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Children thermal comfort in primary schools in Ho Chi Minh City in Vietnam

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Abstract: Indoor environmental quality significantly impacts on students' performance and productivity, particularly thermal comfort levels. Currently in Vietnam, very few studies have dealt with the issue and the current trend is to install energy-intensive air-conditioning in primary schools as this is perceived as more comfortable. In this study, the authors investigated the users' perceptions of thermal comfort in three primary schools in Ho Chi Minh City during the mid-season (September 2015) and the hottest season (April 2016). In-situ spot and long-term measurements were recorded. Questionnaires were completed by 2,145 children (from 8 to 11 years-old) and 62 teachers to understand their experiences and the extent of their interaction with the building in 62 naturally ventilated classrooms. The results were analysed by correlating the conditions measured and the comfort mean votes. Throughout this study, children were observed to tolerate higher thermal comfort condition than the recommended values in the standards. Around 7% of the occupied time during academic year presented temperatures over 33°C, in which less than 80% of the children voted acceptable. The results indicated that Vietnamese children had higher thermal comfort tolerance than the comfort levels suggested in the standards. Using air conditioning system all year round was deemed unnecessary.

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

Introduction

The indoor environment significantly impacts on students' performance and productivity (Fisk, 2000, Mendell and Heath, 2005, Teli et al., 2015). Among the factors required to achieve satisfactory indoor environmental quality, thermal comfort can be considered as one of the most important issues, especially in tropical countries (Al horr et al., 2016). After investigating several case studies, Frontczak and Wargocki (2011) stated that the building type, outdoor conditions and the season all have an influence on thermal comfort.

Research on thermal comfort to date has been based on adult comfort and mainly focused on residential buildings and offices. There have been a limited but increasing number of studies about comfortable thermal environment for young children in primary schools. Teli et al. (2015) suggested that UK children's comfort temperature could be 2°C lower than adults', Trebilcock et al. (2017) came to similar conclusions in Chile and de Dear et al. (2015) in Australia. Fabbri (2015) also argued that children are less sensitive to cold condition due to higher metabolism. In summary, a number of field studies showed evidence that children have different thermal comfort requirements than adults and therefore existing international standards, which are based on adults' perception, may not be appropriate for children.

In Vietnam, there has been a few studies about thermal comfort in residential buildings in Da Nang (Nguyen, 2013) and in secondary schools in Ho Chi Minh City (Tran, 2010). Tran (2010) suggested that the neutral comfort temperature for classrooms in secondary schools

was approximately 29.3^{o}C and that the other environmental factors affecting comfort should also be taken into account.

Currently, there is a trend to install air conditioner in primary schools in Ho Chi Minh City due to a perceived need and pressure from parents. One of the case study schools investigated by the authors, which was part of the research for the mid-season (Vi Le et al., 2016), has recently had air condition installed in three classrooms. Parent believed that their children may study better in a cooler environment. However, young children in primary schools may experience thermal environment differently from adults. Therefore, in order to provide a comfortable environment for teaching and learning activities, it is essential to understand the children's perception of the environment in their classrooms.

In this work, the authors have evaluated the thermal environment in naturally ventilated classrooms and the children's 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 and air quality but these are outside the scope of this article.

Case studies

Three primary schools with similar characteristics all located in central Ho Chi Minh City were investigated. School 1 is in the medium density residential area whilst the others (School 2 and School 3) are in the high density residential area. There are 62 classrooms in total in the three schools with approximately 35 pupils per class on average. The typical room size is 40-50m^2. The floor-to-ceiling height is 3-3.3m. The walls are made of single/double bricks without thermal insulation. Doors and windows have single glazing and steel frames in School 1 and School 2. In School 3, most of classrooms have wooden louvered windows and a door. There are ceiling fans and artificial lighting in all classrooms. Some classrooms have curtains or blinds. The academic year in Vietnam is from the middle of August to the end of May every year. The school time is 7:00 - 10:00 and 13:00 - 16:00 Monday to Friday. Children wear similar uniform in these schools with the clothing insulation level of 0.55clo on average.

