conducted by the authors provided evidence that there is limited need for air conditioning in Vietnamese mid-season and the hottest season.*

*In this study, the authors investigated thermal comfort and users' perceptions in three primary schools in Ho Chi Minh City during the hottest season (April 2016) and the coldest season (December 2016 – January 2017). In-situ spot and long-term measurements were recorded. Questionnaires were completed by 3,960 children (age range from 8 to 11 years) and the teachers to inform the study about their experiences and the extent of their interaction with the building in 97 free-running classrooms. The results were analysed by correlating the conditions measured and the comfort mean votes.*

*The neutral temperatures were respectively 31.7°C and 31.1°C for the hottest and coldest seasons. Children were observed to tolerate higher thermal comfort condition than the recommended values in the standards. Compared with the results of the hottest season, the thermal sensation mean vote reduced from (0.29) to (0.12) when the decrease of the mean temperature was from 33.3°C to 31.8°C in the coldest season. The temperature of 33°C was proposed for the overheating benchmark*

*The results indicated that Vietnamese children adapted to hot climate and had higher thermal comfort tolerance than adults. Preliminary findings suggest that it is unnecessary to use air conditioning system all year round. These findings could help and encourage architects and engineers to deliver schools reaching acceptable comfort levels without the need of air conditioning system.*

*Keywords: thermal comfort, primary school, natural ventilation, indoor environmental quality, children*

## 1. INTRODUCTION

The indoor environmental quality significantly affects the students' performance and productivity (Fisk, 2000, Mendell and Heath, 2005, Teli et al., 2015). Thermal comfort is one of the most important factors which is required to achieve satisfactory indoor environmental quality. The building type, outdoor conditions and the season all have an influence on thermal comfort (Frontczak and Wargocki, 2011).

Using air conditioning systems to achieve thermal comfort has become more popular in primary schools in Ho Chi Minh City, Vietnam. However, this leads to high levels of energy consumption and environmental problems in the primary schools. It also impacts on children's health and performance in the long term. Therefore it is recommended to operate the building in free-running mode for as much of the year as possible (Nicol et al., 2012).

In naturally ventilated buildings, the indoor thermal condition is linked to the outdoor temperature through the building envelope. Thus the comfort temperature in these buildings can change with the outdoor conditions (Nicol et al., 2012). The international standards have recently developed methods for determining thermal comfort in naturally conditioned spaces (CEN, 2007, ASHRAE, 2004). Research on thermal comfort to date, for the naturally ventilated buildings, has been based on adult comfort and mainly focused on residential buildings and offices. There is no promise that the current thermal comfort models are appropriate to children. Thus different comfort criteria might be required in order to achieve satisfactory thermal conditions for children (Teli et al., 2012).

There have been a limited but increasing number of studies about comfortable thermal environment for young children in primary schools. Data from several filed studies suggest that children have different desired thermal comfort than adults (Teli et al., 2015, Trebilcock et al., 2017, de Dear et al., 2015, Fabbri, 2015). Similarly, Tran (2010) proposed that the neutral comfort temperature for children in secondary schools in Vietnam was approximately 29.3ºC, which was higher than for adults. In addition, the investigation, which is conducted by the authors in September 2015 in Ho Chi Minh City, Vietnam, indicated that the children had higher thermal comfort tolerance than the adults (Vi Le et al., 2016). Therefore the existing standards, which are based on adults' perception, may need to be revised in order to apply for children.

In this work, the authors have evaluated the thermal environment in naturally ventilated classrooms and the occupants' perception of comfort in three primary schools in Ho Chi Minh City, Vietnam. Quantitative and qualitative approaches were used in the study. This study is a part of a larger research project developing environmental design standards for primary school in Ho Chi Minh City, Vietnam. The larger study includes other environmental conditions such as daylighting, indoor air quality and noise but these are outside the scope of this article.

## 2. CASE STUDIES

Three primary schools located in central Ho Chi Minh City in Vietnam were investigated. School 1 is in the medium density residential area while School 2 and School 3 are in the higher density area. There are 97 naturally ventilated classrooms, which were investigated during the hottest and coldest season, with the average of 35 children per class. The school time is Monday to Friday, from 7:00 to 10:00 for the morning session and from 13:00 to 16:00 for the evening session. The children, who join the all-day programme, have lunch and rest/sleep in the classrooms. The school uniforms are similar in these schools with the clothing insulation level of 0.55clo on average.

