Assessment of thermal comfort inside primary governmental classrooms in hot-dry climates Part II – a case study from Egypt

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Previous work (Gado and Mohamed, 2009) investigated the subjective response of occupants inside nineteen primary schools in 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. This paper presents an objective assessment of the thermal comfort inside three case studies out of the nineteen schools previously studied. These three case studies represent the most common school prototypes built by the General Authority of Educational Buildings (GAEB) in Egypt. The three prototypes are: Single Row Linear Form (SRLF), Double Row Linear Form (DRLF), and L Form (LF). Human and environmental factors affecting thermal comfort were monitored during the hottest month of the academic year. Results suggested that thermal performance of classrooms in terms of thermal comfort was poor, justifying by such the results of the subjective assessment previously published.

Keywords: assessment, assessment tools, environmental assessment, performance, sustainable buildings

1. Introduction

In the first part of this paper, thermal comfort inside nineteen case studies was subjectively assessed. Analysis of results suggested that the occupants were thermally discomfort most of the time during the academic year. This part of the paper presents the findings of a study where thermal comfort inside three case studies out of the nineteen schools was assessed objectively.

2. Research background

It is relatively difficult to access thermal comfort inside buildings due to the complexity of the contributing factors deciding whether the conditions in question will make people feel discomfort or not. It is generally agreed that factors affecting thermal comfort inside buildings can be grouped into two groups; human factors and environmental factors. The later include air temperatures, air velocity, mean radiant temperature and relative humidity while the human factors include insulating value of clothing (Clo) and the metabolic rate (Met) that depends on the activity level. Szokolay added a third category and called it the contributing factors that include the person's age, gender, food, drink, body shape, subcutaneous fat, colour of internal surfaces and lighting system used (Szokolay 2004). Fanger and Humphreys (Humphreys 1977) in addition to several studies cited in ((CIBSE 1999), pages 1-10) revealed that, at a given activity and clothing level those contributing factors do not significantly affect thermal comfort.

From all the environmental factors, air temperature is the most commonly used indicator of thermal comfort (Rosenlund 2000) and is considered to be the most important factor determining heat stress. Mean radiant temperature which is determined by the temperature of the surrounding surfaces is also a significant factor contributing to thermal comfort. Relative humidity is another important factor affecting thermal comfort. High levels of humidity inside buildings prevent the evaporation of sweat from skin; the main method human body losses heat (Givoni 1976). In hot climates this could have a significant effect on the thermal comfort. On the contrary, low humidity levels can cause symptoms such as dryness of throat and skin, and can cause irritation of the mucous membranes. In normal circumstances, relative humidity should range from 40 to 70% (CIBSE 1999). Another factor affecting thermal comfort is air movement which is not to be confused with air change and is not always caused by ventilation (McMullan 2002). It affects the evaporative capacity of the air and consequently the cooling efficiency of sweating (Givoni 1976). Air movement helps the heat loss from human body by convection, but it can in some cases cause the sensation of draught (McMullan 2002). A related factor to air movement is the ventilation rate. Results from previous research (Ajiboye et al. 2006; Clements-Croome et al. 2005; Coley and Beisteiner 2002; Griffiths and Eftekhari 2008) suggested that children studying in ill ventilated classrooms are likely to be less attentive. The concentration of carbon dioxide (as an indication of ventilation rate) in all teaching and learning spaces at seated head height should not exceed 1500 ppm (Department for Education and Skills 2005). The minimum required ventilation rate in any teaching area is 3 l/s per person. It is recommended that the ventilation approach used in school buildings should be capable of providing an enhanced rate of at least 8 l/s per person to be able to handle sudden increase in ventilation needs (Kukadia et al. 2005).

