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Analysis of Thermal Comfort and Energy Consumption in Long Time Large Educational Halls (Studios), Assiut University, Egypt

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Abstract

Reducing energy use in buildings is a critical component of meeting carbon reduction commitments. Architects and engineers are the major players, making technical improvements to existing buildings and designing new ones with higher standards. The aim of the present research is to analyse indoor thermal comfort and energy consumption inside the large educational halls of the Faculty of Engineering, Assiut University, for determining the acceptable operative temperature for student comfort. Two approaches are presented; physical measurements and comfort surveys for 6 naturally ventilated halls. Several parameters were measured: indoor and outdoor air temperatures, wind speed, globe temperature, CO_2 concentration and relative humidity. A questionnaire adapted from ASHRAE 2004 was answered by 269 respondents selected from a total of 331 respondents.
The results showed that the indoor temperature exceeds 28°C and is far from 90% acceptable comfort range with high PMV range and PPD >10, particularly for female students with Islamic head veils (hijab) and 83% of the students prefer a cooler indoor climate. The lighting power ranges from 50% to 75%, and laptops ranges from 25 % to 44% of total nominal electrical power. Also, the students' thermal sensation ranges between warm and slightly warm in the six halls. The results of this research provide information for future indoor cooling design strategies and energy efficiency in large educational halls.

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Keywords: Thermal comfort; thermal sensation; education halls; energy consumption

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1. Introduction

The rapid growth of energy production and consumption is strongly affecting and being affected by the Egyptian economy in many aspects. It is evident that energy will continue to play a critical role in the development of Egypt's economy in coming years [1]. The indoor environment quality depends on the characteristics of the building, the function, the indoor air quality and many other variables [2]. Providing thermal comfort in lecture halls and classrooms is a necessity because students spend up to one third of the day in educational facilities [3]. Hyde recommended passive building design to avoid dependence on active energy mechanisms for indoor comfort and illumination [4]. The indoor spaces in educational facilities have been much less studied compared to other buildings such as offices and hospitals. Dewidar et al. studied one large lecture hall in Cairo University for only one hour without any occupants inside. The only measurements they conducted were for temperature, relative humidity and wind speed for 30 points without comparing with thermal comfort index and considering the thermal sensation scale [3]. Yau et al. conducted a field study and questionnaire survey in six lecture halls of University of Malaya, Kuala Lumpur (tropical region). They measured the six parameters contributing to thermal comfort in different points for one day in every hall in order to promote sustainable air condition design. They assessed the thermal conditions in the lecture halls against the ASHRAE Standard 55 [5]. Also, they assessed the satisfaction of the occupants on the level of thermal comfort in the lecture halls [6]. Amgad et al. conducted a measurement and subjective vote on thermal comfort in three educational buildings over a period of twelve days in the cold season in order to predict the comfortable environment (adaptive comfort approach) in hot climate [7]. It is obvious that only few studies have tackled the environmental performance of long time educational halls in Egypt.

The objective of this study is to investigate indoor environment (thermal comfort, and energy consumption) in long time educational halls in the Faculty of Engineering using indoor measurements and questionnaire survey in order to determine the acceptable temperature for student comfort and provide information for indoor cooling design strategies and energy efficiency in large halls.

2. Methodology

Two approaches were used in collecting data; physical quantities measurements with a simultaneous questionnaire for student's thermal sensation of naturally ventilated spaces. Investigation was carried out during the period 24 April-20 May 2014.

2.1. Indoor measurement data

As thermal comfort depends on environmental and personal factors including airflow (wind), air temperature, air humidity, physical activity, the type and amount of clothing worn, and radiant heat [8]; the six parameters contributing to thermal comfort were measured and monitored (Temp., Relative humidity, Wind speed, Globe temperature, Clothing, Met). A measurement was taken during the morning and afternoon studios for at least 2h in each period. Calculations were done using Fanger comfort model [8]. The calculations of predicted mean vote (PMV), Perdicted percentage dissatisfaction (PPD) and Adaptive Comfort Standard were done by an ASHRAE (2010) thermal comfort online tool developed by the University of California Berkeley [9]. The linear regression coefficient for the predicted mean vote and neutral operative temperature was determined.

