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Experimental Study on Thermal Comfort Conditions in Existing Public Primary Schools Buildings in Upper Egypt

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Abstract

The present study is an attempt to primarily examine thermal performance of public primary school in Assiut city, Upper Egypt (hot arid climate) targeting to identify how much time pupils achieve thermal comfort conditions in their classrooms. In order to achieve this aim the current status of a typical public primary school is investigated through field measurements in terms of thermal comfort indices. These thermal comfort indices are the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied people (PPD). The results show that for the recent school building design there are strong relation between indoor comfort conditions and outdoor temperature. In addition to the average measured values of both the PMV and PPD inside the classrooms were 1.17 and 38.86%; respectively. Clearly, these results indicate that a higher level of thermal discomfort is existing within the primary public school classrooms as the pupils spent more than 36.5% of their time inside the classrooms under thermal stress conditions.

Keywords*: Thermal comfort; school building; hot-arid climate; naturally ventilated.*

1. Introduction

With increased global concerns on climate change caused by anthropogenic greenhouse gas emissions [1], the need for innovative spaces which can provide thermal comfort and energy efficiency is also increasing. Predictions published by the Intergovernmental Panel on Climate Change (IPCC) [2] indicate an increase in global average surface temperature in different scenario ranges of 1.1–2.9℃ to 2.4–6.4℃ from a 1990s baseline towards the end of the 21st century. Across the Egypt, which is the focus of this study, air temperature has already increased between 1℃ and 2℃ since 1970 and is expected to increase another 4℃ by 2100 as the special Report of Emission Scenario states, SRES, A1F [3]. In addition, Egypt has a significant variation in the climatic conditions. The Housing and Building Research Centre (HBRC) divides the country into eight different climatic design regions as reported by Mahmoud [4]. According to Koeppen's climate classification [5], Egypt experiences the 'hot desert climate type' (BWh) in the southern and central parts of the country and the 'hot steppe climate type' (BSh) along the coast. Most parts of Egypt are occupied by the Sahara desert, which represents the most extensive arid area on the planet. In general, Egypt possesses a hot-arid climate throughout the year. Within these aspects, this research addresses thermal comfort evaluation for public primary school classrooms in the Egypt. It is known that the primary school education system deals with pupils in such a sensitive yet promising age as they are shaping the milestones of their characters. In addition, children are more vulnerable than adults to environmental pollutants [6].

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2. Theoretical Background

In Egypt it is reported that there are about 15600 schools all over the country with 37.6% of all pre-university education [7]. This demand had considerably increased after the 1992 earthquake that devastated a considerable number of schools [8]. In response, the Egyptian government established the General Authority of Educational Buildings (GAEB) to design new schools around the country. These designs relied on an infiltration air of cross-ventilation with ceiling fans to achieve thermal comfort within the classrooms. GAEB uses the same prototype designs to establish schools across the various climatic conditions in many regions of Egypt without consideration to the significant variation in all climatic conditions. This led to uncomfortable interior conditions within the classrooms which span from heat stress, lack of adequate ventilation, glare to exposure to excess solar radiation.

Throughout the literature in the field of thermal comfort criteria met with the school buildings, the majority of research work had carried out in various settings for climate conditions ranged from temperate to tropical zones. On the other hand, few studies in the literature were investigated the thermal comfort criteria within public buildings in hot-arid climate so far: Gado and Mohammed [8] investigated the subjective response of occupants inside primary governmental schools in AL-Minya, Egypt with regard to their state of thermal comfort. The results of this work, suggested that the majority of occupants were thermally discomfort for most of the time during the academic year. Further on, Farghal [9] set an Adaptive Comfort limit for education university buildings in Cairo through a subjective field study of occupants in educational halls in three of Cairo's Universities. In Egypt the majority of the researches approached school design from social, educational, economical or theoretical points of view. Studies on thermal comfort within schools has been noticed recently in Egypt and most of these studies were focused on the residential building environments such as [10–12].