3. Monitoring methodology

Five classrooms inside three case studies from the previously investigated nineteen schools in part 1, were chosen. The layout and typical plans of the schools are presented in Figure 1- Figure 3. The environmental factors affecting thermal comfort (air temperature, relative humidity, mean radiant temperature, and ventilation rate) were monitored during the same time of the subjective assessment. This took place during the hottest months of the academic year; May. This allowed the comparison between the subjective response of occupants and the objective assessment of the environments.

Figure 1: Case study 1 layout

Notes: a) classroom under investigation is hatched

b) Numbers on surrounding buildings are their height in meters

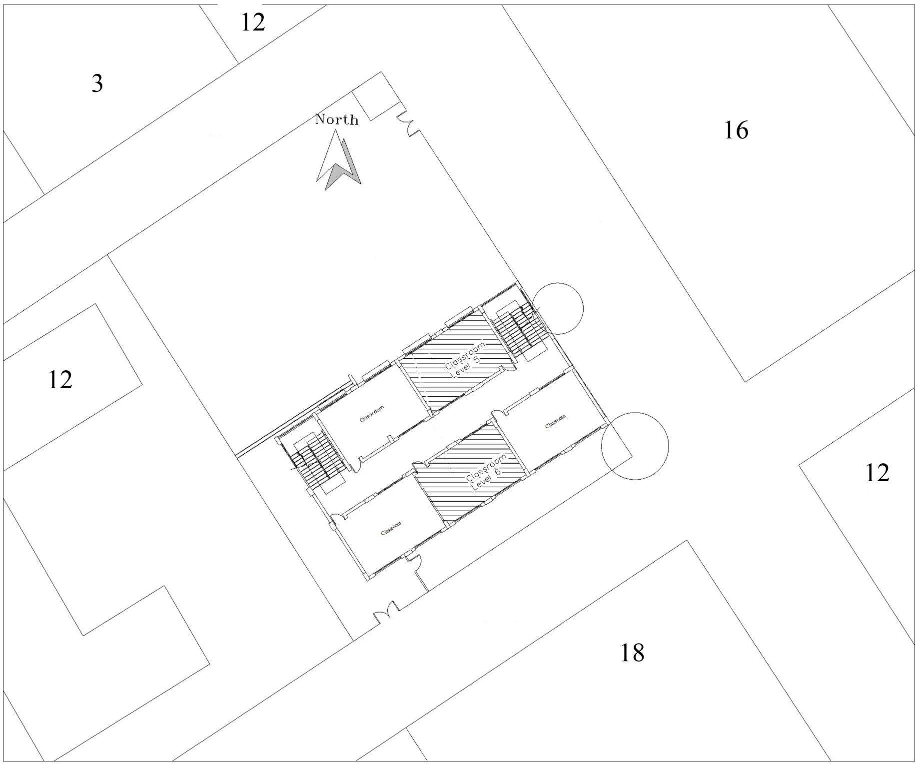

Figure 2: Case study 2 layout

Notes: a) classrooms under investigation are hatched