Methodology

Methods used included the collection of environmental data and the deployment of a questionnaire designed by the authors. The sets of data were then correlated to enable the understating of perception of comfort in relation to actual measured data. The periods of data collection included September 2015 (mid-season) and April 2016 (hottest season). In the mid-season, only School 1 was investigated. The typical weather was hot with little rainfall (average daily temperature 29.9^{o}C and relative humidity 73.6%). In the hottest season, the authors conducted the investigation in three primary schools when the weather was significantly hot without rainfall (average daily temperature 31.8^{o}C, relative humidity 68.4%).

Long term recording

Two modules of a NETATMO environment/weather station were installed in one selected classroom in each school in order to conduct long term in-situ measurement of environmental conditions. The outdoor unit recorded outside air temperature and relative humidity while the internal unit monitored the indoor environmental parameters. The data were recorded every five minutes and continuously recorded from August 2015 to May 2016. The NETATMO system has an accuracy of ±0.3 ^{o}C for temperature and ±3% for relative humidity. The long-

term data recorded in School 2 was excluded from this analysis because the classroom where the data was collected was not representative of the norm for the school.

Spot point measurement

Spot point measurements of temperature and humidity were conducted using an environmental meter inside and outside the classrooms. The accuracy of the meter is ±3%rdg±2^{o}C for temperature and ±5% for relative humidity. Due to the small room size, temperatures in various points in the classroom were found to be similar. Therefore the temperatures in the middle of class were recorded in controlled intervals in the occupied rooms during the deployment of the questionnaires.

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. The target public were children from eight to eleven years old due to their reading skill level required to undertaken the survey. The questionnaire contained several questions about indoor environmental quality and was formulated in a way which could help children respond more easily. Perception of the thermal environment was a part of the questionnaire. In mid-season, the children were asked only about their thermal sensation. In the hottest season, the questionnaire included three key questions about thermal sensation (very hot (+3), hot (+2), warm (+1), neutral (0), cool (-1), cold (-2) and very cold (-3)), thermal comfort (yes - no question) and thermal preference (prefer to be cooler, no change, prefer to be warmer).

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

Analysis

This study compared the results from the measurement with the European Standard (EN) 15251 (CEN, 2007) and Vietnamese Building Standard (TCXDVN) 306:2004 (Ministry of Construction, 2004). The Vietnamese Standard TCXD VN 306:2004 (2004) states that the comfort zone for Vietnamese people is 21.5^{o}C-29.5^{o}C and that the temperatures in buildings should not be lower than 19.8^{o}C or higher than 31.5^{o}C.

The adaptive thermal comfort equation (1) from EN 15251 was adopted in order to evaluate the users' thermal comfort perception because similar equation is not available for the Vietnamese climate. In the equation (1), T_{comf} [^{o}C] is the comfort temperature and T_{rm} [^{o}C] is the external running mean temperature.

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

The European Standard 15251 (2007) specified the Building Categories of indoor environment as shown in Table 1. The Building Category I, II and III are considered for different levels of acceptable environments whilst the Building Category IV is out of expectation and should only be accepted for a limited time of the year (CEN, 2007). The recommended values and the adaptive thermal comfort equation for each Building Category are shown in Table 1.

Table 1 Recommended criteria for thermal comfort in classrooms (CEN, 2007)

	Fixed approach	Adaptive approach
Category I	23.5^{o}C - 25.5^{o}C	$0.33T_{rm}$ + 18.8 ± 2
Category II	23^{o}C - 26^{o}C	$0.33T_{rm}$ + 18.8 ± 3
Category III	22^{o}C - 27^{o}C	$0.33T_{rm}$ + 18.8 ± 4
Category IV	<22^{o}C or >27^{o}C	

The authors applies the algorithm developed by Montazami et al. (2017),in which the differences between adults' (adopted from EN15251) and children's comfort temperature (calculated from the field study) are compared. The relationship between children's thermal sensation vote and the indoor temperature are considered in order to propose the comfort temperature and the benchmark for overheating calculation in primary schools in Vietnam.

Results and discussion

An analysis of all the data collected in the hottest season showed that throughout the investigation period, the children questionnaire results indicated an overall thermal sensation mean vote of 0.33. Thus the general thermal sensation of the children was comfortably warm in their classrooms when the temperatures ranged from 29.2^{o}C to 36.1^{o}C and the relative humidity ranged from 42.8% to 83.4% (see Table 2).

