Architectural evaluation of thermal comfort: Sick building syndrome symptoms in engineering education laboratories

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Abstract

Providing comfortable and healthy learning environment in tertiary institutions is beneficial to the teaching and learning process. However, uncomfortable and unhealthy indoor conditions may increase the risk of sick building syndrome (SBS) symptoms, discomfort and illness among building occupants. This study was conducted to investigate thermal conditions and SBS symptoms in three air-conditioned engineering education laboratories (EEL) located at Universiti Tun Hussein Onn Malaysia (UTHM). Building-related factors (such as space layout and adequacy, seating, furniture layout, surfaces’ colors, windows, architecture aesthetic value and windows/ opening) of the lab were also evaluated and rated as good in terms of overall quality (range between 3.71, SD= 0.48 and 3.93, SD= 0.36). Objective measurement was conducted for thermal variables; mean radiant temperature (\(t_r\)), relative humidity, and air velocity. Results shows that the mean radiant temperature (\(t_r\)) were not within recommended range (minimum 17.8°C in EEL3 and maximum 22.42°C in EEL1). Subjective measurement with questionnaire surveys was distributed to 71 undergraduate and postgraduate students. Investigations were made with a particular focus at SBS symptoms and thermal sensation votes. Results show that most students in each lab have experienced all the SBS symptoms. Among the symptoms, dry skin received the highest percentage (40.85%), followed by runny nose (31%), dry eyes (29.58%), blocked/ stuffy nose (28.17%), tiredness (26.76%) and flu-like symptoms (21.13%) with unacceptable thermal conditions among the respondents in all laboratories. Based on the results, centralized air conditioned in engineering education laboratories should be designed adequately. Without a proper functioning control system, it is impossible to sustain a comfortable indoor environment for student occupants.

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1. Introduction

The World Health Organization (WHO) emphasizes that indoor environmental conditions influence health and well-being of building occupants. These are true since poor indoor environmental conditions affects occupants’ satisfaction and comfort perception (WHO, 1990). Several studies in commercial and residential buildings have been conducted to better understand these issues. Moreover, the increase of concern over the quality of the indoor environment improves the standard of livings in society, while failure to provide satisfactory condition has resulted in discomfort and illness (Cheong et al., 2003; Kruger & Zannin, 2004). Discomfort and illness among building occupants is commonly discussed in terms of “sick building syndrome” (SBS). SBS appear due to the association of time spent in building however no specific illness or cause can be identified.

Nomenclature

| Abbreviation | Description |
|--------------|-------------|
| AV           | air velocity |
| ASHRAE       | American Society of Heating, Refrigerating and Air Conditioning Engineers |
| EEL          | engineering education laboratory |
| FTVE         | Faculty of Technical and Vocational Education |
| FCEE         | Faculty of Civil and Environmental Engineering |
| tr           | mean radiant temperature |
| RH           | relative humidity |
| SBS          | sick building syndrome |
| TSS          | thermal sensation scale |
| TSV          | thermal sensation vote |
| WHO          | World Health Organization |

1.1. Research background

The term SBS is used to describe situations in which building occupants experience acute health and comfort effects. Some of the investigated symptoms were dry eyes, eye strain, watering eyes, blocked or stuffy nose, runny nose, dry or irritated throat, flu-like symptoms, and difficulty in breathing, headache, tiredness as well as dry skin. Other scholars have emphasized the association between SBS and indoor environment. For example, thermal environment has direct/indirect impact on human’s health. A recent clinical study has been conducted regarding both direct and indirect effects of humidity and temperature on human health in air-conditioned buildings in Thailand (Sookchaiya, Monyakul, & Thepa, 2010). It was found that medical experts agreed temperature and RH are most likely factors that cause disease and worsen the symptoms of patients. Too high RH is associated with the growth and spreading of bacteria, virus, house dust mite (small insect that can bite and cause irritation to human) and fungi especially in air-conditioned rooms with poor ventilation system. Furthermore, RH has potential to increase the intensity of chemical pollutants in the air by changing the distribution rate of gas from materials used inside the buildings and the reaction between water and chemicals. A control system for temperature and RH in air-conditioned rooms was proposed to improve health and comfort of occupants, however these variables were difficult to control in hospital buildings (Sookchaiya et al., 2010).