b) Numbers on surrounding buildings are their height in meters

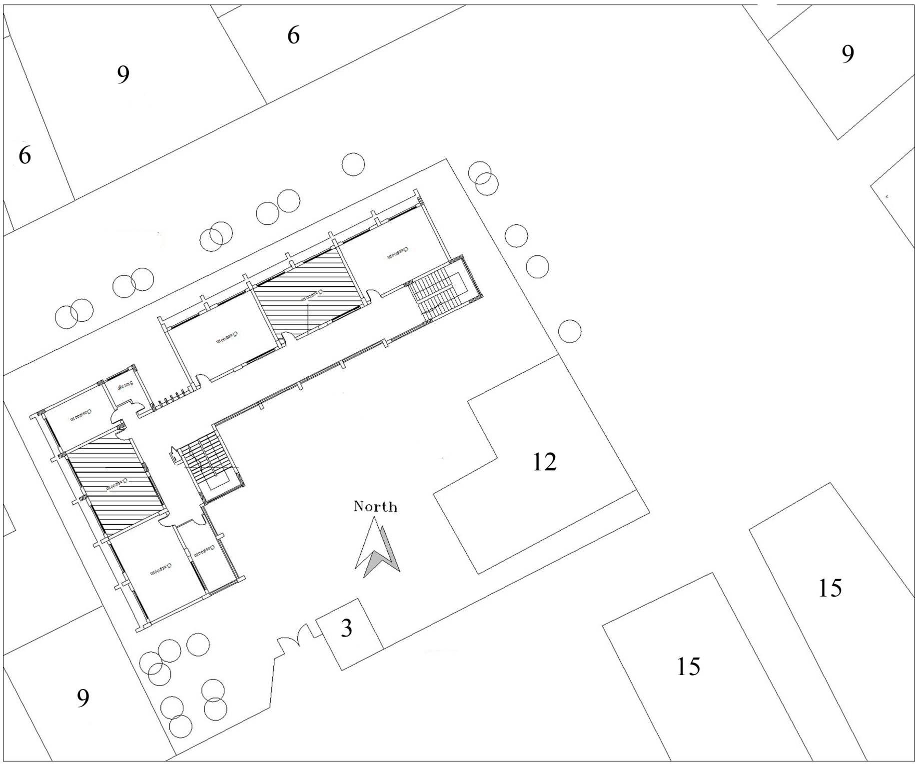

Figure 3: Case study 3 layout

Notes: a) classroom under investigation is hatched

b) Numbers on surrounding buildings are their height in meters

Due to the young age of occupants, it was important to choose a reliable data logger that could be easily concealed away from the children and can be quickly installed while accurately logging and storing data for the duration of the investigation. For this Hobo U12 was chosen to log air temperature and relative humidity. Two external sensors (TMC6-HD) were connected to the logger to allow taking measurements at three levels as shown in Figure 4 and Figure 5) a) ankle level (200 mm above floor level) b) head height (1100 mm above the floor, the standard height according to ISO 7726:1998 (ISO 1998) c) below the ceiling height by 200 mm (Figures 4-5).

