ISSN: 1999-1630

SEU Journal of Science and Engineering, Vol. 12, No. 1, June 2018

Thermal Comfort Conditions in a Residential Unit Of a Low-Rise Apartment in Dhanmondi , Dhaka Using PMV- PPD Model and Field Survey

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Abstract: The present study aims to explore the thermal comfort conditions in a residential unit of a low-rise apartment in Dhanmondi, Dhaka experiencing warm-humid climate. Thermal comfort conditions in three bed rooms, a living room and a dining room are analyzed using PMV-PPD (Predicted Mean Vote and Predicted Percent Dissatisfied) model and field survey. Thermal behavior of the rooms are analyzed in relation to their orientation, position and no. of window openings, nature/type of usage, mode of ventilation ,time of the day and season and also considering the factors associated to thermal comfort such as temperature, air velocity, relative humidity, metabolic rate (Met) and clothing value (Clo). Finally, from analyzing different factors of thermal comfort it is derived which space satisfies the residents most and also the reasons for their satisfaction are stated.

Keywords: Natural Ventilation, PMV-PPD Model, Residential Building, Thermal Comfort, Warm-Humid Climate.

I. Introduction

Based on the relevant statistics, people spend 80% of their lifetime indoors (S. Wei). Therefore, it is required for Indoor environment to be made safe, healthy and comfortable to a certain extent. It has been shown that the productivity will be increased by 15% when occupants are satisfied with their thermal environments (K. Kim, B.S. Kim). It is believed by (P.O. Fanger) that maximum potential of human being can be showcased if only they are in a comfortable thermal environment. A quality night sleep has been observed to play a significant role in allowing adequate daytime functioning: concentration, attention and comprehension as well as learning level (S.C. Sekhar and S.E. Goh) (Z. Lin, and S. Deng),Naturally ventilated buildings (NV) used the freely available resources of wind and solar energy and with proper design, they could represent an alternative technique for reducing the energy consumption in buildings and for creating sustainable thermal comfort and healthy indoor conditions (G.W. Stavrakakis). According to (A.D. Stavridou and P.E. Prinos) natural ventilation promotes not only protection and restoration of indoor air, but also sustainability and energy saving. Despite these acclaimed benefits, the results of recent studies conducted on naturally ventilated buildings often deviated from the actual scenario (C. Cândido, R.J. de Dear, R. Lambert, and R.L. Bittencourt; M . Haase, and A. Amato). Here the residents are considered as respondents and it can be observed that the majority wanted sufficient air flow and relatively cooler environment.

Different people may have different response regarding comfort in the same space due to certain factors such as temperature, air velocity, relative humidity, metabolic rate (Met) and clothing value (Clo).The reason for creating thermal comfort is first and foremost to satisfy man's desire to feel thermal comfortable, in line with his desire for comfort in other directions (P.O. Fanger). Comfort is sensed by body and perceived by brain. That's why the science of indoor climate engineering comes before HVAC (Heating, Ventilation and Air conditioning) engineering. It is well known that poor thermal comfort forced the users to look for high energy alternatives to achieve thermal comfort (M. Indraganti). By investigating the thermal comfort attributes in the residence, the indicators of thermal problems and also the reason of higher energy consumption by the building can

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be determined. The factors affecting human thermal comfort are : air temperature, air velocity, metabolic activity (met), clothing value (clo), mean radiant temperature and humidity. To predict thermal comfort conditions the **PMV** *(Predicted Mean Vote)* and **PPD** *(Predicted Percentage Dissatisfied)* models are used as tools. **PMV** *(Predicted Mean Vote)* is a means of tool by which thermal comfort can be assessed according to human perception. This index helps individuals to determine their impression regarding thermal comfort in indoor climate which holds the amalgamation of the thermal comfort factors such as air temperature, air velocity, metabolic activity (met), clothing insulation (clo) , mean radiant temperature and humidity.