Table 2 Spot point measurements and the overall thermal sensation mean vote in the three primary schools

	Thermal Sensation Mean Vote	Indoor Air Temperature Range [^{o}C]	Relative Humidity Range [%]
School 1	-0.2	29.2 - 34	49.1 – 83.4
School 2	0.56	31.7 – 35.8	42.8 – 78.5
School 3	0.51	31.1 – 36.1	48.4-79.3

The temperatures measured were higher than 27^{o}C in all investigated classrooms. Therefore they were classified as Building Category IV (CEN, 2007), which is out of the range for good indoor thermal comfort.

If compared with the Vietnamese standards, only seven classrooms presented temperatures below 31.5^{o}C during the investigation period (equivalent to 14% of classrooms) and therefore could be classified as 'acceptable' in terms of thermal comfort conditions, even though they are still out of the desired comfort zone. Only one classroom, which was measured in the morning, presented the temperature of 29.2^{o}C (below 29.5^{o}C) and therefore was within the comfort zone. Generally, the measured conditions did not achieve thermal comfort based on Vietnamese standard.

The results showed that thermal conditions in School 1 differed from the others. Perhaps the location of the buildings caused the differences between the schools but there is not enough evidence to infer this conclusion. Even the best environmental comfort conditions recorded in School 1 were not maintained throughout the day as temperatures would go above the comfort zone from around 8:00am until the end of school time.

School 1 in the mid-season and the hottest season

The data collected in School 1 were used to compare the mid-season and the hottest season results. The recorded outdoor temperature ranged from 26^{o}C to 35 ^{o}C in the mid-season and from 28 ^{o}C to 37^{o}C in the hottest season. Compared with the results of the mid-season (Vi Le et al., 2016), the thermal sensation mean vote raised from (-0.43) to (-0.2) when the mean indoor air temperature increased from 29.9^{o}C to 31.8^{o}C and the mean relative humidity decreased from 78.3% to 69% in School 1. The result showed that although the children felt comfortably cool in both seasons, they perceived warmer thermal environment in the hottest season in their classrooms.

Children thermal sensation votes

The relationship between the thermal sensation vote and the offset from the adaptive comfort temperature was plotted and is shown in Figure 1. The relationship between the thermal sensation vote and the indoor temperatures is shown in Figure 2. The data shown includes all the data collected in the mid-season and the hottest season of the year. In general, the indoor air temperatures were higher than the desired comfort temperature as discussed before (based on CEN (2007)).

As shown in Figure 1, the percentage of the children feeling warm-neutral-cold peaked at 86% when the difference between the indoor air temperature and the comfort temperature was about 0.67K. In this condition, 39% of the children voted neutral. The highest percentage (52%) of children feeling neutral occurred when the temperature difference was approximately 3.8K. In this condition, 79.6% of the children voted warm-neutral-cold.

These findings differed from the previous study by Montazami et al. (2017). The children were observed to tolerate higher temperatures than the values recommended for adults in the standards. The percentage of children feeling neutral decreased when the difference between indoor temperature and comfort temperature reduced from 3.8K to 0.67K. However, the percentage of children voting warm-neutral-cold to reach the highest levels (86%).

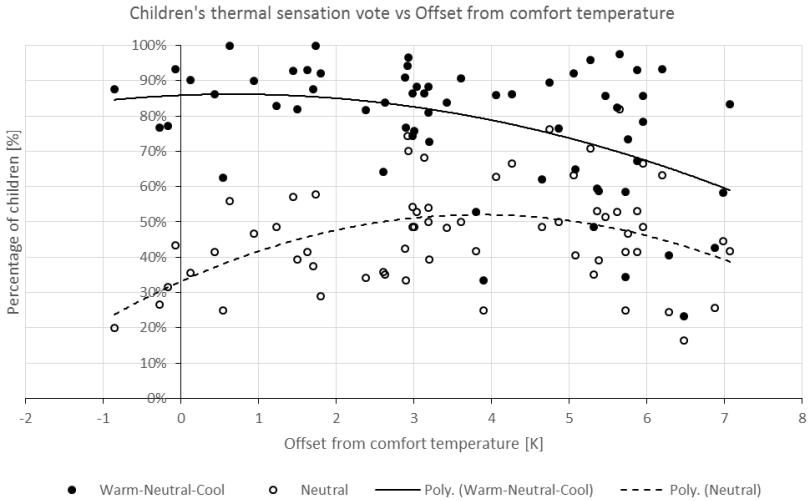

Figure 1 The percentage of children voting Neutral and Warm-Neutral-Cool in relation to the offset from the comfort temperature in the mid-season and the hottest season

