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OPTIMIZING BUILDING PERFORMANCE BY INTEGRATING EXPERIENTIAL THERMAL COMFORT IN STUDENTS' ACCOMMODATION

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ABSTRACT

In the absence of thermal comfort standards in India, architects and designers have no choice, except to provide air conditioning to meet thermal comfort criteria for achieving green building rating for their projects and thus end up using more energy eventually. Significant Energy saving can be brought about by promoting naturally ventilated buildings as thermally comfortable building by retrofitting them with energy conserving measures for improving thermal performance. This paper analyses effect of various ECBC measures on thermal comfort in naturally ventilated hostel buildings in composite climate with respect to occupants' responses vis-à-vis thermal comfort standards based on the adaptive model of ASHRAE 55-2010 and simulated model so as to prove naturally ventilated buildings to be thermally comfortable due to adaptive opportunities.

INTRODUCTION

With fast changing urban landscape due to high growth rate and increasing urbanization, energy consumption scenario is drastically changing due to changing lifestyle of more indoor activities, use of air conditioning to achieve higher thermal comfort and climate change (Paula, 2014). Given, there is an already growing concern for quality and quantity of energy available in cities, the thrust is to reduce energy consumption by managing the demand side in new and existing buildings and also provide unprecedented opportunity to reduce CO2 emission by 2050 (Architecture 2030, 2014).

As per the study report of the United Nations' Intergovernmental Panel on Climate Change in its report on "Mitigation of Climate Change", largest energy and carbon savings potential in 2030 can be achieved by retrofitting and renovation of existing buildings (IPCC, 2013). Most of the building stock in India comprises of typically three to four storied free running structures or are partially air-conditioned. Practically due to a very narrow band specified for naturally ventilated buildings in the National building Code in India and stringent requirements of condition of thermal comfort for 90% of all occupied hours for buildings in composite climate for 80 % of occupants by National rating System Green Rating for Integrated Habitat Assessment (GRIHA), designing of free running buildings to meet thermal comfort criteria is far more difficult task than energy guzzling air conditioned buildings. Thus, in the wake of absence of thermal comfort standards in India, architects and designers have no choice, except to provide air conditioning to meet thermal comfort criteria and end up using more energy eventually. Significant Energy saving can be brought about by promoting naturally ventilated buildings as thermally comfortable building by retrofitting them with energy conserving measures for improving thermal performance. Most of the building performance simulation tools do not take into account effect of elevated air speed as outlined in ASHRAE 2010 and 2013 for assessing thermal comfort in case of naturally ventilated buildings.

Various thermal comfort models outlined in ASHRAE 55 and CEN 15251 have been developed primarily for office buildings and there is a dearth of studies on residential buildings (Indraganti, 2010). It is reported worldwide that although huge energy is utilized in neutralizing buildings for thermal comfort by cooling or heating, rarely more than 80 % of the occupants get satisfied thermally
(de Dear, 2014).

Whereas residential sector has significantly higher potential to harness passive low energy techniques to save energy or aim towards net zero carbon footprint, the present study is based on case study of student housing in university campus which can serve as prototype for understanding various parameters of thermal comfort, demonstrate potential of passive solar techniques and post occupancy evaluation as a tool integrated with whole building simulation approach to restore thermal comfort without resorting to high end energy consumptive air conditioning.

Typically Students' accommodation in universities is low rise free running buildings, having large footprint, high occupation density and exhibit diversity in terms of personal adaptive controls such as the use of windows and balconies, clothing, metabolism, higher tolerance level of students due to age, occupancy schedule. Correlation is drawn between simulated thermal comfort with respect to revised thermal comfort standards and real performance of building obtained from occupants' surveys in the specific context of university hostel buildings in composite climate. Simulation results are integrated with real performance of buildings to evolve design strategies for retrofitting these buildings with energy conserving measures.