2.2. Questionnaire survey

The questionnaire aimed to identify whole body thermal comfort. The questionnaire was ad-ministered in three parts. The first part contains demographic and student characteristics information. The second part contains information on the level of indoor wind speed, humidity, and temperature according to thermal sensation scale The third part addresses the source of feeling uncomfortable, reason of discomfort inside the hall according to temperature. A number of 331 questionnaires were distributed to the students, while only 269 questionnaires were analyzed.

3. Results and discussion

3.1. Thermal response vote

Indoor humidity perception votes (HPV) was analyzed. The humidity level ranged between "Just right" and "slightly humid" and a small portion of the students feel humid with an average of 15%. Fig.1 shows the distribution of thermal sensation vote (TSV). Most of the halls range from slightly warm to hot with an average of 83% of the students feel uncomfortable with the indoor environment.

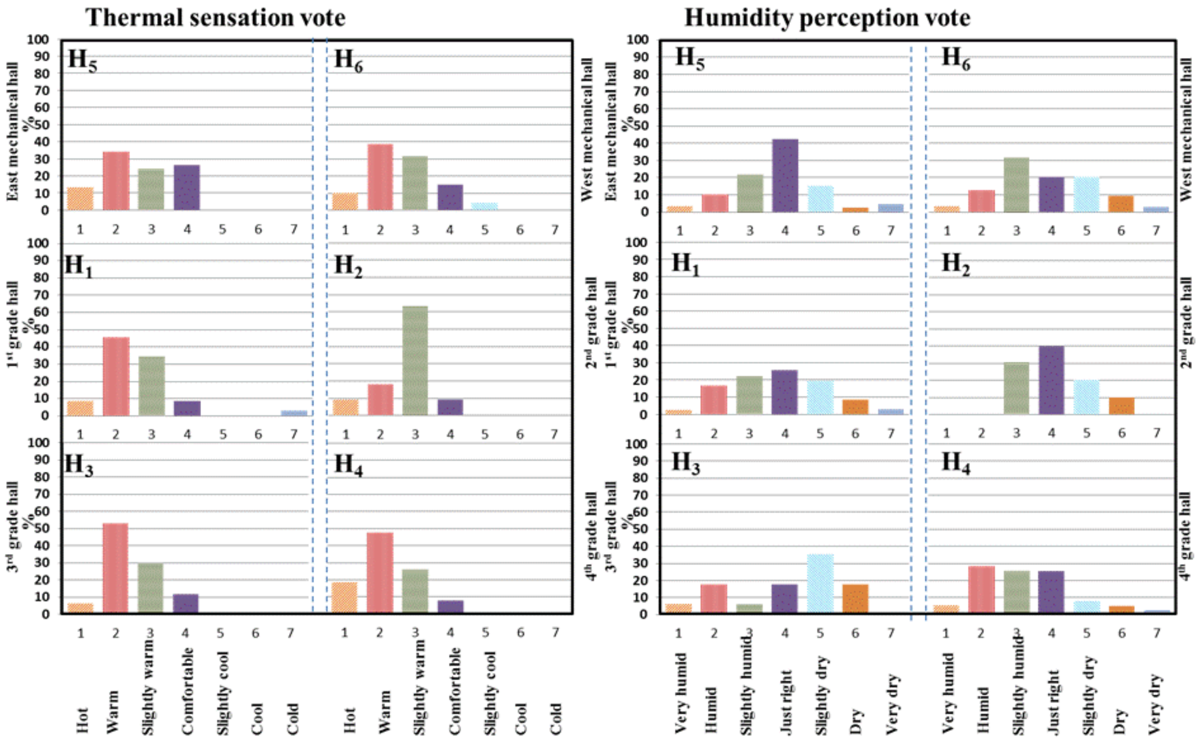

Fig. 1. The result of the questionnaire survey (TSV and HPV) in the six halls.