1.2. Significance of the study

In the built learning environment, scholars provide evidence that thermal conditions influence students’ behavior (Cash, 1993), attitudes (Weinstein, 1979), preferences and comfort (Corgnati, Filippi, & Viazzo, 2007), personality
development (Roberts & Robin, 2004), learning (Lashari & Alias, 2014) and performance such as reading, calculating, understanding and typing (Lee et al., 2012). Recent study of thermal comfort also associated with motivation and performance (Cui, Cao, Park, Ouyang, & Zhu, 2013). In addition, high quality facilities supports learning activities (Earthman, 2002; Hill & Epps, 2010; Mendell & Heath, 2005; Uline, Tschannen-Moran, & Wolsey, 2009; Uline & Tschannen-Moran, 2008).

According to the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), Standard 55, thermal comfort is defined as “a state of mind which expresses satisfaction with the thermal environment” (ASHRAE, 2004). The most effective way to determine comfort is through a combination of indoor environment variables and response from building occupants (Akasah & Ng, 2012). The question arises, why do we need to evaluate the architectural thermal comfort in laboratory setting? Most of indoor environmental studies not only focused on residences (Choi, Aziz, & Loftness, 2010; Dahlan, Jones, & Alexander, 2011; Dahlan, Jones, Alexander, Salleh, & Alias, 2009), health care (Fransson, Västfjäll, & Skoog, 2007), and office buildings (Huang, Zhu, Ouyang, & Cao, 2012) but also classrooms both in secondary and tertiary institutions (Farooq & Brown, 2009; Yatim, Zain, Darus, & Ismail, 2011) as well as lecture theater (Cheong et al., 2003; Lee et al., 2012). However, little is known on how students’ evaluate their comfort perception in a laboratory setting particularly in engineering education (Alias, Lashari, Akasah, & Kesot, 2014). Moreover, laboratories in higher education institutions simulate a real workplace setting for engineering education students, where this place is usually exposed to thermal environments, machines and equipment vibration, and chemicals (Akasah & Alias, 2010; Md Amin, Razzaly, & Akasah, 2012). Design for future engineering education laboratories can be improved if indoor environment issues (SBS symptoms and thermal discomfort are examples to name here) can be tackled earlier in the design and planning stage.

2. Methodology

2.1. Procedures

The study was conducted in three new engineering education laboratories (EEL) in Universiti Tun Hussein Onn Malaysia (UTHM), situated in a warm and humid climate. The outdoor weather conditions during the measurements period were observed since it contributes to the indoor conditions of the selected labs. AutoCAD lab (EEL1) and Electronic lab (EEL2) located in the new building of the Faculty of Technical and Vocational Education (FTVE), while Highway, Traffic and Transportation Engineering lab (EEL3) is located in the new complex building of the Faculty of Civil and Environmental Engineering (FCEE). Learning activities in the labs ranges from low, medium and high physical activities. These labs are designed to assist students in research, experimentation, teaching and learning activities. Architectural features such as a room’s dimension, surface reflectance factor, lighting system and windows were identified from architectural drawings that obtained from the Development and Property Administration Office, UTHM and labs’ inventory during the measurements.