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STUDY AREA CONTEXT

Detailed study of thermal comfort of boys' hostels at Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Sonipat (near vicinity of National Capital Region of Delhi), falling in composite climate zone, was carried out by installing data loggers on every floor and rooms with different orientations. Each hostel is a three-storied structure with two blocks, housing 138 rooms in each block. The Building, having receding walls and deep balconies, create self-shading for walls and windows by virtue of its geometry and are having a large central courtyard, which provides access to individual rooms and acts as a heat sink for the building? (Figure 1).

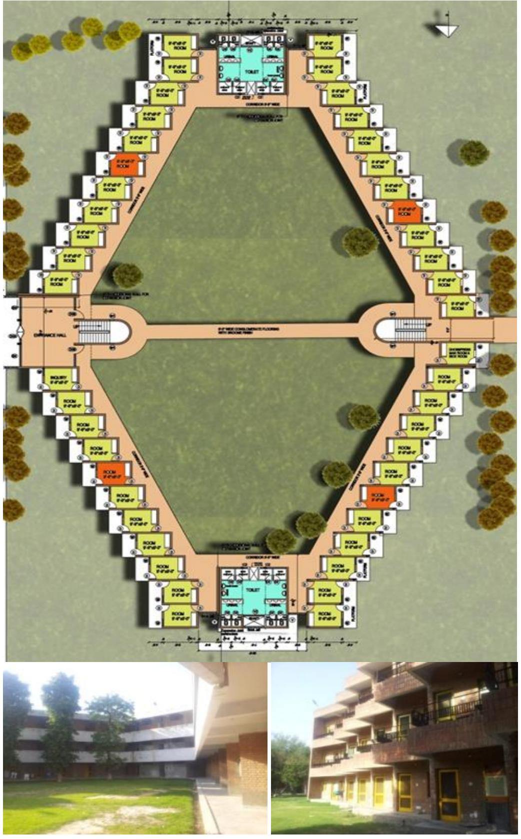

Figure 1 Plan and View of the Hostel building

Construction of the building is typically conventional with 230 mm thick walls in exposed brickwork, 150 mm thick RCC slab with 100 mm mud phuska and brick tiles and windows in wooden frames and single glazed shutters of 5 mm thick polished plate glass.

The site falls in Hot arid climate zone having steppe (Bsh) as per Koppen climate classification (the composite climate as defined in National building code of India) having temperature ranging from 45^{o}C in summers to 4^{o}C in winters and humidity ranging from 20 to 50% in dry months and 50-90% in wet months as seen in Figure 2.

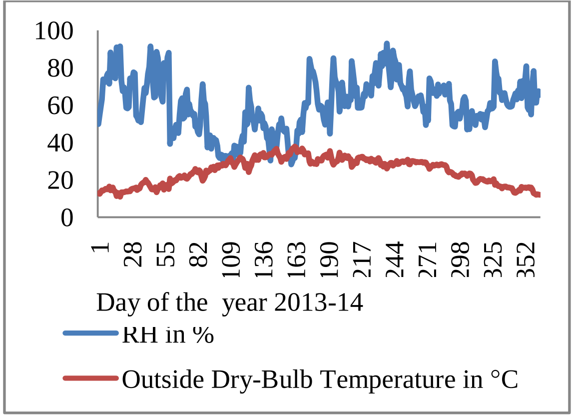

Figure 2 Outside environmental conditions of study area for 2013-14

Data Collection and Field Surveys

Data collection was done by installing 12 no. of data loggers at height 1.1 m from finished floor of the room to record air temperature and relative humidity in different rooms with different orientation on different floors continuously round the entire year in 2013-14. In addition, spot measurements were conducted to find globe temperature, RH and air temperature synchronous with post occupancy evaluation surveys for thermal comfort during various months representatives of different seasons in the year. Data of outdoor temperature and humidity conditions was retrieved from 16 channel data logger mounted on top of building of Centre of energy and environmental studies in the university campus. A total of 204 respondents drawn by using proportional stratified random sampling method were surveyed by using online as well as offline questionnaire based on ASHRAE- 55 adaptive comfort guidelines revealing the background of the occupants, occupancy schedule, clothing pattern, metabolic activity, thermal comfort vote, thermal comfort sensation vote on a seven point scale, occupants adaptive controls etc.