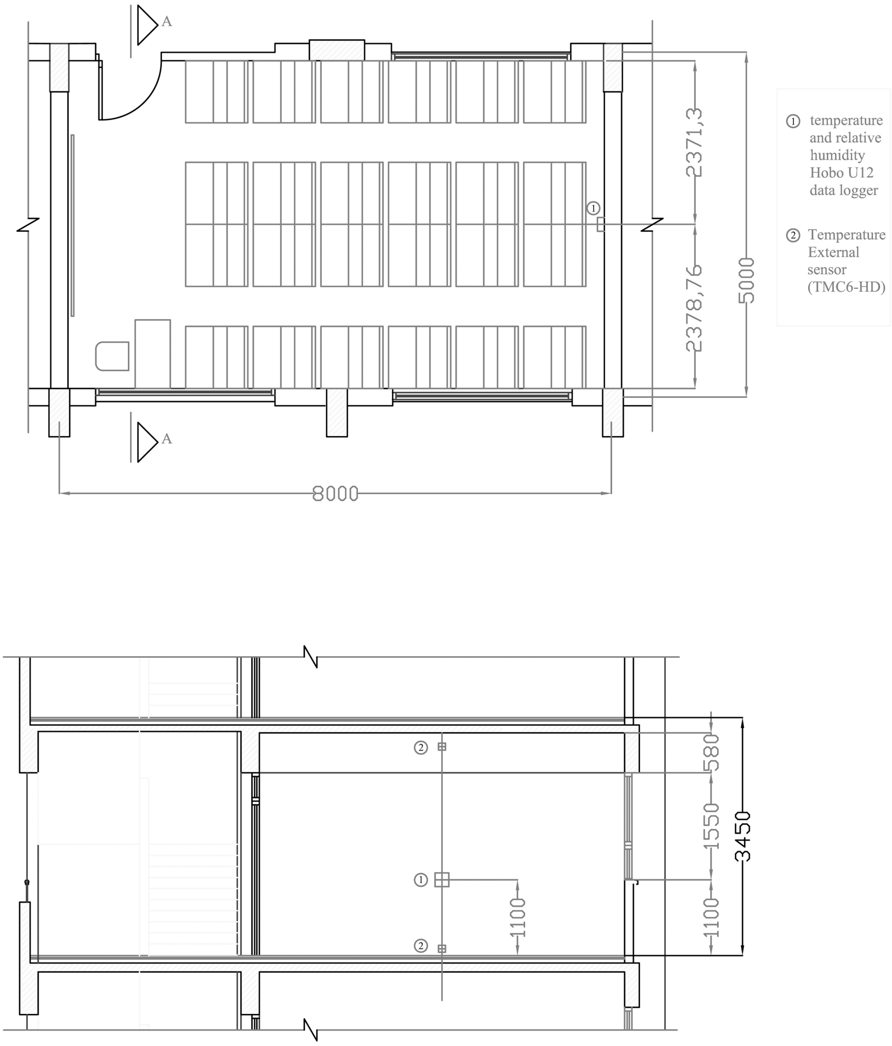

Figure 4: Location of the Hobo U 12 data logger and sensors inside the classroom

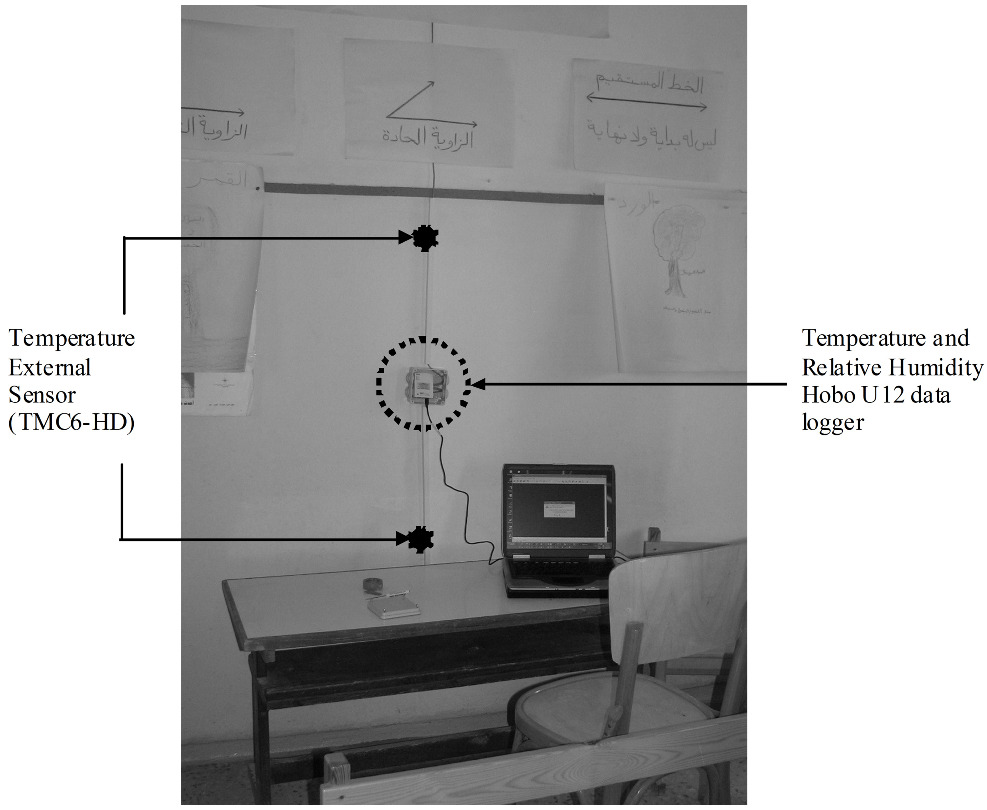

Figure 5: Hobo U12 and sensors on the back wall of the classroom

Measuring the temperature at those levels allowed studying the temperature stratification inside the classroom; a factor affecting thermal comfort. The effect of temperature stratification is important since a large difference between head and ankles temperature can cause discomfort (ISO 1998). Ideally, the feet should be a few degrees warmer than the head (Environmental Engineering Science 2007) and this should not exceed 3oC (CIBSE 1999). Studying this factor will also generate data to allow further work to investigate the application of passive ventilation systems.

Internal air speeds were measured at several points over a period of a day using a hand held anemometer. Ventilation rate was gauged by logging the CO2 concentration levels every two seconds over a single day using a TEL-7001 Telaire CO2 Monitor H22-001 sensor and a Hobo FlexSamrt data logger. CO2 levels was used as an indication of the indoor air quality and ventilation rates inside the classrooms (ASHARE and American Society of Heating 1999). In this case, it was not possible to log the CO2 inside the classrooms over the whole month as it was not possible to leave the monitoring equipment unattended.

Mean radiant temperature were calculated using the surrounding surfaces temperatures at seated head level at the centre of the classroom using equation 1 (ASHRAE 2005) and the angle factor between the location and the measured surfaces was determined graphically using ASHRAE hand book method (ASHRAE 2005).

$$tr = t_1^{\,4} Fp\_1 + t_2^{\,4} Fp\_2 + \ldots\ldots + t_n^{\,4} Fp\_n$$ equation 1

Where

Tr= mean radiant temperature

TN^4 = surface temperature of surface N

Fp_N = angle factor between a person and surface N

An infrared thermometer (MicroRay Pro++) was used to measure the temperatures of all the internal surfaces of the classroom. The equipment used is a high-end thermometer that features adjustable emissivity allowing the measurement of the temperature of any surface irrespective of its material.