The classroom size is 40-50m2 and the floor-to-ceiling height is 3-3.3m. The walls are made of single/double brick and not thermal insulated. The doors and windows are usually single glazed with the steel frames. In School 3, most of classrooms have wooden louvered windows and door. There are ceiling fans, artificial lighting system in all classrooms. Most of classrooms have curtains or blinds.

## 3. METHODOLOGY

The research methods used included the collection of environmental data and the deployment of a questionnaire designed by the authors. The data was collected during the hottest season (March 2016 – May 2016) and the coldest season (November 2016 – January 2017). In the hottest season, the average daily temperature was 31ºC and the relative humidity was 68.4%. In the coldest season, the average daily temperature was 28.8ºC and the relative humidity was 75.9%. There was no rainfall in both seasons.

### 3.1. Long term recording

A NETATMO environment/weather station was used to record the long-term in-situ data of environmental conditions in one selected classroom in each school. The outdoor module recorded the outside temperature and relative humidity. The indoor module monitored the indoor environmental conditions. The data was recorded continuously every five minutes from August 2015 to May 2017. The accuracy of NETATMO system is ±0.3ºC for temperature and ±3% for relative humidity.

The long-term data recorded in School 2 during the coldest season was excluded from this analysis because the classroom was air conditioned from August 2016. The data was recorded in School 3 from April 2016.

*Table 1 The arrangement for the long term recording in three primary schools*

| | Hottest season | Coldest season |
|---|---|---|
| School 1 | March 2016 – May 2016 | November 2016 – January 2017 |
| School 2 | March 2016 – May 2016 | Not available |
| School 3 | April 2016 – May 2016 | November 2016 – January 2017 |

### 3.2. Spot point measurement

The data was collected from spot point measurements in the hottest season (April 2016) and the coldest season (December 2016, January 2017). The temperature and humidity were measured inside and outside the classrooms by using an environmental meter. The accuracy of the meter is ±3%rdg±2ºC for temperature and ±5% for relative humidity. The temperatures in various points in the classrooms were similar due to the small room size. Thus the temperatures were recorded in the middle of class.

### 3.3. Questionnaire

Questionnaires were carefully developed by the authors based on an extensive literature review and experience. The questionnaires were carried out at the same time as the spot measurements were made in the occupied classrooms in the hottest season (April 2016) and the coldest season (December 2016, January 2017).

Children from eight to eleven years old were the main subjects of this questionnaire due to their reading skill level required to undertaken the survey. A range of questions about indoor environmental quality was formulated in a way which could help children respond more easily. There were three key questions about children's perception on thermal condition, as seen in Figure 1.

Teachers also took part in the survey and answered similar questions about thermal sensation, thermal comfort and thermal preference in the hottest and coldest season.

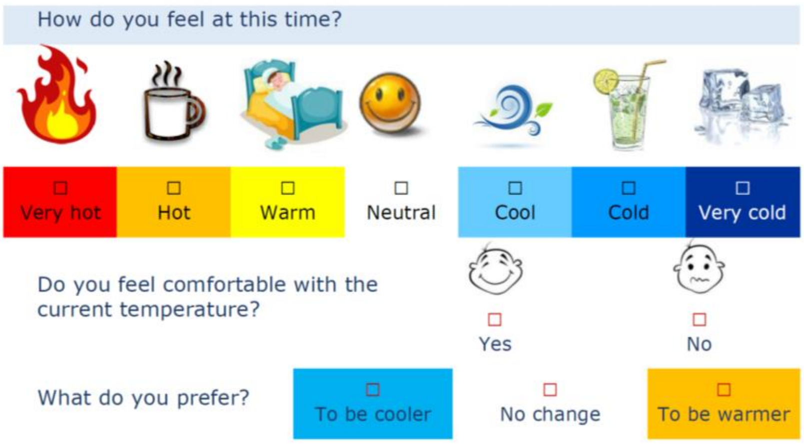


*Figure 1 Thermal comfort questionnaire for children*

### 3.4. Analysis

This study compares the results from the measurement with the current standards and research. As stated in the Vietnamese Building Standard TCXD VN 306:2004 (2004), the comfort zone for Vietnamese people is 21.5ºC-29.5ºC and the temperatures in buildings should not be lower than 19.8ºC or higher than 31.5ºC. As seen in Table

2, European Standard (EN) 15251 (CEN, 2007) suggests the indoor air temperature should not be over 27ºC in order to achieve acceptable thermal environment. These fixed values are recommended generally for controlled environment and widely used in practice.