Subjects surveyed were found to be sound, strong and healthy. Respondents consisted of 80% of students of second year of undergraduate programs of the university in the age group of 17-20 years and 20 % of students were of second year of postgraduate programs of the university in the age group of 20-24 years.

Results from post occupancy evaluation surveys synchronous with spot measurements have revealed thermal sensation votes v/s indoor temperature conditions. The value of thermal sensation vote obtained between -1 and +1 implies satisfaction of 80 % of occupants of the building. Any change in operative temperature resulting in values greater than +1 or less than -1 will not be comfortable for occupants. Indoor operative temperature bins which have been voted thermally neutral i.e. Tsv as 0 have been plotted against mean monthly outdoor temperature in Figure 3. Regression of two variables provides the value of thermal neutral temperature based on occupant survey against prevailing mean monthly outdoor temperature and is represented by following equation. (Kumar, 2014)

$T_n = 4.234+0.904\ T_{mmo},\ R^2= 0.975$ ....(1)

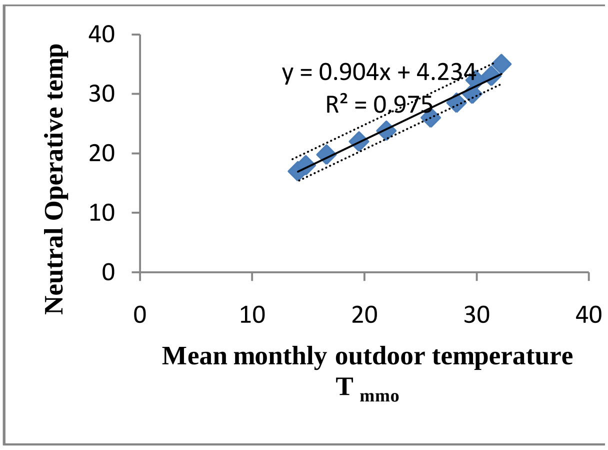

Figure 3 Plot between Outdoor temp conditions and occupant survey based thermal neutral temperature. Dotted lines represent upper and lower limits of comfort band

SIMULATION/ EXPERIMENT

Building modelling

Inputs were obtained from occupant surveys revealing clothing patterns, metabolic activities, occupancy pattern and detailed architectural drawings of the project along with construction details. These were finally used to develop 'As is' case' in the simulation model of the existing hostel building for thermal comfort assessment. Simulation was carried out in Design builder software version 4.10.25 using natural ventilation option as shown in Figure 4 and Figure 5.