In Figure 2 it can be seen that the highest percentage (87.3%) of children voted warm-neutral-cold around 29.9^{o}C while only 41.6% of children voted neutral. In addition, 51.2% of children voted neutral around 32.8^{o}C while 81% of the votes were for warm-neutral-cold. These results suggested that the percentage of children feeling acceptably comfortable (warm-neutral-cold) increased although the number of neutral votes reduced for temperatures below 32.8^{o}C.

In Figure 2, the results showed that 80% of children felt acceptably comfortable at 33^{o}C. Therefore, it can be suggested a maximum temperature of 33^{o}C could be taken as a threshold to evaluate overheating issues in primary schools in Ho Chi Minh City, Vietnam.

The comfort line in Figure 2 shows the percentage of children voting comfortable for the question of 'Do you feel comfortable at the moment?' in the hottest season. The results showed that 87.6% of children felt comfortable at 29.9^{o}C and 77.4% votes for comfort were

at 32.8°C. As seen in Figure 2, the results from the comfort line is likely close to the warm-neutral-cool line at the temperature range of 29.2 °C – 36.1°C. The difference between these two lines was less than 5% at that temperature range. Therefore the thermal sensation vote of warm-neutral-cool could be a reasonable indicator of thermal comfort for children.

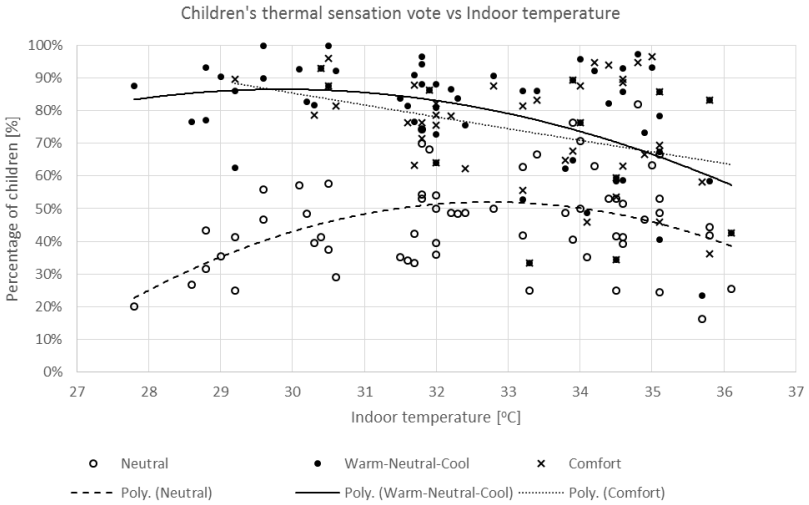

Figure 2 The percentage of children voting Neutral and Warm-Neutral-Cool in relation to classrooms' indoor temperature in the mid-season and the hottest season

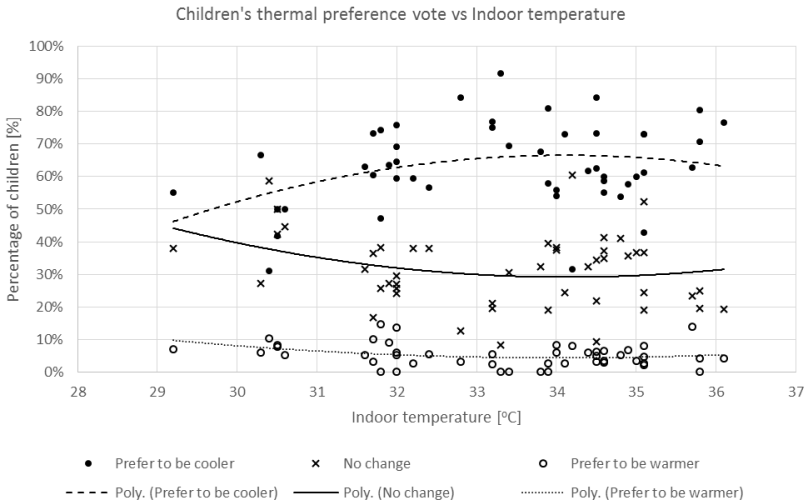

Figure 3 The percentage of children's thermal preferences in relation to classrooms' indoor temperature in the hottest season