Outdoor climatic conditions were logged over the same period using Hobo microstation (H21-002). Measurements included air temperature, relative humidity, and direct solar radiation. This data were then compiled and a meteorological data file for Al-Minya was created.

4. Results and discussion

Clothing level affects heat exchange between the body and the surrounding environment by forming a barrier to the convective and radiative heat exchange between the body and the environment (Givoni 1976). Different cloths will have different effects on the required comfort temperature. It was found during the field study that children's ability inside the classrooms to adapt their clothing level by adding or removing layers of clothing according to their thermal environment was very limited. The boys' typical uniform at the time of the survey was a long sleeve shirt or tee-shirt and a long trousers, socks and shoes. Girls' typical uniform was a dress with long trousers, socks and shoes. In some cases their clothes were similar to the boys' uniform. Normal underwear was assumed to avoid offence. In all cases it was found that the clothing was equivalent to a value of 0.7clo (ISO 1998).

Level of activity affects the metabolic rate which in turn affects the body temperature. Under the current Egyptian education system, children inside primary classrooms are seated in pairs on a 900mm wide wooden desk for long periods of time. This level of activity metabolic rate is equivalent to 70w/m2. The average total number of children per classroom under investigation was 48 i.e. 0.83 m2/pupil. This high density is expected to contribute to the level of thermal discomfort. The classroom furniture is arranged in three rows perpendicular to the blackboard as seen in Figure 4. Children in this setup are normally not allowed to change there location during the lessons. This means that almost 25% to 35% of the children are left in direct solar radiation (Figure 6) across the academic year depending on the time of the day and the solar orientation.