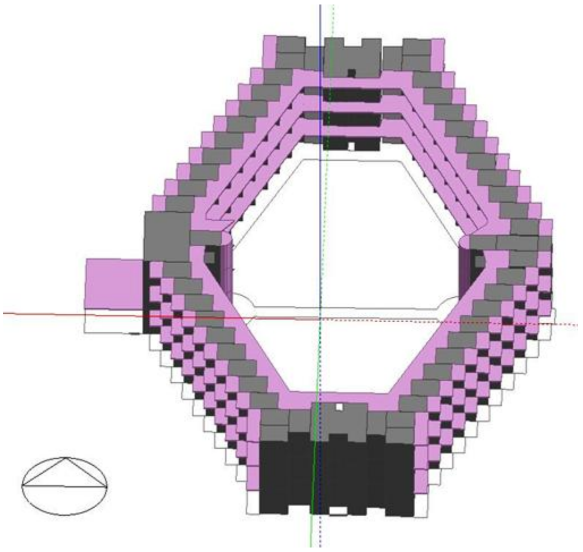

Figure 4 Building model using Designbuilder 4.10.25

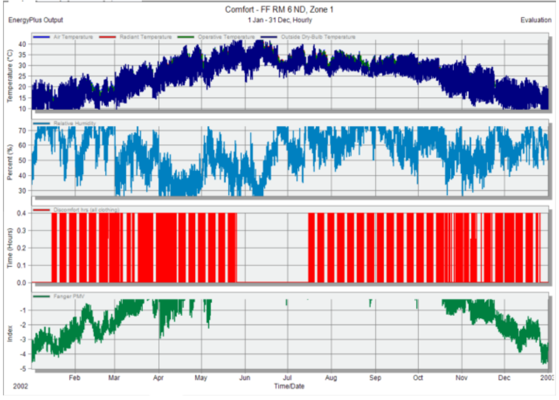

Figure 5 Typical hourly output of First floor zone

Calibration of Model

Calibration of model is very important and critical task so as to bring model for simulation to perform akin to real building performance data. Although IPMVP (International Performance Measurement and Verification Protocol) option D is applicable to conditioned buildings and calibration of the model is done on the basis of energy consumption, the procedure and limits as prescribed by IPMVP can be used as guidelines for reducing the mismatch between the model and actual building performance (Dhaka et al., 2012**).** The IPMVP prescribes a range of percentage Mean Bias error (MBE) and Coefficient of Variation Root Mean Square Error C_V (RMSE), as shown in Table 1(IPMVP, 2007).

Table 1
Range of MBE and C_V(RMSE) in IPMVP and ASHRAE

BASIS CALIBRATION	INDEX	IPMVP (%)	ASHRAE 14-2002(%)

Monthly	MBE monthly (%) C_V (RMSE monthly)	±5 15	±5 15
Hourly	MBE hourly (%) C_V (RMSE hourly)	±10 30	- -

The C_V (RMSE) is a normalized measure of variability between two sets of data. For calibrating simulation purposes, it is obtained by squaring the difference between paired data points, summing the squared differences over each interval through the period, and then dividing by the number of points, which yields the mean squared error. The square root of this quantity yields the root mean squared error (RMSE). The C_V (RMSE)) is obtained by dividing the RMSE by the mean of the measured data for the period.

In this study procedures and guidelines of IPMVP have been followed as criteria for calibrating the model with respect to thermal comfort or operative temperature. Statistical indices such as MBE and C_VRMSE have been taken as basis as per limits shown in Table 1 for calibrating the simulated model as close to the actual model by comparing actual measured temperature with simulation temperature. MBE (%) and C_V RMSE of actual measured temperature on an hourly basis for occupied periods in all months from May 2013 to April 2014 for different thermal zones have been checked so as to have a very fine tuned model.

First run of the simulation model of hostel building block produced the mean bias error (MBE) 13.20% and coefficient of variation root mean square error (C_VRMSE) of the order of 17.89 on an hourly basis. . The percentage MBE and C_VRMSE error specified in IPMVP on hourly basis is ± 10% and 30 %.Several iterations of simulations of the building model were run till the temperature of simulated model came closer to actual temperatures observed on hourly basis for different zones Firstly, Ground temperatures were modified instead of default temperature specified in software in Designbuilder model, then option of Calculated ventilation mode was activated instead of earlier model of Scheduled ventilation, after that surface absorption coefficient was changed for roof and wall in steps of 0.1 , resulting in very fine tuned model of MBE (Max value 9.56%)and very low value of coefficient of variation root mean square error (C_VRMSE) of the order of 19.15%(Max. value in the year) on an hourly basis, indicating better calibration value. The average MBE of all zones measured was 4.59% and the CVRMSE of all thermal zones was computed as 11.53%, thus producing model acceptable to real time conditions(Table 2). Cronbach's alpha coefficient for two sets of temperatures was found to be 0.808, indicating good reliability of calibrated model. Figure 6 illustrates superposition of simulated operative temperature v/s actual operative temperature retrieved from data loggers and spot measurements.

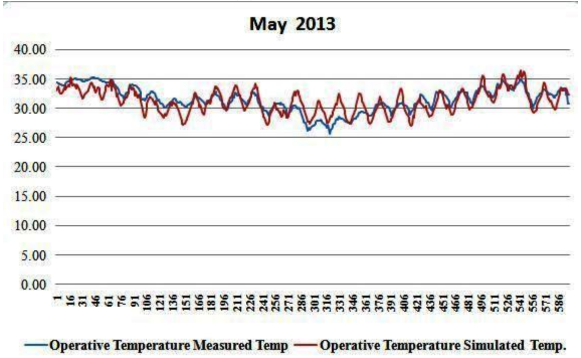

Figure 6 Calibration of operative temperature (^{0}C) in First Floor rooms on hourly basis. Any further attempt to calibrate the model resulted in deviations particularly in winter months.