Fig.2 shows indoor air velocity perception vote results with an average of 60% of the stu-dents indicating sufficient air velocity using mechanical fans with cross ventilation strategies in Mechanical halls (H5, H6). Meanwhile, low air velocity level appeared in the architecture hall using mechanical fans with single side ventilation or closing windows with an average of 75%.

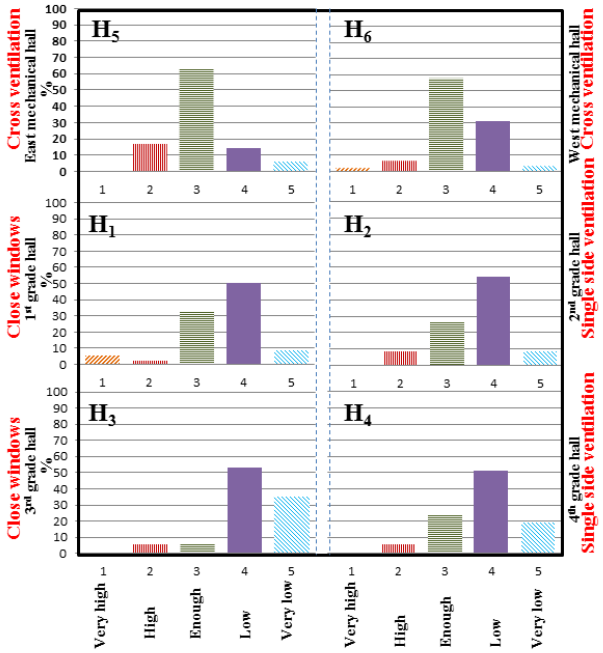

Fig. 2. The level of wind speed inside the six halls.

3.2. Reason for feeling uncomfortable

From the survey, the sources for feeling uncomfortable inside the hall are low wind speed, high indoor surface temperature and the penetration of solar radiation with an average 22%, 24.3% and 11.3%, respectively as shown in fig.3. In addition, the students concluded that most of the educational halls range between "often too hot" and "occasionally too hot" as shown in fig. 3. Therefore, it seemed that the students were dissatisfied inside the hall because of temperature increase. Also, they stated that high temperature affects their productivity and attention in studio halls. They preferred to decrease indoor temperature by mechanical cooling or search for indoor cooling design strategies. Fig. 4 shows the interior of the educational halls.

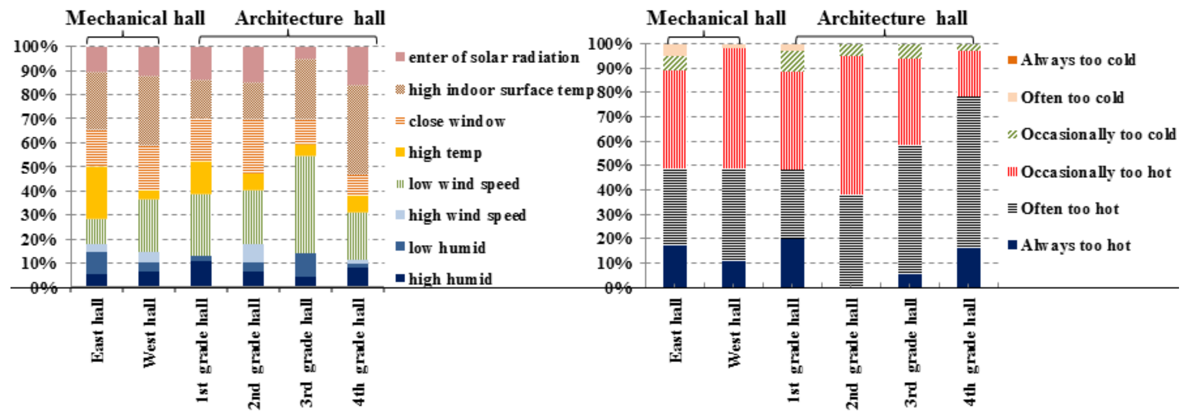

Fig. 3. (a) Source for feeling uncomfortable inside the hall; (b) Feeling of students inside the halls.