The PMV index predicts the mean response of a larger group of people according the ASHRAE thermal sensation scale (P.O. Fanger):

PMV	-3	-2	-1	0	+1	+2	+3
Thermal Sensation	cold	cool	Slightly cool	neutral	Slightly warm	warm	hot

The PMV index is expressed by (P.O. Fanger) using the equation

$PMV = (0.303\ e^{-0.036M} + 0.028)\ L$ (1)

,where

PMV = Predicted Mean Vote Index

M = metabolic rate

L = thermal load - defined as the difference between the internal heat production and the heat loss to the actual environment for a person at comfort skin temperature and evaporative heat loss by sweating at the actual activity level (Engineering ToolBox)

Developed by (P.O. Fanger) , the predicted percent dissatisfied (PPD) is an index that predicts the percentage of thermally dissatisfied people who feel too cool or too warm, and is calculated from the predicted mean vote (PMV).

The PMV and PPD form are therefore closely related, and both indices take the form of a U-shaped relationship, where percentage dissatisfied increases for PMV values above and below zero (thermally neutral). At the neutral temperature as defined by the PMV index, PPD indicates that 5 % of occupants will still be dissatisfied with the thermal environment. The standard BS EN ISO 7730:2005 (British Standards Institution 2006) uses both the PPD and PMV.

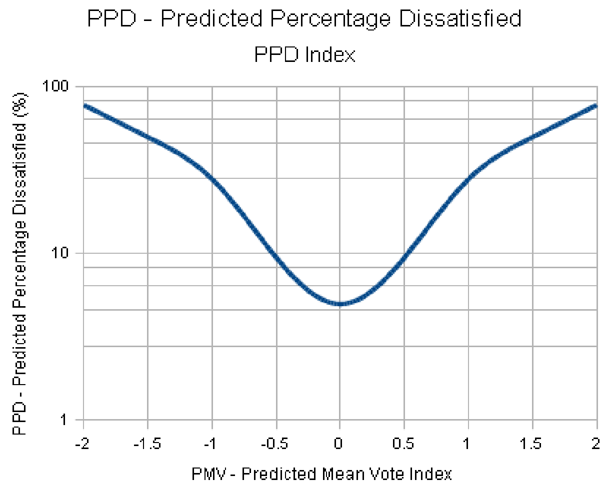

Figure 1: PPD vs. PMV

II. Case study

In this study, the field survey was carried out in a naturally ventilated residential unit located on Dhanmondi, Dhaka using PMV-PPD model. Dhaka is located on latitude 23.7000° N, longitude 90.3667° E within a warm-humid tropical area. The building is a low-rise reinforced concrete structure housing consisting of three floors . The study area was located in the 2nd floor.

General Information Regarding the Study Area:

Floor Area: 1400 sft Total No of residents: 06 Male User: 03

Female User: 03

No of Bedrooms: 04 No of toilets: 03

Age of the users: 29,32,33,35,58,72

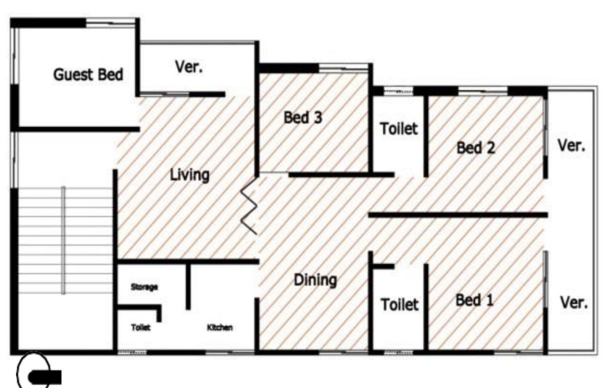

Figure 2: Study area (2nd Floor Plan) details of study

Room	Area	No. and type of windows	Cross Ventilation	A/C
Living	192 sft	1,Sliding	No	No
Dining	168 sft	1,Sliding	No	No
Bed 1	160 sft	2,Sliding	Yes	Yes
Bed 2	136 sft	2,Sliding	Yes	Yes
Bed 3	100 sft	1,Sliding	No	Yes

III. Methodology

The research is conducted on basis of field survey. Field study provided better context for analysis rather than climate chamber, because the respondents did not have any additional restrictions being in their everyday habitats, wearing usual clothing. In the field survey people are able to act as "meters" (units) of their environment (M. A. Adebamowo and O. Olusanya). The field study is conducted in the month of March which is spring in Bangladesh and from the meteorological data it is seen that high humidity and temperature with low air movement is the characteristic of hot season in Dhaka.

Thermal analysis was based on 50% occupancy during weekdays and 90% occupancy during weekends. Number of inhabitants was assumed to be same for all the rooms.