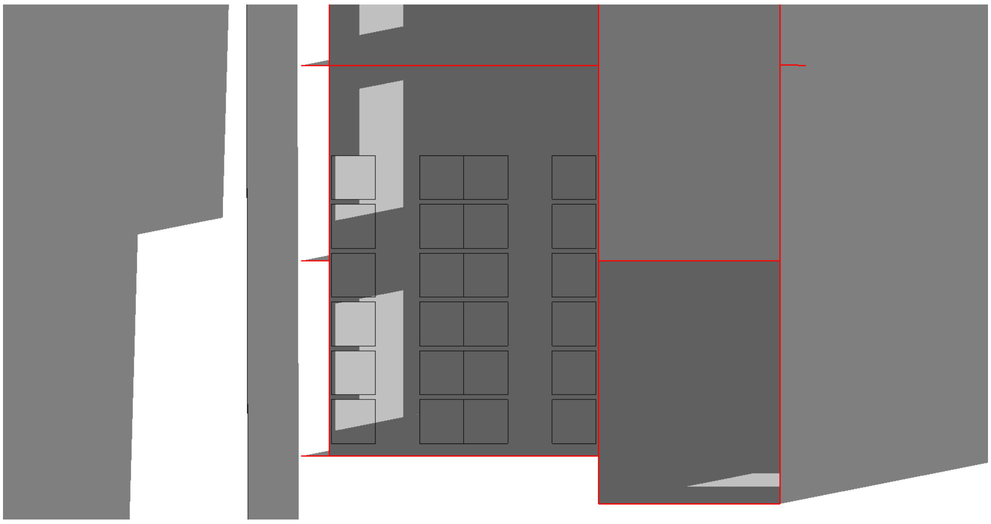

Figure 6: Solar penetration at 14:00 during mid May

All the classrooms under investigation were naturally ventilated. However, there were several reasons that prevented the effective use of windows. They were closed most of the time and in many cases were painted in black or covered with newspaper to prevent solar penetration. This consequently led to a severe drop in air speeds, which were less than 0.1 m/s across the five cases. Even when all the windows were opened, air speeds were not noticeable inside the classroom and slightly exceed 0.1 m/s only near the windows.

CO2 levels in two of the five classrooms exceeded the recommended levels of 1500ppm (Department for Education and Skills 2005) reaching 2142ppm and 1908ppm respectively. In is worth mentioning that there were no measures in place that could respond to sudden ventilation needs.

The average internal air temperature across the case studies was 29oC. It exceeded 30oC for 23% to 48% of the time, reaching just over 34oC in some cases. Over a single day the internal temperature varied by more than 2oC during 58% of the time across the case studies. According to Humphreys (Humphreys 1977) this level of variation in internal air temperature could result in incident of discomfort. Humphreys suggested this might be due to that fact that children are sent to the schools wearing relatively warm cloths in the cool morning than required for the range of temperature during the day. In the context of this work, this could only be true during winter when morning temperatures are relatively low ranging from 06oC to 119oC at 8am. Air temperature at head level was always higher than the temperature at the feet level by an average of 0.5oC reaching in some cases a difference of over than 2oC for 20% of the time increasing by such the state of thermal discomfort.

Levels of internal relative humidity ranged from 17.8% to 52.6 % during the operation hours. For 80% to 96.4% of the time, relative humidity was under 40% across the case studies and was less than 30% for 5% to 41% of the time. This low level of humidity may be acceptable for short periods as long as there are precautions to limit the generation of dust and airborne irritants (CIBSE 1999). In this case, there were no precautions taken to limit this from occurring and in turn this increased the discomfort of occupants as suggested by the subjective assessment.

The year during which this work was conducted was slightly hotter than the typical meteorological year. Typically the average outdoor air temperature in Al-Minya during the school operation hours (8am - 1pm) is 26oC, reaching a maximum of 40.5oC. However, in this case the average outdoor air temperature was 31.4oC reaching a maximum of 43oC. Typical average direct solar radiation is 630w/m2 when the typical value is 525w/m2.

5. Assessment of thermal comfort

In this study, two methods were employed to assess the thermal comfort inside the case studies: 1) comparing the internal temperatures with the comfort temperature 2) calculating the PMV and PPD values for the classrooms.