As seen in Figure 3, during the hottest season of the year, 63% of children preferred to be cooler and less than 5% of votes preferred to be warmer. When the temperature decreased, the percentage of children wanted 'no change' and 'being warmer' increased and less children preferred to be cooler. Despite the children's responses that they felt comfortable with the current temperature in their classrooms, 38% of the children preferred a cooler thermal environment.

At the temperature of 32.8°C, when the highest percentage of the children voted neutral (Figure 2), the majority of the children (more than 50%) still preferred to be cooler (Figure 3). This suggests that the warm-neutral-cold line is a better indication of thermal comfort. The temperature when most of the children voted warmed-neutral-cool was 29.9°C as shown in Figure 2.

Long term measurement

CIBSE Guide A (2015) indicated that the threshold temperatures that defines overheating in European schools is 28°C. However, the evidence gathered by this work has shown that children in Ho Chi Minh City have more tolerance of higher temperatures and therefore the authors suggest that overheating should be measured at a higher temperature. Table 3 showed the number of hours in the hottest season when the temperatures were over 33 °C and 34.5 °C, corresponding to 80% and 70% of children voting warm-neutral-cool (Figure 2).

Table 3 Number of hours and percentage of occupied time in unacceptable thermal conditions

Temperature	>33°C	>34.5°C
School 1	52 (2.7%)	0
School 3	134 (7%)	40 (2.1%)

As seen in Table 3, in School 1, in less than 3% of the school time during the academic year the temperatures were over 33°C. As a result, the thermal environment in School 1 was acceptable. This suggests that the use of air conditioning in this school may be deemed unnecessary. In School 3, there was over 120 hours, equivalent to 7% of the occupied time during academic year, when temperatures were over 33°C. Although the building could experience some overheating problem, this indicates that air conditioning is not necessary all year round. It is recommended that air conditioning could be used only around midday when the temperatures go above 33°C. The long-term assessment showed that the thermal conditions in School 1 were better than in School 3. The authors' hypothesis is that the location and the building envelopes may have a large influence on the difference observed but further work is needed to confirm it.

Occupant behaviour and teacher votes

The teachers gave the long term evaluation of indoor thermal comfort in the mid-season and the hottest season. The teachers' thermal sensation mean vote was 0.77, which was higher than children's. This result implied that the teachers could perceive higher thermal environment than children in the same space. This result was consistent with the findings, indicating that the children have more tolerance to higher temperatures. Similar to the children's preference, the teachers also preferred a cooler thermal environment.

The questionnaire also provided feedback on how the occupants used the building elements and facilities to adjust their thermal environment. The teachers opened doors and turned on the fans and lights during the school time. The children also had opportunities to open/close the curtains and windows when these were close to their desks. The windows were open almost all the time to provide natural ventilation.

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. Ventilation in schools is enhanced on occasion by user controlled ceiling fans as a supplementary cooling method. The investigation was conducted during the mid-season (September 2015) and the hottest season (April 2016).

In general, the thermal environment of the studied primary schools in Ho Chi Minh City in Vietnam in the hottest season did not meet the comfort recommendations in the international and the Vietnamese standards. However, the authors questioned the validity of these standards for children since they are based on adults' responses. The highest percentage of children feeling comfortable was 87.3% when the temperature reached 29.9°C.

Most children felt neutral at 32.8°C. This indicated that Vietnamese children had higher thermal comfort tolerance than the comfort levels suggested in the standards.

The findings also suggested that the benchmark for overheating calculations could increase to 33°C in the hottest season when at least 80% of the children were satisfied with the thermal condition.

The authors suggest that air conditioning all year round, which is current trend in schools in Vietnam, may be unnecessary from a comfort perspective and would lead to unnecessary energy and associated carbon emissions. These findings could help and encourage architects and engineers to design and deliver schools that do not need the aid of air conditioning systems. In the next steps of this study, the authors will explore the influence of design on the thermal environment of primary schools in Vietnam.

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