Table 2
Result of calibration hourly basis for operative temperature

	Permissible Range of IPVMV	Prior to calibration	Calibrated model
MBE%	±10%	13.20%	4.59%
C_V (RMSE)	30	17.89	11.53

Optimizing thermal comfort using ECMs

As the building is naturally ventilated and equipped with ceiling fans, as it is using miniscule energy in the form of lighting fans and plug loads in the evening and night time in weekdays and as well as daytime on holidays. Buildings are not occupied in peak summer i.e. from 25th May to 15th July due to summer vacation break and from 25th December to 15th January due to winter break every year. There is not much one can save on electrical energy except by replacing tube lights by LED's and regulators for fans. There is a need to restore thermal comfort of occupants (students) as it affects their physical well-being and academic productivity. Thus, thermal comfort becomes the most important criteria for rating natural ventilated buildings for green building certification.

Effects of various retrofitting measure were studied by applying various energy conserving measures (ECMs) as prescribed in Energy Conservation Building Code 2007. List of various measures applied is tabulated in Table 3.

Table 3
Various ECMs for retrofitting based on ECBC

SN	ECM	DETAIL
1	Simulated	As is
2	ECM W	ECBC Wall U value 0.44

3	*ECM R*	*ECBC Roof U value 0.26*
4	*ECM GU*	*ECBCglass U value 3.3;*
5	*ECM GS*	*ECBC glass SHGC value 0.25;*
6	*ECM CR*	*Cool roof*
7	ECM W+R	ECBC Wall U value 0.44 + *Roof U value 0.26*
8	ECM W+R+GU+GS	ECBC Wall U value 0.44 + *Roof U value 0.26*
9	ECM CR +W+R+GU+GS	ECBC Wall U value 0.44 + *Roof U value 0.26*
10	*ECM 9+ SCH Ventilation*	*ECM 9+ Scheduled Ventilation*
11	*ECM 10+ Permanent vents*	*ECM 10+ Permanent Vent 0.46 x 0.46 m for Naturally ventilation MV: Mechanical ventilation by exhaust fan*
12	*ECM CLO*	*ECM 11+ Clothing as per occupant survey*
13	*ECM 11+4ACH*	*ECM 11 +4 Air change per hour*
14	ECM 11+ 6 MV+6NV	ECM 11+ 6 *Air change per hour* for Mechanical Ventilation +6 *Air change per hour* due to Natural Ventilation
15	ECM 11+ 8 MV+8NV	ECM 11+ 8 *Air change per hour* for Mechanical Ventilation +8 *Air change per hour* due to Natural Ventilation

Calibrated model was simulated on an hourly basis for all occupied hours i.e. 5328 hours in the year for each of the energy conserving measures.

DISCUSSION AND RESULT ANALYSIS

Hourly data of operative temperature of various thermal zones was obtained from simulation runs by applying various retrofitting measured as listed in Table 3. To calculate discomfort hours or hours, not meeting criteria of thermal comfort, filters were applied to hourly operative temperature outputs obtained by simulation models of various ECMs run on an hourly basis for all occupied hours in excel files on the basis of three parameters

a) Thermal comfort temperature range obtained by adaptive thermal comfort equation for 80 % of occupants' acceptability T_n=17.8 + 0.31T_{mmo}, by taking $T_{c} = T_n \pm 3.5^0C$

b) Enhanced thermal comfort range due to elevated air speed by increasing thermal comfort, upper limit $T_{c'}=T_c + 2.2^0C$ (applicable only when the operative temperature is more than 25^{0}C).

c) Thermal comfort temperature range obtained by Thermal comfort equation based on occupant surveys i.e. Eq 1; $T_n = 4.234 + 0.904 T_{mmo}$. (The temperature ranges have been obtained by considering thermal sensation votes from -1 to +1 as comfortable for 80% of occupants at those temperatures).