Fig. 4. The interior of educational halls (H5, H2, and H1).

3.3. Thermal comfort evaluation according to ASHRAE, ACS and PMV

The calculated psychrometric chart for the six halls was studied in fig. 5 along with the highest acceptable humidity value (absolute humidity: 12g/kg’). It is shown that the halls are located within the acceptable range of relative humidity (20%~60%) according to ASHRAE 2004 standard [5]. In addition, all the humidity values didn’t exceed 30% most of the time. However, indoor temperature was higher and far from the comfort temperature and 90% acceptability limits of the Adaptive Comfort Standard (ACS) using mechanical fans and cross ventilation, single side ventilation or closing all windows. Indoor temperature was above 30°C and ranged between 30°C~37°C. This is due to the high heat gain of the indoor environment and the inadequate ventilation entering the hall. Also, indoor temperature is higher than outdoor in H1, H2 and H5. This is due to the increasing number of students and increased internal heat gain in the halls without sufficient ventilation. Also, high solar heat gain coefficient (SHGC) is caused by the relatively high windows to wall ratio.

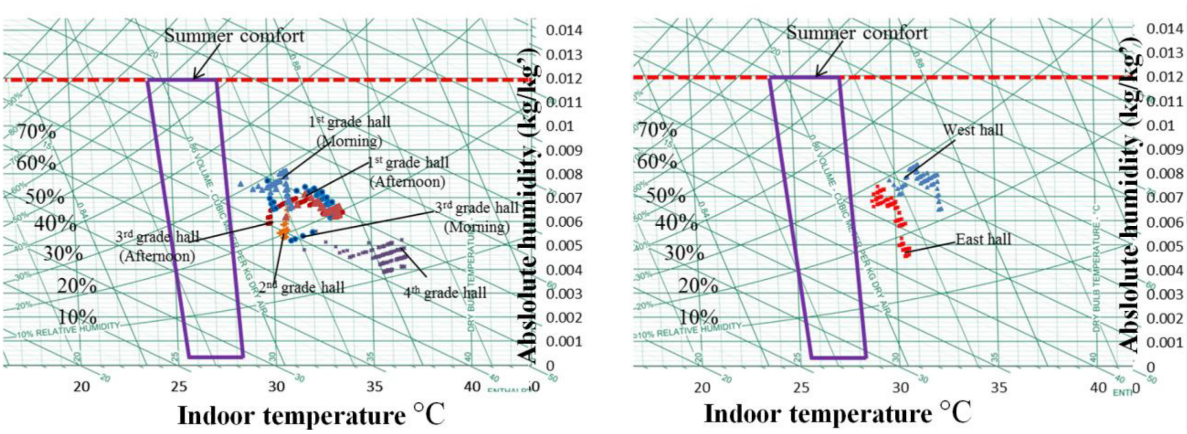

Fig. 5. Temperature and humidity conditions in the six halls.

Windows are single glazed and poorly constructed. As students' attainment is affected by comfort level, discomfort decreases attention levels when temperature and humidity exceed their comfort zone [10]. Therefore, increasing indoor temperature in the six halls affect students' attainment. Fig. 6 shows indoor and outdoor temperature profiles in the six halls with T_{comf} and 90% acceptable range of ACS.

