Perception of thermal comfort and prediction of heat stress (PHS) due to heat gain in tropical university classrooms

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Abstract. Comfortable indoor climate is anticipated in hot-humid tropical condition. University classrooms are such kind of space which quality can improve the occupant’s performance directly. Due to lack of their adaptation ability, like the fixed schedule of activities and clothing causes extra heat gain from the environment and make hazardous situation. In this research, we focused to find out the comfortable condition of university classrooms in Bangladesh. The field monitoring was conducted at Chittagong University of Engineering and Technology (CUET) during the hottest months in the country (April-July). The measurements included the basic thermal environmental parameters like air temperature (AT), relative humidity (RH), indoor air velocity (V), and indoor light (L) during regular class time 9:00 to 17:00. Predicted Heat Strain (PHS) has been calculated using obtained data with a known metabolic rate and clothing. It is found that the skin temperature crosses 34°C frequently in PHS scale and creates health risk.

1. Introduction

According to university grants commission of Bangladesh (UGC) [1], governing body of universities in Bangladesh, there are 37 government universities in the country. University student’s performance including attention, concentration, learning and hearing significantly depends on a healthy and comfortable indoor climate [2-4]. But most of the cases the indoor climate is not well maintained or designed for the students. Their performance is overlooked according to health impact analysis [5] like other tropical countries. For a vast population as well as financial barriers, it is hard to maintain a proper healthy indoor condition. But its impact is phenomenal. Students have a small adaptive opportunities comparing to residential occupants [6-7]. They have scopes to add or remove clothes, control windows and can adjust sun shading devices [8-11]. So heat stress occurred and it paramount discomfort and reduce the performance of the students [12-14]. From field monitoring, it was observed that in hot humid tropical climate, university classrooms are highly affected by the ambient environment. Basic thermal parameters like air temperature (AT) °C, relative humidity (RH) %, air velocity (v) ms⁻¹ and indoor light (lux) are not properly maintained as per thermal comfort defined by ASHRAE [15]. Students need to spend a lot of time in classrooms due to their fixed schedules, as a result, their heat gain is constant without any significant adaptation and it indicates a health issue.

Our whole prediction process was conducted by a series of field monitoring on a regular basis. The purpose of this study was to figure out the thermal condition in classrooms by objective measurement and comparison with ASHRAE standards [15] for the hottest months of the year April to July. The objectives are:

- Figure out the heat gain and heat loss factors in indoor climate for heat balance.
- Find out the basic thermal condition in university classrooms during class time at summer season.
- Calculating predicted heat strain (PHS) [16], skin temperature ($t_{sk}$) to determine the risk in the classrooms and evaluating the safety of students.

2. Methodology
The aim of this study is to investigate the present indoor climatic condition of the university classrooms by means of the objective as well as subjective approach and relate it to the comfort parameters. For figuring out the thermal comfort, it is important to create a relationship between the indoor environments with the comfort parameters. The field study is conducted in a university classroom at the Chittagong University of Engineering and Technology (CUET), Bangladesh. Because of its close proximity to the Bay of Bengal, its location can be identified as the hottest and humid zone in the country. So it shows a vulnerable climatic condition due to comfort analysis. Figure 1 shows the different steps of the research.

2.1. Classroom selection
For selecting classroom it is an important consideration that the building should be constructed of brick and concrete, which is common material all over the country. Another consideration is the climatic complexity. In Chittagong, the climate is mostly hot and humid because of the sea Bay of Bengal is very near to it on the west side. For that reason, the humidity goes higher from another part of the country. Our field monitoring was conducted on the 3rd floor (East part) of a 12 storied building. The building is surrounded by small hills at the east side, at west a 3 storied brick building, and north as well as south parts are open with green trees. Table 1 shows the basic information about study zone. Figure 2 shows the basic layout of the studied space (plan) and Figure 3 shows the longitudinal section of it. The building has a natural ventilation (NV) system with windows and mechanical ventilation (MV) system is controlled by electric ceiling fans. In Bangladesh, most of the classrooms have the same kind of mixed ventilation system.

2.2. Data collection
Our study was conducted during the regular class time started from 9:00 to 17:00 with a 1-hour interval in 2016 during the hottest month of the country April, May, June and July. Measurement was taken at the point shown in Figure 2 and Figure 3. Picture of the classroom and sampling point are shown in Figure 4(a). Indoor air temperature, relative humidity, and air velocity were measured by LM-8102 and Digital Thermo-Hygrometer (Figure 4(b)). Table 2 shows the detail information on these two instruments. After taking data from both of the tools, they were averaged for minimizing the operating errors. At the sampling point, the tools were left to run 3 minutes before taking the values and parameters were recorded. Clear height of the classroom was 2.9meters. All data were recorded at 1.1 meters height of the floor, which recommended the seated level of the occupants [23]. Here metabolic rate and clothing insulation were considered from ASHRAE standards [24]. For this study metabolic rate was taken 1.1 met, where students were seated and involved with some light activities such as reading, writing, speaking etc. Clothing of the subject was considered by checklist. For male, it was long pants and shirt or T-shirt with underwear and in case of female, mostly salwar kameez and underwear. The average clothing insulation was found 0.53clo. For determining the clothing insulation, subjects were asked to fill about their wearing. After summing and averaging the value was 0.53 clo according to ASHRAE standards [15].
For this research, a group of 30 students was performed in the classroom. 15 were male and 15 were female out of them. Average ages of the subjects were between 21 to 23 and had a good health to commit the study works. Table 3 shows the information of the subjects. Subjects were uniformly distributed during the class hours in their classroom. The recorded information was elaborated to evaluate heat stress.