In light of the aforementioned, the present study aims to investigate the thermal comfort conditions within public primary schools in Upper Egypt to identify how much the pupils stay within thermal comfort in their classrooms.

3. Methodology

3.1. The case study

Experimental investigation of thermal comfort conditions within public primary schools that are designed based on natural ventilation (infiltration) and air movement within the classrooms through ceiling fans was carried in Assiut city (27°3′ N; 31°15′E), which located northeast of the southern Upper Egypt zone. The small scale field survey was carried out in three naturally ventilated classrooms at Assiut distinct language school. All the studied classrooms based on natural ventilation (infiltration) and air movement within the classrooms through ceiling fans. Windows are single glazed and poorly constructed with very high levels of air permeability at both sides (1.5x1.2m), window to wall ratio reaching 32%. There is no solar protection in the windows, only the roof edge slightly mitigates the sunshine. The occupancy rate of this school is 1.1 m^2 for each pupil (the USA ratio is 2.15m^2).

3.2. Measurements and data recording

The field measurements were performed over three days during the period from 29th to 31th October, 2013. This period of time in Upper-Egypt is the end of the hot weather condition season and the beginning of moderate weather condition season. In

this field study, Thermal Comfort Datalogger-INNOVA 1221 was used for measuring and recording the classroom indoor environmental parameters such as operative temperature, relative humidity, air velocity in order to derive predicted mean vote (PMV/PPD) during the students' lesson hour. Three external sensors were connected to the device which was placed in front of classroom beside the board, at height 0.6m as recommended by ASHRAE [13], in order to not to interfere with ongoing teaching activities. The data values were measured and recorded every minute and the average of each 15 minutes was determined and is presented in the results section. In addition, outdoor Assiut climate data were obtained from the meteorological records of the nearest regional weather station (WMO 62392) for the same period in addition to a Mobile Weather station to measure the outdoor temperature in the school yard.

4. Results and discussion

In compliance with ASHRAE standard 55 [13], comfort conditions based on operative temperature and relative humidity plotted on the psychometric chart for people dressed into two different levels of clothing: 0.5 *clo* (typical for summer) and 1.0 *clo* (typical for winter) as shown in Fig. 1.

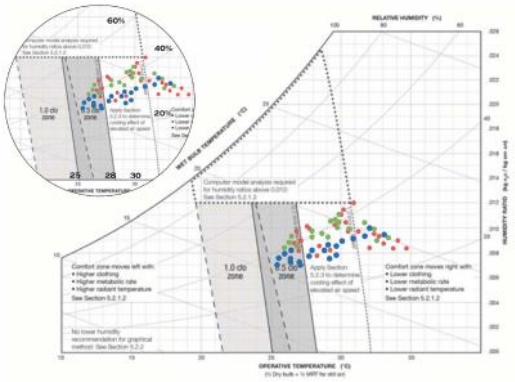

Fig. 1 Indoor climate condition plotted on a psychometric chart of ASHRAE 55

The measured data clearly show that there has been a steady increase of operative temperature in the measurement within the classrooms ranged from 25.5ºC to 34.5ºC during that day time. As depicted from Fig. (*2a*), the internal classroom temperature is raised by 7ºC and according to the results of Humphreys [14] this level of increase well led to discomfort condition for the pupils. This might be due to the fact that children are sent to the schools wearing relatively warm clothes in the relatively cool morning than required for the range of temperature variation during the school day. During the school day time, it is noticed that the difference between the outdoor and indoor temperature are 3ºC.In addition, the level of variation of the relative humidity within the classrooms is fluctuated between 14.20% and 48.78% over school hours. For 66.67% of the school time the relative humidity was below the value of 40% (recommended by ASHRAE) of all the studied cases as can be seen from Fig. (8). Arundel *et al.* [15] indicated that low relative humidity may develop signs of a dry irritated skin.