2.2. Objective measurement

Objective measurements within thermal parameters were confined to mean radian temperature (tr), relative humidity (RH), air velocity/movement (AV). All measurements were conducted within two month according to the lab’s schedule from November to December 2012, within 3 hours of each lab sessions. The schedules of data gathering were obtained from respective faculties (FPTV and FKAAS). Three labs were selected as below:

- **EEL1 – AutoCAD lab with 15 student occupants, low level of physical activity and centralized air-conditioning system**
- **EEL2 – Electronic lab with 34 student occupants, medium level of physical activity and centralized air-conditioning system**
- **EEL3 – Traffic and Highway Engineering lab with 22 student occupants, high level of physical activity and centralized air-conditioning system**
For indoor conditions, the occupied and unoccupied zones (Fig. 1), and measurement points for thermal variables were identified, while physical measurements for \( t_r \), RH and AV were recorded using two sets of Thermal comfort stations Babuc A. The instruments were located at 1.1 m from floor level at two measurement points of the most occupied zones. InfoGAP software was used to analyze the indoor environmental data including estimated clothing characteristics and metabolic heat production, while Thermal Environment Measurement Report was also auto-generated by the same software for all respective laboratories. ASHRAE Standard 55 was referred in relation to the metabolic rate for different kind of activities (ASHRAE, 2004).

![Fig. 1. Occupied zones of (a) EEL1, (b) EEL2 and (c) EEL3](image)

2.3. Subjective measurement

Subjective measurements were conducted through questionnaire survey. The samples were undergraduate and postgraduate students at FPTV and FKAAS, UTHM. Three sections were developed in the survey: (1) demographic data, (2) architectural evaluation, and (3) thermal sensation scales (TSS). Section 2 and 3 were related to subjective measurements of thermal variables. Survey activities were administered an hour before the lab sessions end in order to enable respondents to adapt to the indoor lab environment.

In Section 1 of the questionnaire, students were asked for their gender, age, educational level, clothing wear, and symptoms of illness. Four age groups were provided, namely 20-29, 30-39, 40-49 and 50 years old and above. Two degree types were asked, namely undergraduate (e.g. Diploma/Bachelor’s degree) and post-graduate (e.g. advanced diploma, Master’s degree). Clothing selection was given for respondent, which represents how adaptation is made to the indoor conditions. Occupants were asked if they have experienced discomfort symptoms or also known as SBS symptoms (e.g. dry and watering eyes, eye strain, block or stuffy nose, dry or irritated throat, flu-like symptom, breathing difficulty, headaches, tiredness etc).

In Section 2, architectural evaluation of the physical conditions of the lab, namely space layout, adequacy of space, seating layout, surface color, aesthetic value and windows were included with 5-point scale: 1-very good, 2-good, 3-adequate, 4-fair, 5-poor. These represented building variables that influence students’ satisfaction with architectural space features. In Section 3, the evaluations of thermal, visual and acoustical sensations were based on a 7-point scale for each question. For thermal evaluation, scale indicated “very cold (-3), cold (-2), slightly cool (-1), neutral (0), slightly warm (1), warm (2), hot (3)” for \( t_r \), scale indicated “very dry (-3), dry (-2), slightly dry (-1), neutral (0), slightly humid (1), moderately humid (2), humid (3)” for RH, scale indicated “very still (-3), moderately still (-2), slightly still (-1), neutral (0), slightly draughty (1), moderately draughty (2), very draughty (3)” for AV. The seven points thermal sensation scale were then divided into three interval (-3, -2), (+2, +3) and (-1, +1). The first and second interval shows unacceptable microclimate condition, while votes of -1, 0 and +1 describe acceptable thermal environment.
3. Results and discussion

3.1. Objective measurement

Table 1 shows the environmental conditions (number of measuring points =2) for EEL1, EEL2 and EEL3. The mean radian temperature (tr) in EEL1 was between 21.46°C-22.42°C with relative humidity (RH) reading was between 68% - 71.1%, and surrounding air velocity of 0.0-0.17ms⁻¹. For EEL2, where the same criteria is observed but with occupants conducting medium physical activity, the minimum mean radiant temperature was recorded at 17.8°C, while the maximum temperature was 20.7°C. The relative humidity (RH) percentage of the lab was between 55.7% - 60.9%, with air speed of 0.0-0.15ms⁻¹. From the same table, it can be seen that the mean radian temperature in EEL3 was range between 18.5°C – 21.4°C, with relative humidity (RH) data measured between 69.3% - 78.3%, air velocity was minimum at 0.05ms⁻¹ and maximum at 0.49ms⁻¹. It should be noted that students were involved with higher level of physical activity in EEL3.