### Table 1. Characteristics of the study space

| Input consideration       |                  |
|---------------------------|------------------|
| Room area                 | 271.45 m²        |
| Room length               | 30.5 m           |
| Room width                | 8.9 m            |
| Room height               | 2.9 m            |
| Building material         | Brick, Concrete, Plaster |
| Occupants                 | 30 (Male 15, Female 15) |
| Window size               | 1.22 m X 1.22 m  |
| Window ratio against wall | 1 : 9.6          |
| No. of Fan                | 15 nos. (75 W, air delivery 250 m³/min) |
| No. of Light              | 40 nos. (60 W)   |

For human body thermal balance is important to maintain comfort level and reduce heat stress. Core body temperature must remain balanced and constant around 37°C and skin temperature around 34°C. All surplus heat

### 3. Results analysis and discussion

From field monitoring air temperature (AT) °C, relative humidity (RH) %, air velocity (v) m s⁻¹ and indoor light (lux) were recorded. Using these data skin temperature ($t_{sk}$) and core body temperature ($t_{cr}$) are calculated.

#### 3.1. Basic thermal condition

For human body thermal balance is important to maintain comfort level and reduce heat stress. Core body temperature must remain balanced and constant around 37°C and skin temperature around 34°C. All surplus heat
must be released to the environment. Body heat gain occurred by the metabolism (Met) of basal and muscular
tissue, conduction (Cnd) with warm subjects, convection (Cnv) process if the air is warmer than the skin, and by
radiation (Rad) from the sun, sky or hot bodies. Where heat loss process is conduction (Cnd) with cold
subjects, convection (Cnv) process if the air is cooler than skin, radiation (Rad) to night sky or cold
surfaces and by evaporation (Evp) process like sweating.

So when the sum of the heat gain and heat loss is “0” it indicates thermal balance. When the heat

gain is higher than the heat loss it increases core body temperature and skin temperature and causes
discomfort.

\[
\text{Thermal balance} = \text{Met} - \text{Evp} \pm \text{Cnd} \pm \text{Cnv} \pm \text{Rad} = 0 \quad (1)
\]

Figure 5 shows the heat gain and heat loss process to the human body from the ambient environment. Figure 6 shows the heat exchange process of buildings. Conduction of heat may occur either inward or outward side depending on temperature and here denoted as \( Q_c \). Solar radiation passes through the clear or opaque window and denoted as \( Q_s \). Movement of air creates convection heat flow and denoted as \( Q_v \). Where \( Q_m \) is the heat production of outside energy supply in the space. \( Q_i \) indicates the internal heat gain from human bodies, lamps, motors and appliances. And if evaporation occurs on the surface of the building and the vapours are removed, this produces cooling effect and denoted as \( Q_e \).

\[
\text{So, thermal balance} = Q_i + Q_s \pm Q_c \pm Q_v \pm Q_m - Q_e = 0 \quad (2)
\]

In Figure 7 air temperature is plotted from the field study. Every line represents a full day temperature character. Measurement was conducted during regular class time 9:00 to 17:00 in 2016 (April- July). Data were collected in every one hour interval. It shows that ambient air temperature
range travels 27 °C to 35 °C. Where during 12:00 to 15:00 the range is higher and most of the cases it is above skin temperature and heat gain occur due to convection process.

Figure 8 shows the humidity of the air. Data collecting process was same. High humidity restricts heat loss and creates discomfort and it shows that in the study space it is almost 75-85% humidity every time. It increases the skin and core body temperature.
Figure 9 shows the air flow in the study space. Air ventilation helps to exchange the hot air from the adjacent skin and creates scope for heat loss due to convection way. Figure 9 shows that air flow varies between 0.2 -0.8 ms$^{-1}$.

Figure 10 indicates the heat gain from radiation and indoor artificial light. It is around 600-800 lux. It represents the indoor light intensity during the class time. Heat gain occurs for the lighting intensity. These are the basic thermal parameters which are directly related to the heat loss and heat gain process. Data were collected by the pre-mentioned measuring tools and plotted by hourly basis. Every horizontal line indicates the data through the day mentioned in the figures (Figure 7-10).

3.2. **PHS prediction calculation**

For establishing PHS criteria, here established formulas was in term according to ISO standards 7933. For calculation of PHS, these formulas have been conducted.