Using the adaptive thermal comfort model, the monthly comfort temperature and the total number of hours spent above this limit during the operation hours of the day was calculated. Figure 7 presents the internal air temperatures across the five case studies in relation to the comfort limit. Analysis of results suggested that the internal air temperature across the classrooms exceeded the comfort limit for 82.26% of the time and exceeded it by 2oC for 43.55% of the time (Figure 7).

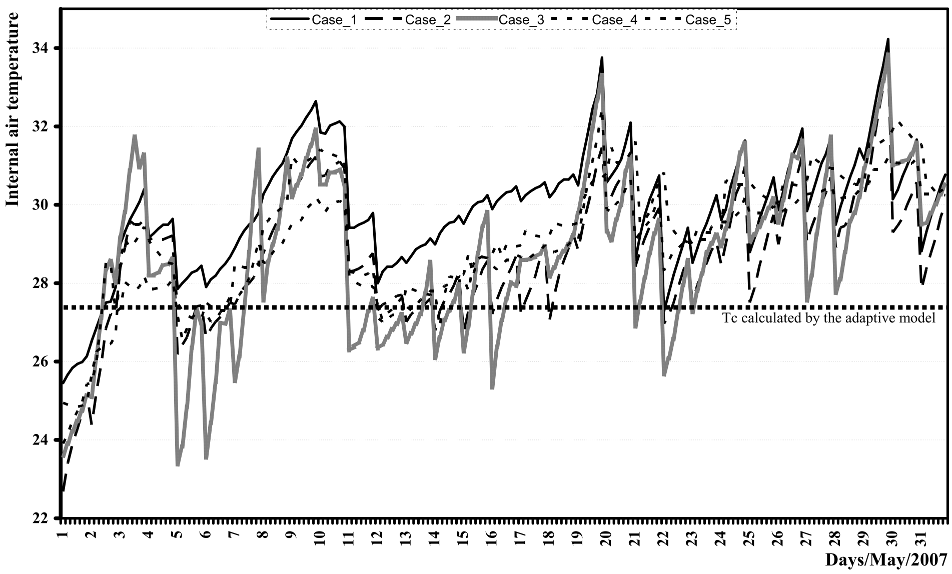

Figure 7: Internal air temperatures across the five case studies in relation to the thermal comfort temperature

The two indices widely used to predict the state of thermal comfort of occupants inside buildings are the Predicted Mean Vote (PMV) and the Predicted Percentage Discomfort people (PPD). Both the PMV and the PPD of each classroom were calculated during the operation hours (08.00 am to 01.00 pm). The average PMV and PPD across the classrooms was 1.7 and 51% respectively indicating by such a high level of thermal discomfort. The later confirms the PPD found in previous work (Gado and Mohamed In review) that was equal to 53%.

6. Conclusions

This paper was concerned with the objective assessment of thermal comfort inside three primary schools built in the desert climatic design region of Egypt. All factors affecting thermal comfort were monitored and analysed. The adaptive thermal algorithm was used to calculate the comfort temperature and both the

PMV and PPD indices were calculated. The conclusions from the analysis of results can by summarised as follows:

1. The internal air temperatures of all the case studies exceeded the comfort temperature for most of the time;
2. Half the occupants were thermally discomfort. This was indicated by the average PPD that reached 51%;
3. Temperature difference between the head and the ankle level exceeded 2 degrees for 20% of the time;
4. Average PMV across the case studies was 1.7 suggesting that the majority of the occupants would feel warm.

7. Further work

Further work will investigate ways of enhancing the environmental performance of the prototypes used by the Government in Egypt. A computer based study is under way to quantify the effectiveness of a number of passive measures and strategies used to enhance the performance of the typical designs investigated in the paper. Further work will also investigate the effect of the climatic variation across the Egyptian climatic design regions on the thermal performance of the Governmental prototypes.

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