It was finally possible to make existing building thermally comfortable in composite climate by integrating new thermal comfort equation based on occupant surveys and the effect of various (ECMs) without resorting to air conditioning as shown in Figure 7 ; thus leading to low energy and comfortable residential facilities in composite climate.

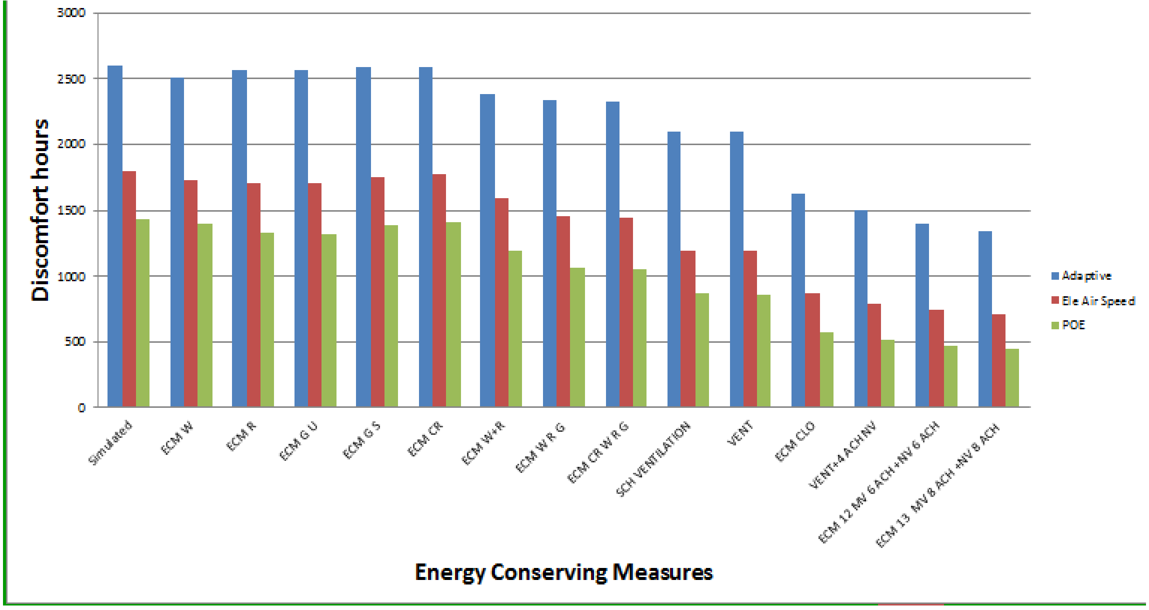

Figure 7 The Comparative Analysis of different strategies on thermal comfort using the Adaptive ASHRAE Model, Elevated Air Speed, Occupant survey based thermal comfort model. ECM W: ECBC wall; ECM R: ECBCroof; ECM GU : ECBC glass U value, ECM GS: ECBC glass SHGC value; ECM CR: Cool roof; SCH Ventilation: Scheduled Ventilation; Vent : Permanent vents; ECM CLO:

Clothing as per survey; ACH: Air change per hour; NV :Natural ventilation; MV: Mechanical ventilation by exhaust fan.