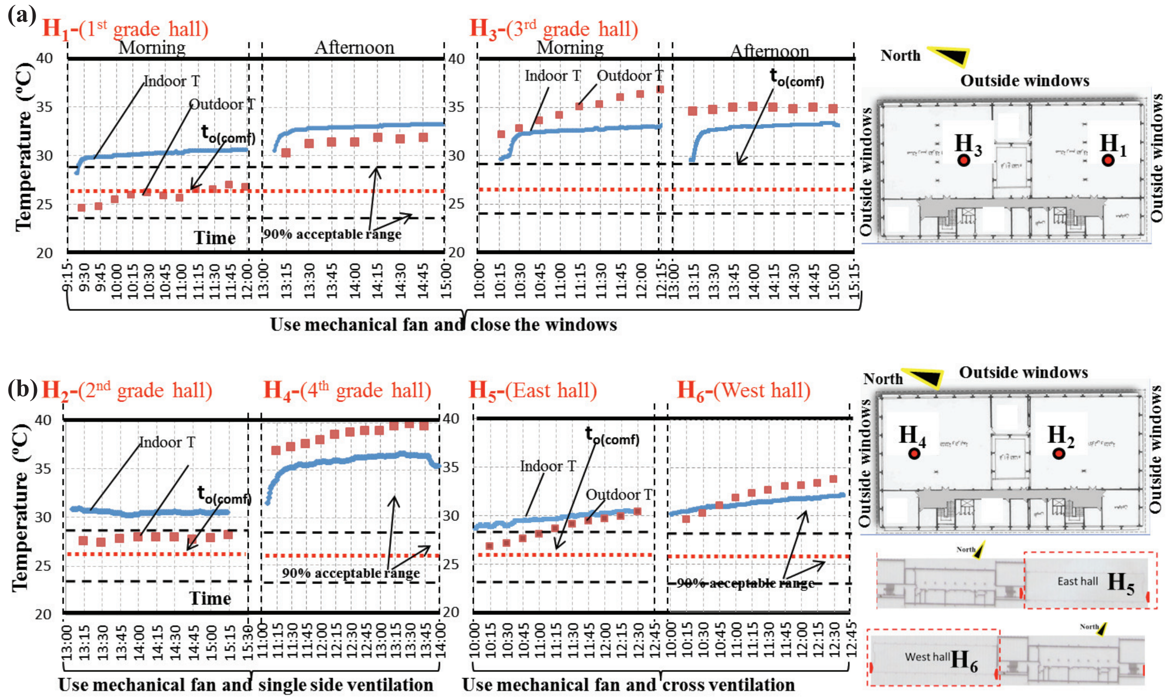

Fig. 6. (a) Temperature profiles in halls 1 and 3 using mechanical fans and closing the windows; (b) Temperature profiles in halls 2 and 4 using mechanical fans and single side ventilation and halls 5 and 6 using cross ventilation.

PMV and PPD were calculated based on the combined results of the physical measurement and observing of the type of activity and clothing. PPDs for the six halls are far from PMV range and PPD >10 especially for female student with Islamic head veils (hijab) (Clo=0.8) based on ISO 7730 and Fanger model except in the morning time for the 3rd grade hall. Further analysis was conducted to find neutral operative temperature as a function of PMV. The linear regression coefficient for the predicted mean vote is 0.59 as shown in fig. 7. The gradient of the regression line represents the sensitivity of the students with respect to the operative temperature and was found to be 0.408/°C. The neutral operative temperature for PMV was determined to be 29.1°C.

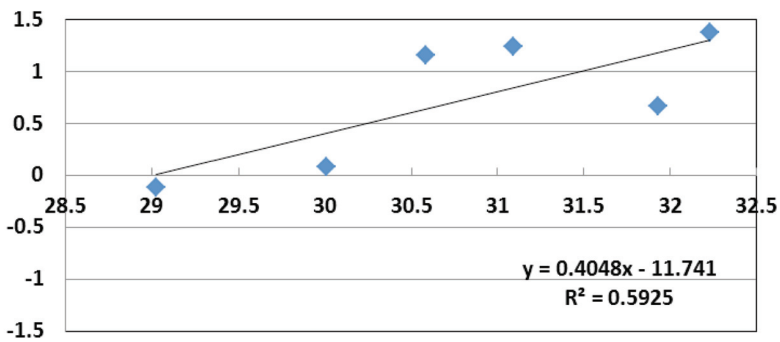

Fig. 7. The linear regression calculation based on PMV versus the operative temperature.