Using the thermal comfort calculator (ISO-7730-1993) the PMV and PPD values of the residence is calculated.

IV. Data Collection and Findings

Air temperature, Air velocity, Relative humidity of the different zones of the residence is collected three times at five minutes interval using Thermo-Anemometer and Hygro- thermometer. And the average values of each zone are finally put in the comfort calculator to determine PMV and PPD.

Data collected from the reading of Thermo-Anemometer and Hygro-thermometer are given below

Bed 1: (South-west facing)
Bed 1 has provision of cross ventilation and verandah on south side.

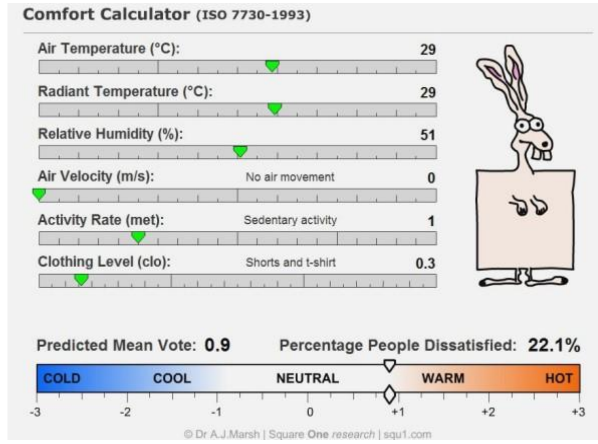

Figure 3: Thermal Comfort Calculator

Time	Wind Velocity (m/s)	Max temp °C	RH%
10:15 am	0	28.9	51%
10:20 am	0	29.0	51%
10:25 am	0	29.1	51%

Bed 2: (South-east facing)
Bed 2 has provision of cross ventilation and verandah on south side.

Time	Wind Velocity (m/s)	Max temp °C	RH%
10:30 am	0	29.3	51%
10:35 am	0	29.4	51%
10:40 am	0	29.6	51%

Bed 3: (East facing)
Bed 3 has no provision for cross ventilation

Time	Wind Velocity (m/s)	Max temp °C	RH%
10:45 am	0.2	29.4	51%
10:50 am	0.2	29.3	51%
10:55 am	0.1	29.5	51%

Living: (East facing)
Living has no provision for cross ventilation.

Time	Wind Velocity (m/s)	Max temp °C	RH%
11:15 am	0	29.5	51%
11:20 am	0	29.4	51%
11:25 am	0	29.5	51%

Dining: (West facing)

Dining has no provision for cross ventilation.

Time	Wind Velocity (m/s)	Max temp °C	RH%
11:00 am	0	29.7	51%
11:05 am	0	29.8	51%
11:10 am	0	29.9	51%

So, putting the average values of each room in the thermal comfort calculator (ISO-7730- 1993) we can get the following PMV and PPD rate.

Room	Met (Activity rate)	Clothing Level (Clo)	PMV	PPD
Living	1	0.7	0.8	18.5%
Dining	1	0.7	1	26.1%
Bed 1	0.7	0.7	-0.4	8.3%
Bed 2	0.7	0.7	-0.3	6.9%
Bed 3	0.7	0.7	-0.2	5.8%

From the charts it can be seen the measured indoor air temperature in the residence ranged between 28-30◦C. Relative humidity is 51%.The clothing value is same for all zones but the met rate differs slightly. Therefore, depending upon these factors the PMV and PPD index of each zone varied.

V. Conclusion

It can be observed from the study that all zones more or less satisfy thermal comfort conditions during the time of study (March, Morning time) as the PMV values are within the ideal range [-1 to 1] . Bed-1 and Bed-2 have cross ventilation provision and are south-east facing. Therefore, the occupants are more or less comfortable being mostly in resting or relaxed situation. The PPD in the dining zone is highest among the studied five zones and the PMV value of the dining zone also indicates slightly warmer condition than the other four zones as it's west facing and has no cross ventilation provision. Moreover, position wise it's between Bed-1 and the kitchen. Hence, from study it's evident that the location of rooms, provision of cross ventilation, temperature, clo value and activity all these factors influence the respondents' comfort sensation. Therefore in conclusion it can be stated that PMV-PPD model can predict the thermal comfort conditions of Naturally Ventilated buildings to a satisfactory level.

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