Table 1. Measured parameters in three EELs compares with ASHRAE and WHO. (mean radiant temperature (tr), relative humidity (RH) and Air Velocity (AV))

| Parameter | EEL1     | EEL2     | EEL3     | ASHRAE   | WHO      | NAE      |
|-----------|----------|----------|----------|----------|----------|----------|
| tr (°C)   | 21.46    | 22.42    | 17.8     | 20.7     | 18.5     | 21.4     | 22.5     | 26.0     | 24.0     | 28.0     | -        | -        |
| RH (%)    | 68.0     | 71.1     | 55.7     | 60.9     | 69.3     | 78.3     | -        | 50.0     | -        | -        | -        | 70.0     |
| AV (ms⁻¹) | 0.0      | 0.17     | 0.0      | 0.15     | 0.05     | 0.49     | -        | 0.25     | -        | -        | -        | -        |

For air-conditioned buildings, the ASHRAE Standards 55 (ASHRAE, 2004) recommended range is between 22.5°C-26°C while the WHO’s between 24°C-28°C (WHO, 1990). In this study, the tr were no within the suggested range. It should be noted that in tropical countries like Malaysia, the outdoor air is commonly very hot and humid throughout the year (maximum 31.5°C of temperature and maximum 90% of RH according to the Batu Pahat meteorology station) (Meteorology Department, 2014). The National Environment Agency (NEA) of Singapore on the other hand suggested the maximum humidity levels at 70%. In respect to this study, the mean relative humidity was recorded higher in EEL3 (78.3%), which was beyond the maximum limit of NEA. The mean air velocity seemed to be almost consistent in EEL1 and EEL2, while was peaked at 0.49ms⁻¹ in EEL3.

3.2. Sick Building Syndrome (SBS) symptoms

A questionnaire survey was distributed to a total of 71 undergraduate and postgraduate students in three engineering education laboratories. Fig. 2 illustrates the SBS symptoms experienced by all participants of this study. Descriptive analysis was conducted to investigate sick building syndrome (SBS) symptoms. Results shows that dry skin received the highest percentage (40.85%), followed by runny nose (30.99%), dry eyes (29.58%), blocked/stuffy nose (28.17%) and tiredness (26.76%). The largest percentage was recorded for dry skin (68.2%) followed by runny nose (50%) and blocked/stuffy nose (45.5%) in EEL3 where high physical activity involved. Noticeably, the lowest percentage, range from 0 - 20% was recorded for breathing difficulties in all EELs. Generally, SBS symptoms were found in all EELs in relation to the respiratory system, particularly in EEL3. However, it was not appropriate to claim the symptoms were experienced by the occupants because of single factor.

The SBS symptoms may occur due to the use of air conditioning system, where the conditions of indoor air movement and relative humidity in air conditioned space may expose student occupants to dust, mold, chemicals and contaminants. The mechanism of SBS remained poorly understood because of its complex relationship between thermal parameters and other multi-factors such as air quality, individual factors (age, gender and working position), and previous as well as current health conditions. However, a recent study emphasized that symptoms and complaints for different aspects related to thermal comfort, including light, noise and indoor air quality are good example to indicate SBS symptoms. It should be noted that incorrect response from occupants will increase the complexity of SBS problem.
Fig. 2. Distribution on subjective response of SBS symptoms experienced by student occupants in all EELs

3.3. Evaluation of architectural features

Architectural features considered for overall quality rating in all EELs were the space layout, seating and furniture layout, surfaces (wall, floor and ceiling) colors, aesthetic value and window design. Students were asked about their perception on the quality of architectural features in EEL1 using 5-points rating scale; (5) very good, (4) good, (3) adequate, (2) fair and (1) poor. Table 2 shows the distribution of overall quality rating in three EELs.

| Physical activity | EEL  | M   | SD  |
|-------------------|------|-----|-----|
| Low               | EEL1 | 3.93| 0.36|
| Medium            | EEL3 | 3.88| 0.78|
| High              | EEL5 | 3.71| 0.48|