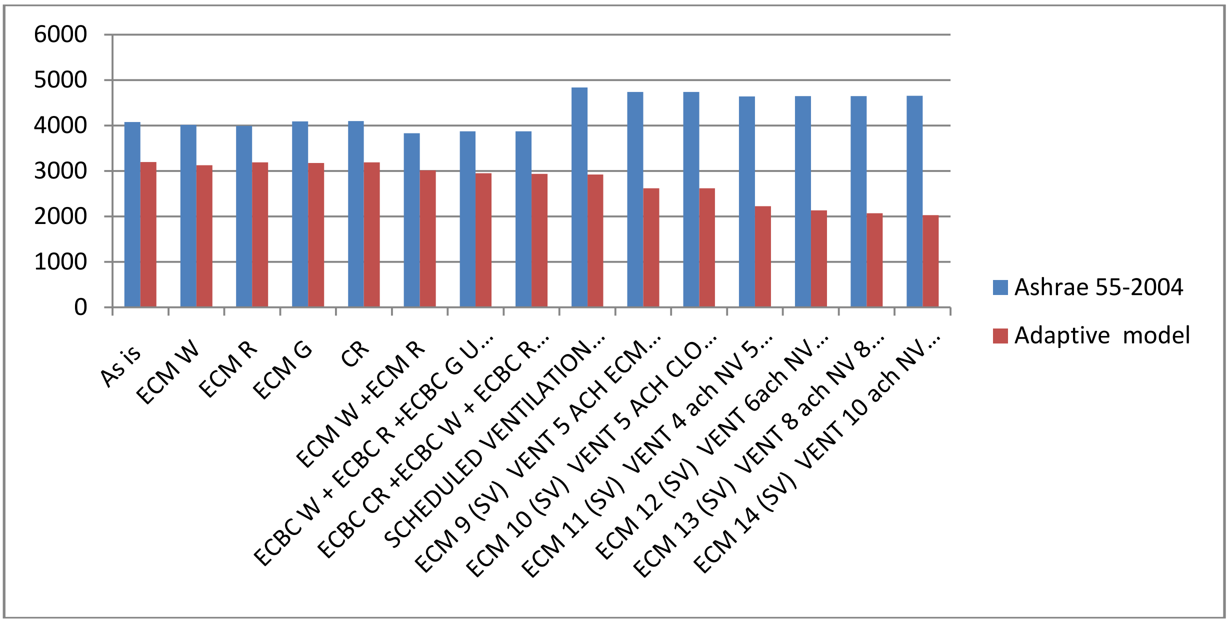

Figure 8 Comparison of Discomfort hours using Adaptive model ASHRAE 55 –(80% acceptability limits) and ASHRAE (fixed set conditions Summer or winter clothes) as given by Design builder results output.

It may be noted as seen in Figure 8 that outputs from designbuilder software will generate two types of summary, one based on fixed set conditions in ASHRAE based on summer or winter clothes and the other on basis of Adaptive comfort theory ASHRAE 55- (80% acceptability limits). No of discomfort, hours are far less in adaptive comfort model, taking advantage of adaptive opportunities. However, one is able to reduce to 2029 discomfort hours (38.08% of total occupied hours) after applying all ECMs from 3194 discomfort hours (59.94% of total occupied hours).

Still the Target of 90 % hours to be comfortable for 80 % of the occupants is far from achievable as there is a gap of 28.08% hours to be bridged. As seen in Figure 7, discomfort hours have been brought down to nearly 5 % using the same strategies, but by applying a filter of discomfort hours from the values of temp ranges obtained by Adaptive model of the thermal comfort equation given by Richard de Dear and CBE thermal comfort tool (Hoyt T. et al. 2013), applying the effects of elevated air speed and finally from thermal comfort equation developed by regression of field survey of occupants.

It can be clearly seen from that clothing and ventilation by providing vents are more effective ways to bring comfort or reduce discomfort hours. Thus a permanent vent of size 0.46 x 0.46 with an exhaust fan can be very effective to restore thermal comfort in summers, particularly in the evening hours when outside conditions are generally more pleasant than indoor conditions. Exhaust fan can create suction in the room to induce fresh and cool outdoor breeze inside the rooms in the evening hours when hostel rooms are actually occupied.

CONCLUSION

Adaptive comfort model can be coupled with simulation outputs to understand the impact of various energy conserving measures for selecting appropriate retrofitting measures for thermal comfort. Energy is primarily used in buildings for thermal comfort and visual comfort. The above study has demonstrated that a naturally ventilated project in the composite climate is nearly impossible to be proven thermally comfortable unless effect of an adaptive approach to thermal comfort is taken in consideration. In addition to this, field data from the occupants’ survey can be instrumental to develop thermal comfort band for a different typology of buildings in different climatic contexts and cultural contexts for existing buildings to be retrofitted and as well as feedback or input for new buildings (Kumar, 2014). Thus, there is a need to undertake more and more studies of thermal comfort assessment of various types of buildings in different climatic and cultural contexts, and particularly residential buildings where there is a wide range of adaptive opportunities and flexibility is available to occupants. Similar studies by other researchers suggest (Indraganti M, 2010) that people can be comfortable at much higher temperature in residential buildings due to adaptive opportunities and long-term acclimatization. One cannot apply ASHRAE standards at its face value to all types of buildings in India for predicting thermal comfort and energy performance index (EPI) of buildings. There is a need to intelligently interweave results from simulation models and occupant surveys, particularly in the context of naturally ventilated buildings to promote low energy and yet comfortable buildings rather than seeking energy intensive air conditioning for restoring thermal comfort.