In terms of air velocities, at hot times of year, ceiling fans are used almost all over the school hours. As shown in Fig. (9), the mean average air velocities in the classroom were about 0.33m/s and ranged from 0.05–0.75m/s during the measurement. Measurements in the present study showed that this value is about 0.1m/s for cases without a ceiling fans operation. In hot climates, the presence of air movement can be equivalent to a reduction in air dry bulb temperature of 4ºC as cited by Nicol [16].

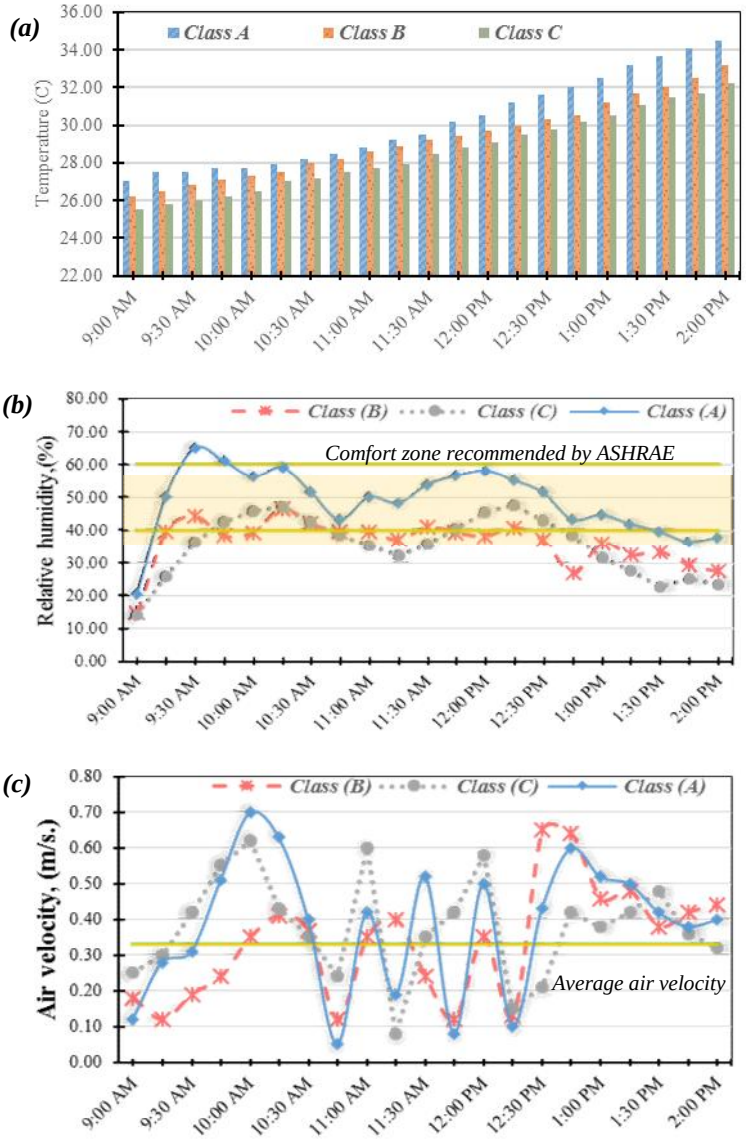

Fig. 2. (a) Operative temperature profile, (b) Relative Humidity profile and (C) Air velocity profile for indoor environment in three classrooms

The thermal comfort evaluation in the presented study is determined by two methods which are:

- Using the PMV and PPD values inside the classrooms in accordance with ISO 7730 [17] specifications which was originally developed by Fanger in 1970 on the basic of climate chamber experiments
- Using the Adaptive Comfort Standard (ACS) for naturally ventilated buildings which were employed by ASHRAE standard 55 [13].