However, the comfort temperature in the naturally ventilated classrooms is significantly related to the outdoor condition (Nicol et al., 2012). Thus in this study the authors also use the adaptive approach to evaluate the free-running environment. European Standard EN 15251 (CEN, 2007) suggests the adaptive thermal comfort equation (1) to calculated the comfort temperature.

$$T_{comf} = 0.33\,T_{rm} + 18.8 \quad (1)$$

where $T_{comf}$ [ºC] is the comfort temperature and $T_{rm}$ [ºC] is the external running mean temperature.

Table 2 shows the application of the equation (1) for each Building Category The Building Category I, II and III are considered for different levels of expectation whilst the Building Category IV is out of comfort zone and should only be accepted for a limited time of the year (CEN, 2007).

*Table 2 Recommended criteria for thermal comfort in classrooms (CEN, 2007)*

| | Fixed approach | Adaptive approach |
|---|---|---|
| Building Category I | 23.5ºC - 25.5ºC | 0.33Trm + 18.8 ± 2 |
| Building Category II | 23ºC - 26ºC | 0.33Trm + 18.8 ± 3 |
| Building Category III | 22ºC - 27ºC | 0.33Trm + 18.8 ± 4 |
| Building Category IV | <22ºC or >27ºC | |

The authors also apply the adaptive thermal comfort equation (2), which was developed by Humphreys et al. (2010) to evaluate the measured thermal conditions in the naturally ventilated classrooms in Ho Chi Minh City in Vietnam.

$$T_{comf} = 0.53T_o + 13.8 \quad (2)$$

where $T_{comf}$ is the comfort temperature and $T_o$ is the prevailing outdoor temperature

The relationship between the children's thermal sensation vote and the indoor temperature are examined in order to propose the neutral temperature. Nicol and Humphreys (2007) suggested that the comfort zone should be around ±2K from the neutral temperature to avoid thermal discomfort. Then some proposed values are consider to define the benchmark for the overheating problem in the primary schools in Ho Chi Minh City, Vietnam.

## 4. RESULTS AND DISCUSSION

Table 3 shows the data collected from the spot point measurements during the investigation periods. In the hottest season (April 2016), the indoor temperatures ranged from 29.2ºC to 36.1ºC and the relative humidity ranged from 42.8% to 83.4%. The range of the indoor temperatures in the coldest season was from 28ºC to 34.5ºC and the relative humidity's range was from 45.4% to 85.4%. The mean temperature in the hottest season was 1.45ºC higher than in the coldest season.

*Table 3 Spot point measurements and the adaptive comfort temperature (obtained from Humphreys' equation)*

| | | Indoor Temperature Range [ºC] | Comfort Temperature [ºC] | Indoor Relative Humidity Range [%] |
|---|---|---|---|---|
| Hottest Season (Apr 2016) | School 1 | 29.2 – 34 (31.8 ± 1.6) | 29.9 | 49.1 – 83.4 (69.1 ± 12) |
| | School 2 | 31.7 – 35.8 (33.8 ± 1.6) | 30.2 | 42.8 – 78.5 (64.6 ± 12) |
| | School 3 | 31.1 – 36.1 (34 ± 1.4) | 30.1 | 48.4 - 79.3 (62.5 ± 11.5) |
| Coldest Season (Dec 2016 – Jan 2017) | School 1 | 28 – 32.8 (30.6 ± 1.6) | 28.1 (Dec 2016)<br>28.5 (Jan 2017) | 48.2 – 85.4 (68.7 ± 11.1) |
| | School 2 | 30.1 – 34.5 (32.6 ± 1.8) | 29.3 (Jan 2017) | 45.4 – 70.9 (61.4 ± 9.5) |
| | School 3 | 29.3 – 33.8 (32.2 ± 1.5) | 29 (Jan 2017) | 50.1 – 77.5 (66 ± 6.7) |

If compared with the Vietnamese Standard, only one classroom, which was measured before 8:00 a.m., presented the temperature below 29.5ºC in the hottest season and therefore was in the comfort zone. There were seven classrooms presenting the temperatures below 31.5 during the investigation period in April 2016. These classrooms could be classified as 'acceptable' thermal environment although they were out of the desired thermal comfort zone.