NOMENCLATURE

ASHRAE	American Society of Heating Refrigerating and Air-conditioning Engineers
C_V (RMSE)	Coefficient of Variation Root Mean Square Error
DBT	Outdoor dry bulb temperature
ECBC	Energy Conservation Building Code
EPI	Energy performance index
GRIHA	Green Rating for Integrated Habitat Assessment
IPMVP	International Performance Measurement and Verification Protocol
MBE	Mean Bias error (MBE)
NBC	National Building Code
NV	Naturally ventilated
PMV	Predicted mean vote
PPD	Predicted percentage dissatisfied
R^2	Coefficient of regression
RH	Relative humidity (percentage)
SHGC	Solar heat gain coefficient
T_{oper}	Operative temperature (^{0}C)
T_a	Indoor air temp (^{0}C),
T_c	Indoor comfort temperature (^{0}C)
T_n	Thermal neutrality temperature
Tout, Tmmo	Mean monthly outdoor dry bulb temperature (^{0}C)
T_{sv}	Thermal sensation vote
U	Thermal conductance (Watt/ m^2/K)

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REFERENCES

Architecture 2030. 2014. *Roadmap To Zero Emissions,* The Built Environment in a Global Transformation to Zero Emission , New Mexico ,USA, Available at *http://architecture2030.org/files/roadmap_web.pdf* <accessed on 6.2.2015)

Dear, R. De. Brager, G.S. 2002. Adaptive Comfort - Climate, Comfort, & Natural Ventilation: A new adaptive comfort standard for ASHRAE Standard 55,Center for Environmental Design Research, Centre for the Built Environment ,University of California, Berkeley, USA

Dear,R.De. 2014. Thermal counterpoint in phenomonology of architecture- A Phsycophysiological explanation of Heschong's Thermal Delight Sustainable Habitat for developing Societies, 30th International PLEA Conference, Ahmedabad, India, Pg 6

Dhaka, S. Mathur, J. Garg, V. 2012. Combined effect of energy efficiency measures and thermal adaptation on air-conditioned building in warm climatic conditions of India. Energy and Buildings. 55 (2012).351–360.

Hoyt Tyler, Schiavon Stefano, Piccioli Alberto, Moon Dustin, and Steinfeld Kyle, 2013, CBE Thermal Comfort Tool. Center for the Built Environment, University of California, Berkeley, USA. Available at http://cbe.berkeley.edu/comforttool/ (accessed 10.3.2014)

Indraganti, M. 2010. Adaptive use of natural ventilation for thermal comfort in Indian apartments, Building and Environment 45; 2010.

IPCC Fourth Assessment Report. 2013. *Residential and commercial buildings, Climate Change 2007.* Cambridge University Press. Available at www.ipcc.ch/.../publications_ipcc_fourth_assessment_report_wg3_repor..., <accessed on 28.4.14

IPMVP.2007. "*Concept and Options for Determining Energy and Water Savings.*" Efficiency Valuation organization-IPMVP . 2007. Available at www.ipmvp.org (accessed 12.10.14)

Kumar, P.2014. Evaluation of thermal comfort of Naturally Ventilated University Students' Accommodation on basis of Adaptive Thermal Comfort Model and Occupant Survey in Composite Climate, International Journal of Architecture, Engineering and Construction, Vol. 3 no: 4, 2014 (pp 298-316).

Paula.2014.Sustainable Habitat for developing Societies, 30th International PLEA Conference, Ahmedabad, India, Pg 1-2