For clothed subject skin temperature:

$$ t_{sk} = 12.17 + 0.020 t_a + 0.044 t_r + 0.194 P_a - 0.253 V_a + 0.003 M + 0.513 t_{re} \quad (3) $$

Table 4. Subjective consideration for PHS calculation

| Input consideration               | unit | value |
|-----------------------------------|------|-------|
| Height (h)                        | m    | 1.72  |
| Weight (m)                        | kg   | 61    |
| Body mass index (BMI)             | m$^2$| 1.50  |
| Metabolic rate (M)                | met  | 1.1   |
| Clothing rate ($I_{clo}$)         | clo  | 0.53  |
| Rectal Temperature ($t_{re}$)     | °C   | 38.00 |
| Moistness cloths thermal efficiency ($g_{cl}$, W) | %    | 0.122 |
| Oxygen uptake (${\text{VO}}_2$ max %) | %    | 30-40 |
Here for light work like studying, sitting metabolic rate was considered as $1.1$ met $= 58.2 \text{ W/m}^2$.

Following equations also considered for evaluating the PHS criteria.

\[
[t_{cr} = t_{crn}, \quad HR = HR_n]
\]

For moderate heat stress range,
\[
t_{cr} = t_{crn} + k_b(t_{sk} - t_{skp}) \quad (4)
\]
\[
HR = HR_n + k_b, HR (t_{sk} - t_{skp}) \quad (5)
\]

And for high heat stress range,
\[
t_{cr} = t_{crn} + (C_k - t_{skp}) \quad (6)
\]
\[
HR = HR_n + k_c, HR (t_{sk} - t_{skr}), \text{ where } t_{skr} = 36^\circ C \quad (7)
\]

And for $t_{sk}$ and $t_{cr}$ the acceptance range is,

Everyday life body surface temperature, $t_{sk} = 34^\circ C$.

In the case of body temperature), $t_{cr} = 37.6 - 38^\circ C$.

For the evaluation of PHS, student’s height, weight, body surface, metabolic rate, clothing and age are considered as per Table 4. From the study, it is found that during the month of April to July indoor AT become very high near about 34.5 $^\circ$C and RH about 75-85%. During this time period $t_{sk}$ leads to higher than the regular comfortable skin temperature. Figure 11 represents the skin temperature throughout the research work. Data are plotted on hourly basis, and it shows that almost every time the temperature is above 34 $^\circ$C which indicates an uncomfortable climatic condition. Figure 12 shows that body surface temperature goes high about 61% time during this period of time because of high RH it creates an unfamiliar environment. Mostly at morning and noon time observed data shows that it is above the comfort range. Further $t_{cr}$ became higher than the normal 38 $^\circ$C for high AT at indoor climate.

4. Conclusions

The major observation of this study is that indoor thermal parameters in classrooms are not satisfying during summer time. Environmental parameters influence a lot on thermal comfort and create health issues. In this study, heat stress criteria were observed in April-July, during the regular class time and from that major findings can be drawn like that:

- At Chittagong region indoor AT remain 30-34 $^\circ$C, while RH is around 75-85% during operative time.
- Minimum ventilation, elevated temperature and high humidity reanimated heat gain from outdoor to indoor environment. As a result, heat gain happed to the occupants. So core body temperature and skin temperature of occupants exceed from its comfort range.
- During this summer time, PHS indicates health risk alert, shows elevated skin temperature during middle of the day (12:00 to 15:00) from the normal skin temperature (34 $^\circ$C).

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### Nomenclature

| Symbol | Meaning                                      | Unit   |
|--------|----------------------------------------------|--------|
| $AT$   | Air temperature                              | ($^\circ$C) |
| $f_{cl}$ | Clothing factor                              |        |
| $HR$   | Heart rate                                   | (bpm)  |
| $HR_{eq}$ | Equilibrium heart rate                   | (bpm)  |
| $I_{cl}$ | Clothing insulation                          |        |
| $k_b$   | Rate of increase in body temperature        | ($^\circ$C) |
| $k_{bhc,hr}$ | Heart rate increase              | (bpm/K) |
| $M$    | Metabolic rate                               | (W/m$^2$) |
| $MV$   | Mechanical ventilation                       |        |
| $NV$   | Natural ventilation                          |        |
| $P$    | Air pressure                                 | (kPa)  |
| $PHS$  | Predicted heat strain                        |        |
| $p_a$  | Vapor pressure of air                        | (kPa)  |
| $R_{cl}$ | Clothing thermal insulation                  |        |
| $RH$   | Relative humidity                            | (%)    |
| $t_{a,T}$ | Air temperature                   | ($^\circ$C) |
| $t_{cl}$ | Surface temperature of clothing              | ($^\circ$C) |
| $t_{cr}$ | Core temperature                             | ($^\circ$C) |
| $t_{crn}$ | Permanent body temperature                   | ($^\circ$C) |
| $t_r$  | Mean radiant temperature                     | ($^\circ$C) |
| $t_{re}$ | Rectal temperature                           | ($^\circ$C) |
| $t_{sk}$ | Skin temperature                             | ($^\circ$C) |
| $t_{skp}$ | Upper limit skin temperature                | ($^\circ$C) |
| $v$    | Air velocity                                 | (ms$^{-1}$) |
| $v_a$  | Volume of air                                | (m$^3$) |