In the coldest season, four classrooms, which were measured before 9:00 a.m., presented the temperatures below 29.5ºC and therefore were in the desired comfort zone. There were 23 classrooms (equivalent to 48% of the classrooms) with the temperature below 31.5ºC and could be 'acceptable' for occupants, according to the Vietnamese Building Standard (TCXDVN) 306:2004 (Ministry of Construction, 2004).

All thermal comfort environments were measured in the early morning in both seasons. During the school time, the indoor temperature increased and reached the peak at 2:00 p.m. – 3:00 p.m., then began to cool down. Even so, there were no measured condition in comfort zone in the late afternoon. It is possible that the overheating problem may occur during school time, especially in the afternoon, even in the coldest season. Although more naturally ventilated classrooms in the coldest season were in comfortable and acceptable conditions, the primary schools generally in both seasons did not achieve thermal comfort based on the Vietnamese Building Standard.

During the investigation periods, all of classrooms in which the measured temperatures were over 27ºC could be classified as Building Category IV (CEN, 2007). These conditions were out of the range for good indoor thermal comfort, based on European Standard 15251 (2007).

The adaptive approach is also used to evaluate the thermal conditions in the naturally ventilated classrooms in the primary schools. The comfort temperature, which is calculated from the running mean outdoor temperatures by using the adaptive thermal comfort equation (1) (CEN, 2007), is compared with the measured indoor temperature in each classroom. The results shows that there were seven classrooms (14%) investigated in the hottest season and 10 classrooms (21%) investigated in the coldest season in comfort condition, which is defined by the zone of 2K from the comfort temperature.

The comfort temperatures, as shown in Table 3, are calculated from the prevailing outdoor temperatures by using the adaptive thermal comfort equation (2). The comfort zones of 2K from the comfort temperatures are used to evaluate the thermal condition in the classrooms. During the investigation periods, there were 16 classrooms (33%) measured in the hottest season and 17 classrooms measured in the coldest season achieving thermal comfort.

The results from the adaptive approaches proposed by EN 15251 and Humphreys shows that the primary schools in Ho Chi Minh City in Vietnam did not fully achieve thermal comfort throughout the investigation periods.