Descriptive analysis was conducted to investigate quality rating of architectural features in all EELs. Results show that the mean quality ratings in all EELs were ranged between 3.71 and 3.93. The mean of total quality rating for EEL1, EEL2 and EEL3 were M = 3.93 (SD = 0.36), M = 3.88 (SD = 0.78) and M = 3.71 (SD = 0.48) respectively (Table 2). Evidently, the mean score was highest in EEL1 followed by EEL2 and EEL1. It can be interpreted that the overall quality of architectural features in all EELs was rated range between ‘adequate’ and ‘good’ by all students.

Similarly, the mean of quality rating for each architectural feature in all EELs were more than 3.00. Table 3 shows that the highest mean score, 4.20, was recorded in EEL1 for ceiling color (SD= 0.56) followed by floor and wall colors, and space layout. The lowest mean score, 3.67 were recorded for furniture layout and window in the same lab (M= 3.67, SD= 0.72 and M= 3.67, SD= 0.62 respectively). In EEL2, highest mean score, 4.06, was recorded for ceiling color with a standard deviation 0.92. The lowest mean score was furniture layout (M= 3.68, SD= 1.01). The highest mean scores, 3.95 and 3.86, were recorded in EEL3 for ceiling color and seating layout with standard deviations .76 and .77 respectively. The lowest mean score was window or opening (M= 3.23, SD= 0.75).
Table 3. Summary of mean (M) of quality rating and standard deviation (SD) for architectural features in three EELs, all architectural/ space features were > 3.00, indicating ‘adequate’ to ‘good’ scales

| EELs   | EEL1 (n=15) | EEL2 (n=34) | EEL3 (n=22) |
|--------|-------------|-------------|-------------|
| n      | 15          | 34          | 22          |
| Space layout | 4.07 (SD= 0.59) | 3.94 (SD= 0.92) | 3.82 (SD= 0.59) |
| Space adequacy | 3.93 (SD= 0.46) | 3.79 (SD= 0.98) | 3.73 (SD= 0.70) |
| Seating layout | 3.80 (SD= 0.56) | 3.79 (SD= 0.91) | 3.86 (SD= 0.77) |
| Furniture layout | 3.67 (SD= 0.72) | 3.68 (SD= 1.01) | 3.77 (SD= 0.87) |
| Wall colour | 4.13 (SD= 0.64) | 4.00 (SD= 0.92) | 3.68 (SD= 0.89) |
| Ceiling colour | 4.20 (SD= 0.56) | 4.06 (SD= 0.92) | 3.95 (SD= 0.76) |
| Floor colour | 4.13 (SD= 0.52) | 4.00 (SD= 0.89) | 3.77 (SD= 0.69) |
| Aesthetic value | 3.80 (SD= 0.56) | 3.74 (SD= 0.71) | 3.55 (SD= 0.67) |
| Window/ opening | 3.67 (SD= 0.62) | 3.91 (SD= 0.75) | 3.23 (SD= 0.75) |

It can be noted that the results showed in Table 3 were possibly influenced by the fact that all EELs were new buildings at UTHM main campus with new building materials and equipments, which might influence students’ judgment in the quality of EELs’ architectural features.

### 3.4. Subjective measurement of thermal comfort

The subjective measurement of thermal comfort using thermal sensation scale (TSS) was conducted on different days and times. Firstly, 15 survey forms were distributed in EEL1 on 21st of November 2012 from 11.30am to 2.30pm, with the observed outdoor weather condition was partly cloudy. Secondly, in EEL2, survey forms were administered to 34 respondents on 5th of December 2012 from 11.20am to 2.20pm with the observed outdoor weather condition was mostly cloudy. Finally, subjective measurement was conducted on 12th of November 2012 from 2pm to 5pm in EEL3, involved 22 students with the observed outdoor weather condition was mostly cloudy. Table 4 below shows mean and standard deviation of subjective measurement for thermal sensation votes in all EELs.