According to ISO 7730 [17] specifications, the acceptable thermal environment for a PMV lies between -1 and +1 and the PPD is below 20%. The PPD is related to the PMV and it is based on the assumption that people voting -3,-2, +2 or +3 are dissatisfied. PMV for case studies started at *-0.14* value and raised until *2.8* value at the end of school day, further analysis showed at the afternoon the PMV value increases the comfort limit as shown in Fig. 3. The average PMV and PPD across the classrooms were 1.17 and 38.86%, respectively which indicate a high level of thermal discomfort in the classrooms. The same trend that was predicted by Gado and Mohamed [8].

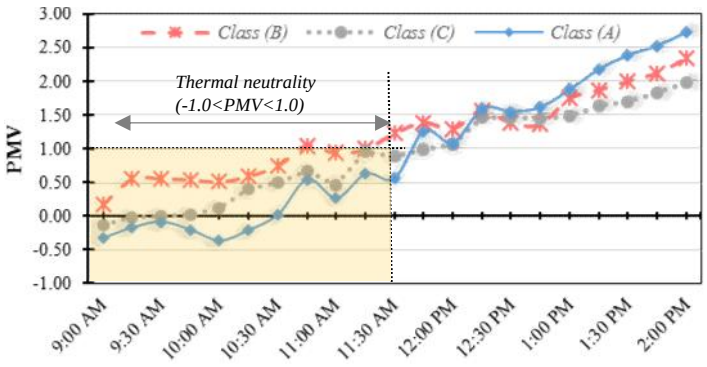

Fig. 3 Indoor operative temperature against PMV

Using the adaptive thermal comfort model needed the outdoor temperature that obtained from climatic conditions. Figure 4 presents the internal air temperatures across the three case studies in relation to the comfort limit. The acceptability ratio of thermal environment decreases less than 80% when the indoor operative temperature exceeds 29.5°C.Clearly from the figure, the internal air operative temperature profiles across the three cases studied are within the comfort limit until noon time. While afternoon time, the results indicate that the internal air operative temperature across the three classrooms exceeded the comfort limit which means that pupils are in discomfort for about 39.86% of the time they spent in school.

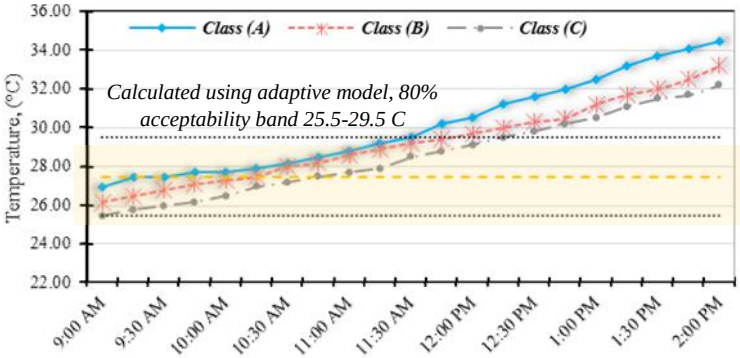

Fig. 4 Indoor operative temperature profiles with (ACS) comfort zone limit

Conclusion

This study investigated the thermal comfort conditions within public primary schools that are designed based on natural ventilation (infiltration) and air movement within the classrooms by ceiling fans. The output results may assist school building designers and stakeholders in the future to improve the thermal environment conditions

within the classrooms of such schools. The main achievements of this study are as follows:

- The acceptability ratio of thermal comfort calculated by (ACS) model ranges from 25.5ºC to 29.5ºC. It has been found that 39.86% of all hours were out of comfort zone.
- The average PMV and PPD across the classrooms were 1.17 and 38.86%, respectively, which indicate a high level of thermal discomfort in the classrooms.
- It is found that the ACS model has different results from PMV model. The author argues that it's due to school policy, students have limited opportunities for behavioral adaptation to modify personal variables consciously to stabilize the heat balance of their body (e.g., they are not allowed to change their clothing value in schools) in addition, the operative temperature exceeded 30ºC after 12:00 pm.

Clearly, these results indicate that a higher level of thermal discomfort within the primary public school classrooms

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