### 4.1. Children's Thermal Comfort

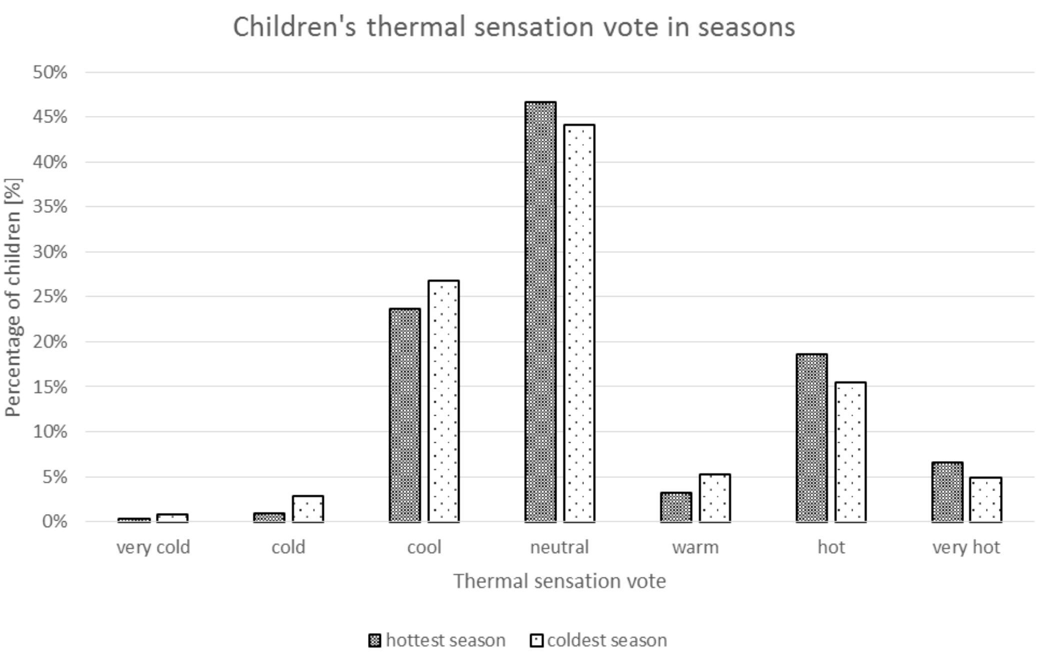


*Figure 2 Children's thermal sensation vote in the hottest and coldest season*

The result from the children's questionnaire indicated the thermal sensation mean vote of 0.29 and the mean indoor temperature of 33.3ºC in the hottest season. In the coldest season, the thermal sensation mean vote reduced to 0.12 and the mean temperature decreased to 31.8ºC. As shown in Figure 2, the percentage of people, who voted cool-neutral-warm, was 73.5% in the hottest season and rose up to 76.2% in the coldest season. This suggests that the children perceived the comfortable condition in the classrooms in both seasons with the temperature of 28-36.1ºC and the relative humidity of 42.8-85.4%. The result also confirmed that the children felt cooler in the coldest season.

The children voted positively for the current thermal condition. However, the environment in the primary schools was apparently out of the comfort zones, based on EN15251 and Vietnamese Standard. According to these data, it can be inferred that the standards may not be appropriate for children. A possible explanation is that the current standards are based on the thermal comfort models with adult subjects.

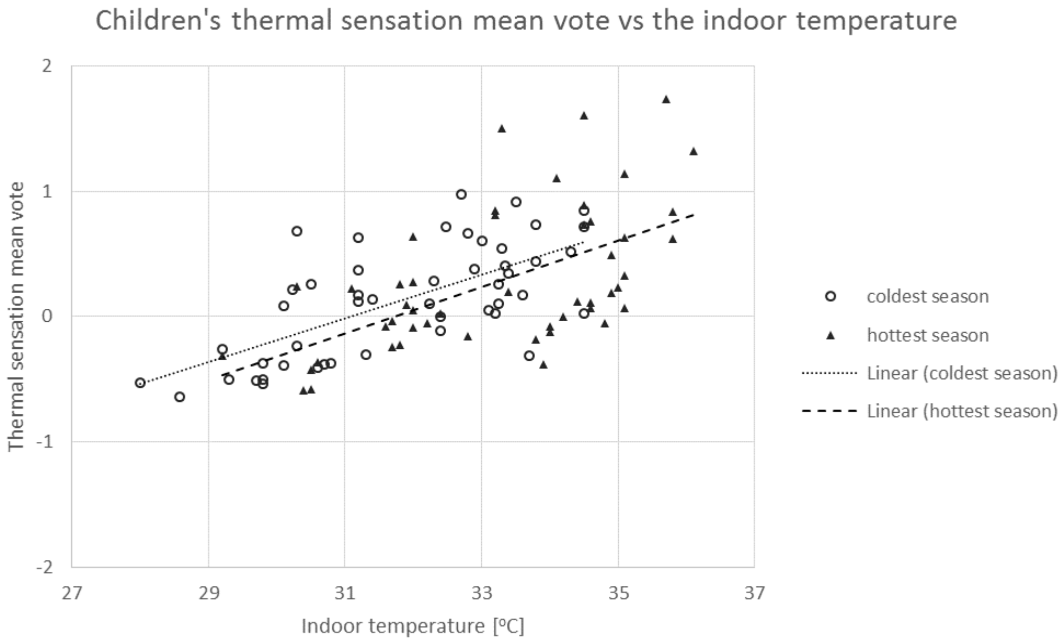


*Figure 3 Regression of children's thermal sensation mean vote against the indoor temperature in classrooms in the hottest and coldest season*

The relationships between thermal sensation mean vote and the indoor temperature in naturally ventilated classrooms in the hottest and coldest seasons are expressed in the simple linear regression fitted equations, as shown in Table 4. As seen in Figure 3, the difference between the regression lines is unremarkable in the temperature range of 28ºC to 36.1ºC. Also the neutral temperature in the hottest season is only 0.6ºC higher than in the coldest season. Therefore, the regression line of the combined data in both seasons could be well represented for the thermal comfort in the whole year. However, the further study is needed to confirm it.

The calculated neutral temperatures for children are higher than the comfort temperature for adults as shown in Table 3 in both seasons. This confirmed that the children's actual thermal sensation differed from adults' and the children felt the most comfortable at the higher temperature than adults.