Table 4. Mean and standard deviation (SD) of thermal sensation votes (TSV) in three EELs

| Mean (M) | EEL1 (n=15) | EEL2 (n=34) | EEL3 (n=22) |
|----------|-------------|-------------|-------------|
| tr       | -1.53 (SD= 0.92) | -2.44 (SD= 0.71) | -2.68 (SD= 0.57) |
| RH       | -0.27 (SD= 1.10) | -0.91(SD= 1.40) | -0.64 (SD= 1.56) |
| AV       | 0.00 (SD= 1.30) | -0.41(SD= 0.82) | 0.23 (SD= 1.44) |

The mean of temperature sensation vote (TSV) for three labs were -1.53 (SD = 0.92) and -2.44 (SD = 0.1) and -2.68 (SD = 0.57) respectively. The subjective judgment on the seven points thermal sensation were divided into three interval (-3, -2), (+2, +3) and (-1, +1). According to the Fanger’s theory, the microclimate is not acceptable in the first and in the second of these intervals, while votes of -1, 0 and +1 describe acceptable thermal environment. Results show that tr was not acceptable for all EELs (Table 4).
On the other hand, according to the ASHRAE Standard 55, an acceptable environment should have 80% of occupants voted for the interval (-1, 0, 1). However, results (Fig. 3) were obviously skewed towards the left for temperature in all EELs. It can be noticed that students expressed a vote within the interval (-3, -2) for temperature, where this represented 66.7% of the total (n=15) students in EEL1, 94.0% of the total (n= 34) students in EEL2 and 95.4% of the total (n=22) students in EEL3. Based on these results, it can be interpreted that all EELs were not in acceptable thermal conditions although all EELs were facilitated with (centralized) air conditioning system. Fig. 3 and Fig. 4 illustrate the subjective votes for temperature and relative humidity in EEL1, EEL2 and EEL3 respectively.

Based on the Fig. 4, the mean of RH sensation votes of EEL1 was higher, at -0.27 (SD =1.1) than of EEL3, at -0.64 (SD = 1.56) and peaked at -0.91 in EEL2 (SD = 1.4) (Table 2). Fig. 4 shows that most of the students expressed votes -1, 0 and +1 in EEL1 (73.4 %) and EEL3 (45.4%) respectively, while majority of the vote was within -3, -2 in EEL2 (44.1%). It should be noted that higher humidity directly affects the amount of allergens indoors and encourage the growth of dust mites and fungus colonies, which finally can be associated with SBS symptoms such as headache, mucosal symptoms (eyes, throat, nose) and skin symptoms (dry skin on face, hand, scalp) (Wang et al., 2013).

In relation to subjective respond of air velocity (AV), the mean of AV for EEL1 was exactly at 0.0 (neutral sensation, SD = 1.3), while AV for EEL2 and EEL3 were at -0.41 (SD = 0.82) and 0.23 (SD=1.44) respectively. Fig.
5 shows that most of the respondents’ votes were within the range of (-1, 0, +1). It can be interpreted that the sensation vote for AV was within acceptable condition in all EELs.

![Fig. 5. AV sensation votes in three EELs](image)

### 4. Conclusion

This study has investigated the architectural indoor condition including sick building syndrome (SBS) symptoms and important variables of thermal: temperature, relative humidity and air velocity, in three engineering education laboratories (EEL). The selected academic setting was under real working condition for engineering education students.

Results of objective measurement show that lower temperatures were found in all EELs, which were not within recommended range either by ASHRAE or WHO. The thermal condition was therefore considered unacceptable. The finding from subjective measurement reaffirmed that the student occupants were not in a thermal acceptable condition. Poor ventilation system of air-conditioned EELs may lead to SBS symptoms and affect students’ health. The study recommends controlling and adjusting the laboratories temperature is necessary to meet the comfortable temperature in order to support learning activities. Without a proper functioning control system (Kreider, Curtiss, & Rabl, 2005), it is impossible to sustain a comfortable indoor environment for student occupants.

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