Monitoring of CO_2 concentration in the six halls helps to understand the effect of different types of ventilations scenarios on carbon dioxide concentration; for ensuring indoor air quality (IAQ) and a safe environment [11]. It was concluded that the concentration in the six halls did not exceed 1000 ppm (ASHREA standard) at any time except in

H1 (morning time) where it reached 1014 ppm. This is due to the increasing number of students with windows closed. It was conclude that indoor air velocity in the six halls was very high. This is due to using mechanical fans with high speed. The average indoor air velocity was 1.1m/s in H1 and H3, 2.0m/s in H2 and H4 (single side ventilation) and 1.3 m/s in H5 and H6 (cross ventilation).

Calculations were done for the average optimum comfort temperature for the 2014 summer season based on continuous monitoring of outdoor temperature. Calculations were done based on ACS model [5] for naturally ventilated buildings. It is concluded that Tcomf =27.5°C. This reduction of indoor temperature ranges from 3°C to 5°C, based on analysis of the bioclimatic chart [12] or building design strategy. The suitable strategy is direct evaporative cooling to achieve comfort for students.

3.4. Halls energy analysis

According to six halls investigation, drawing halls have long operating times; sometimes up to 10 hours from Saturday to Thursday from 8 AM to 6 AM during the academic year and depending on students' schedule. The total electric power loads in the six halls are shown in Table 1. The data in table 2 shows that the fans electric power ranges from 12% to 26%, lighting power ranges from 50% to 75%, and laptops ranges from 25 % to 44% of the total nominal electrical power. Florescent lamps T-12 with magnetic blast are used in lighting. Occupants used ceiling fans of 75 w to reduce heat feeling. Despite an artificial lighting power ranging from 50% to 75% of the total energy consumption and using natural and sky lighting in the halls, the standard illumination level didn't reach the minimum required value.

Table 1. Nominal electrical power (Watt) in the Faculty of Engineering Drawing Halls.

Hall name	lighting			fans			Laptop plugs			Total power	others	Students no.
	no	Power	Total power	no	power	Total power	no	power	Total power			
H1	60	36W	2160W	8	75 W	600W	46	36W	1656	4416W	60	76
H2	60	36	2160	8	75	600	43	36	1548	4308	60	76
H3	60	36	2160	8	75	600	26	36	936	3696	60	26
H4	60	36	2160	8	75	600	60	36	2160	4920	60	60
H5	108	36	388	18	75W	1350				5238		120
H6	108	36	3888	18	75W	1350				5238		120

4. Conclusion

The conclusions from the analysis of the results can be summarized as follows:

The internal air temperatures of the six halls exceeded the comfort temperature of the Adaptive Comfort Standard for most of the time and were higher than outdoor in H1, H2, H5. Similar results were obtained by TSV analysis, showing the majority of the students were thermally uncomfortable for most of the time according to the thermal sensation scale with an average of 83%.

All of the six halls are far from PMV range and PPD >10; particularly for female students with Islamic head veils (hijab) (Clo=0.8). Students stated that high indoor temperature affects student productivity and attention and they preferred to decrease indoor temperature by mechanical cooling. It is concluded that the suitable strategy is direct evaporative cooling to achieve comfort for students.

Average PMV across the case studies suggested that the majority of the students would feel between slightly warm and warm.

To promote sustainable cooling design, the trend should be decreasing air temperature to T_{comf} (27.5°C) while increasing the humidity level to 60 % without reducing indoor air velocity in order to achieve the same amount of CO_2 concentration.

Further work will investigate passive cooling strategies for decreasing indoor temperature, without reducing indoor air velocity, and achieving indoor comfort. Also, smart systems will be integrated to increase indoor lighting intensity with central control for the passive cooling to decrease energy consumption in long time educational halls..

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