*Table 4 Regression Equations and Neutral Temperature in the hottest and coldest season*

| | Number of classrooms | Regression equation | Neutral temperature [ºC] |
|---|---|---|---|
| Hottest Season (Apr 2016) | 49 | TSV=0.1853xT - 5.8793 ($R^2$=0.332) | 31.7 |
| Coldest Season (Dec 2016 – Jan 2017) | 48 | TSV=0.1745xT - 5.4259 ($R^2$=0.453) | 31.1 |
| Whole year | 97 | TSV= 0.1697xT - 5.3175 ($R^2$ = 0.379) | 31.3 |

Nicol and Humphreys (2007) suggested that the thermal comfort zone should be ±2K from the neutral temperature. Therefore, the thermal comfort zone for children should be 29.7ºC – 33.7ºC in the hottest season, and 29.1ºC – 33.1ºC in the coldest season.

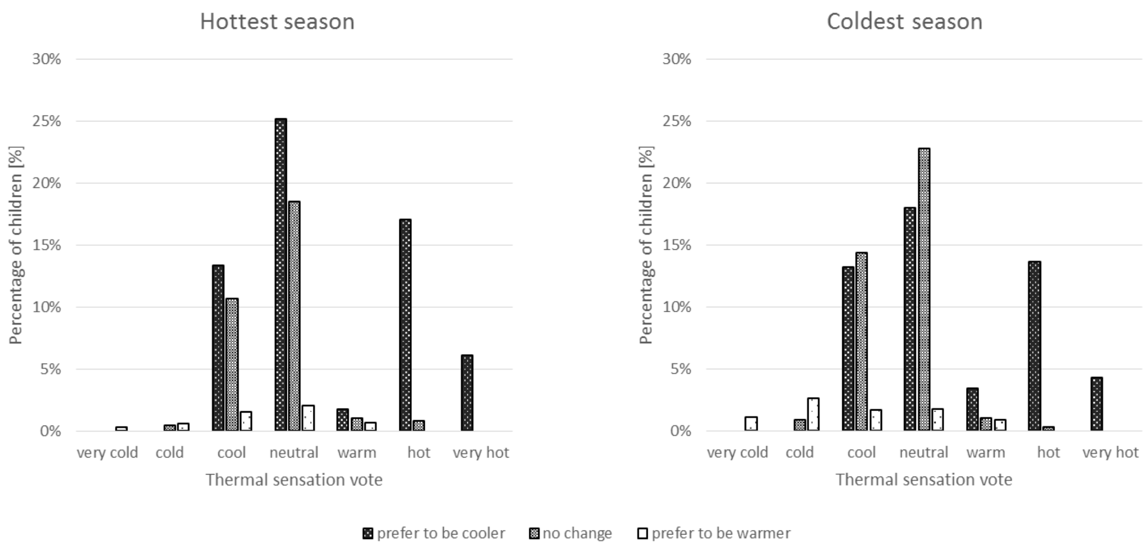


*Figure 4 Thermal sensation vote and preference vote in the hottest season and the coldest season*

As shown in Figure 4, in both seasons, the percentage of children who wanted to be cooler in the classroom was significantly high (more than 50%). the preference votes from the children who felt cold or neutral is significantly different between two seasons. In the hottest season, when the thermal sensation votes were 'cool' and neutral', the percentage of children preferring to be cooler is higher than those who did not want to change the thermal environment. In the contrast, there were more children voting 'no change' when they felt cool or neutral in the coldest season.

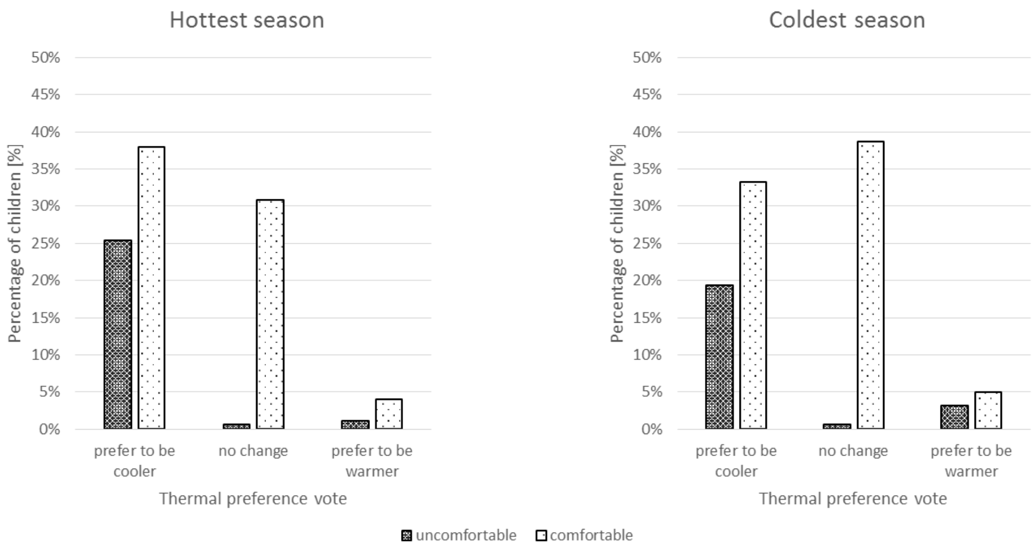


*Figure 5 Preference and comfort vote in 2 seasons*

The results show that in both seasons there was a high percentage of children feeling comfortable when their thermal sensation is cool or neutral. The children questionnaire results show that 75% of children voted comfort in both seasons. The percentage of children voting comfort in the coldest season (77%) was higher than it was in the hottest season (73%). It is suggested that generally, the children felt comfortable in their classrooms in most of school time.

There were 63% of children preferred the cooler environment in the hottest season. Even in the coldest season, more than 50% of children want to be cooler. In, addition the children who voted uncomfortable preferred to be cooler in both seasons. Despite feeling comfortable in the classrooms, the children preferred a cooler thermal environment.

### 4.2. Long-term measurement and overheating occurrence

Figure 6 presents the indoor temperatures during the school time in the primary schools in the hottest season (March – April – May) and the coldest season (November – December – January) of the year 2016. The results shows that April and December is the hottest and coldest month of the year, respectively.

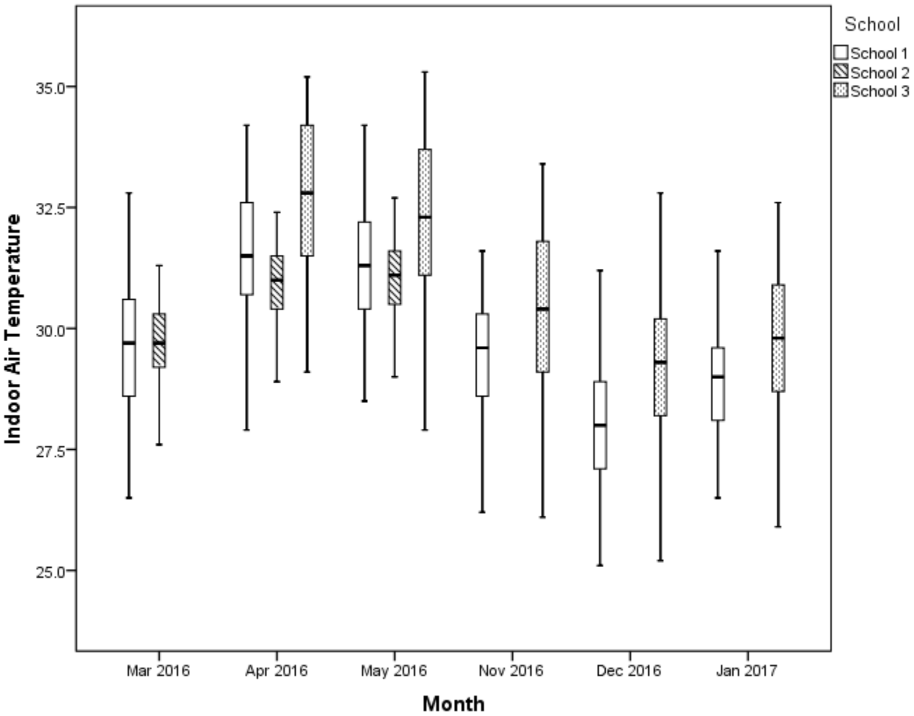


*Figure 6 The indoor air temperature in three primary schools during the school time in the hottest and coldest seasons*

The threshold temperature to avoid the overheating in European schools is 28ºC (DfE, 2006). However, the result shows that Vietnamese children tolerate with higher temperature and thus the overheating problem should be evaluate at a higher temperature.

The upper limits of the calculated comfort zones in both seasons (33.7ºC and 33.1ºC), as mentioned in Section 4.1, are used to examine the overheating occurrence in the primary schools. The study will use the temperature of 33ºC as the threshold for evaluating the overheating problem. This temperature is more practical to apply in design and just below the upper limit of the comfort zone in the coldest season.

*Table 5 Number of hours and the percentage of occupied time in unacceptable thermal conditions*

| | | >33ºC | >33.1ºC | >33.7ºC |
|---|---|---|---|---|
| Hottest Season | School 1 | 52h (2.7%) | 45h (2.3%) | 7h (0.3%) |
| | School 2 | 0 | 0 | 0 |
| | School 3 | 134h (7%) | 128h (6.7%) | 92h (4.8%) |
| Coldest Season | School 1 | 0 | 0 | 0 |
| | School 2 | - | - | - |
| | School 3 | 4h (0.2%) | 2h (0.1%) | 0 |
| Academic year | School 1 | 52h (2.7%) | 45h (2.3%) | 7h (0.3%) |
| | School 2 | 0 | 0 | 0 |
| | School 3 | 202h (10.5%) | 189h (9.8%) | 92h (4.8%) |

The results from the long term recording show that the differences between the indoor and outdoor temperatures did not exceed 5ºC in the naturally ventilated classrooms in the primary schools in Ho Chi Minh City in Vietnam.

Table 5 shows that the temperatures in School 1 were over 33ºC in 52 hours of the school time in the hottest season. During the other season, School 1 presented the temperatures below 33ºC. As a result, School 1 did not suffer overheating. This finding suggests that it is unnecessary to apply air conditioning system in this school. In the School 2, the temperatures, which presented mostly below 33ºC, were acceptable for teaching and learning areas.

School 3 experienced overheating problem the most (more than 120 hours) in the hottest season of the year. There were more than 200 hours of the school time during the academic year, when the temperatures went above 33ºC. In only 10.5% of the occupied time, the building suffered overheating. It can thus be suggested that the use of air conditioning in this school may be unnecessary all the time. The air conditioning can be used only around midday, especially in the hottest season of the year, when the temperatures are over 33ºC.

As seen in Table 5, the overheating problem occurred in School 1 and School 3. The thermal environment in School 1 was better than in School 3 according to the results from the long term recording. A possible explanation for these different results between the primary schools might be that the location and the building envelopes have a great impact on the indoor thermal condition.

### 4.3. Teachers' thermal comfort and occupant's behaviour

The teachers responded the questionnaire in order to provide a long term evaluation of indoor thermal comfort in the hottest and coldest season. The teachers' thermal sensation mean vote in the hottest season (0.77) was higher than it was in the coldest season (0.3). It suggests that the teachers perceived higher temperature than the children did in the same environment. In addition, the results shows that they felt more comfortable in the coldest season.

Generally, the teachers' thermal sensation mean vote was higher than children's in both seasons. Therefore the children may have more tolerance to higher temperatures. Similar to the children's preference, the teachers preferred cooler condition especially in the hottest season.

The teacher also gave the information about how the building elements were used to adjust the thermal environment. In the hottest season, the occupants used the fans and opened the curtains, windows and doors more frequently than in the coldest season in order to reduce the indoor heat. Although the children had more chance to open/close the windows and curtains, in most classrooms the teachers mainly controlled these building elements. The windows were open almost all the school time to provide natural ventilation.

## 5. DISCUSSION AND CONCLUSIONS

This study was undertaken to evaluate the current environmental conditions and users' perception of indoor thermal environment in naturally ventilated classrooms in three primary schools. The classrooms have been operated in free-running mode and using ceiling fans as a supplementary cooling method. The investigation was conducted during the hottest season (April2016) and the coldest season (December 2016 – January 2017).

The thermal environment of the investigated primary schools in Ho Chi Minh City in Vietnam in both seasons did not achieve thermal comfort based on the international and Vietnamese standards. The validity of these standards for children should be examined as these are based on thermal comfort model of adults.

The neutral temperatures for the naturally ventilated classrooms in the hottest and coldest season were respectively 31.7ºC and 31.1ºC. The findings confirm previous study and contributes additional evidence that Vietnamese children tolerated higher temperatures than the values recommended for adults in the standards.

The paper also confirms the finding from the previous study by the authors that the benchmark for overheating calculations could be 33ºC. Air conditioning may be unnecessary all year round. The schools should be operate in free-running mode for as much of the year as possible.

These findings from this study could help and encourage building designers to deliver the most satisfactory thermal condition for teaching and learning area without the need of the air conditioning system. The research presented here is a part of the comprehensive project about indoor environmental quality in the primary schools in Ho Chi Minh City in Vietnam. Further study will be conducted in order to inform the design parameters and propose the update to the current Vietnamese Building Standard.

## 6. ACKNOWLEDGEMENT

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