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Implication of building energy modeling (BEM) and adaptive model to assess the efficiency of multi storied apartments in composite climate of north India

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Abstract

The paper is focused on identifying factors affecting the energy consumption & comfort conditions of multi-storied apartments in composite climate of north India. The findings reveal that the residents are very well adapted to their thermal environment and are comfortable at a broader temperature range (22.5–30.6 ˚C). The TSV-PMV difference was observed to be fairly significant for the winter and summer period, i.e. 5°C and 1.1°C respectively whereas marginally differed for the annual data i.e. 0.6° C. The energy-use evaluation through simulations has identified solar gain through ext. windows to be the most important contributor to the internal gains. The heat conduction through walls & glazing has also shown the highest values for heat gains. Building design, especially, the orientation and WWR is observed to be significantly affecting the thermal behaviour of the building envelope, and are suggested to be the prime focus while designing naturally ventilated buildings in this climatic zone.

Keywords: thermal comfort, adaptive model, simulation, apartments, naturally ventilated

1. Introduction

India shows the lowest figures in energy consumption and carbon emissions as compared to many developed countries but these figures are projected to rise by almost seven times of the present level, by the year 2030 (WBCSD,2008). At present India ranks fifth in primary energy consumption (India Energy Portal); approximately 75% of which is expended on Indian households (Pachauri and Spreng, 2002). One important aspect of energy utilization is the thermal behavior of the building envelope (Zain et al., 2007), which directly influences the indoor comfort levels. It is envisaged that with the growing disposable incomes, the energy demand for better indoor thermal environment (through space heating /cooling) will continue to rise in the foreseeable future. Reports show that energy expended on cooling load in residential buildings accounts for up to 45% of the total electricity consumption in India (BEE, 2007). Thus, it becomes important to frame standards to control the energy consumption, especially, when the construction spending of residential sector is expected to grow at a rate of 10% by the year 2018 (Asia Construction Outlook, 2013).

India is a country with highly variable climate at macro-scale (from region to region) and at micro scale (within a region). And, the existing energy codes (i.e. the ECBC standards) follow a prescriptive component based approach where energy efficiency guidelines are quite ambiguous and nonspecific for each of the climatic zone. Also, the operational thermal comfort standards are based on static ASHRAE standards (BIS, 2005], which does not consider the adaptive behavior and its effect on thermal perception of the subjects. Field studies in tropical climate (Humphrey, 1978; Sharma & Ali, 1985; Nicol, 1999; Mallick, 1996; Heidari, 2002; Indraganti, 2010 etc.) have shown a broader comfort range and high comfort temperature using adaptive model, as opposed to what is suggested by the current standards.

In quantifiable terms, thermal comfort is related to environmental and personal variables which are, in turn, dependent on the building parameters (both physical and thermal). The prime contextual variable in adaptive model and energy efficiency is temperature. It strongly controls the thermal attitudes of the people and the way building is designed. But the case in unconditioned residential buildings is much more complicated and dynamic as compared to other building typologies. Indoor environment varies within a small time scale (Peeters et al., 2009) and depends upon the constantly changing outdoor physical variables, internal heat gains and the ventilation rates. Many thermal comfort researches have been stimulated with the current drive to achieve energy efficiency (Jaggs, 2000; Kolokotsa et al.,2009; Griego et al., 2012). But, the literature on field studies of thermal comfort and energy efficiency (especially residential buildings) in India is still not very profound. Only handful of studies are available on the thermal comfort (Indraganti, 2010; Rajasekar et al.,2010; Pellegrino et al., Sharma and Ali, 1986; Singh et al., 20112012) and energy efficiency (Bhatia et al.,2011; Dhaka et al., 2012; Singh et al., 2012) in India. With this growing awareness for a need to reduce the building energy-use and to improve the indoor thermal environment, it becomes increasingly important to seek ways to assess the indoor thermal environment.

The aim of this study is to identify the predictors for energy load and thermal comfort in naturally ventilated multi storied apartments in composite climate of north India. The adaptive approach is employed to analyze the thermal perception of the subjects whereas the thermal behavior of the buildings and its impact on the energy load is evaluated by running simulations using Design Builder’s software.

1. Study Area

The study was conducted in five naturally ventilated multi-storied (6-9 storeys) apartments in Roorkee and Chandigarh. The studied area falls under the composite climatic zone and experiences four distinct seasons i.e. winter, summer, monsoon and post monsoon. Roorkee lies in 29° 51’N latitude, 77° 53' E longitude at an altitude of 274m, with temperatures ranging from above 40°C in summer to below 5°C in winters (GAIA). Chandigarh is situated at about 30.44°N & 76.47°E with an elevation of 321 meters (1053 ft). Maximum temperatures can rise up to 44°C in summers and drops to 3.68°C in winters (National Information Centre, Chandigarh). Two buildings, i.e., HV & CV are located in Roorkee whereas three buildings are located in Chandigarh (GMR, BMD & TR). The studied areas and the chosen buildings aptly represent the status quo of real estate development in the north Indian cities.

Outdoor Environmental Conditions

Summer (mid March to mid June): Maximum temperature observed was 41.3°C & 41.5°C for Chandigarh and Roorkee respectively. Diurnal range was highest in summer as compared to other seasons with standard deviation of 5.8 for Chandigarh and Roorkee (Table 1). Mean temperature was 30.01°C in Chandigarh and 27.31°C in Roorkee. Relative Humidity (RH) varied moderately with the mean of 61% (SD= 3.2) in Chandigarh and 64.9% (SD=2.69) in Roorkee.

Winter (November to February): Mean outdoor temperature in Chandigarh was 15.1°C, with a minimum and maximum of 5°C and 25.1°C (& standard deviation, SD= 2.1). For Roorkee the figures didn't vary much with the mean of 16.2°C and SD of 1.6 (min.= 7.5°C and max.=26°C). RH varied moderately with the mean of 42.8% (SD= 3.9) in Chandigarh and 40% (SD=3.4) in Roorkee.

Monsoon & Retreating Monsoon (mid June to mid October): In monsoon RH reached to a maximum value of 100% (98% in Chandigarh and 100% in Roorkee). Mean temperature observed was 28.3°C and 28.7°C in Chandigarh and Roorkee respectively. Moderately high temperature (reaching max. up to 36°C, details in Table 1) paired with high humidity made the environmental conditions quite stuffy in this season.

Table1 Annual Temperature and Relative Humidity

	Chandigarh				Roorkee			
	Mean	**Min**	**Max**	**StDev**	**Mean**	**Min**	**Max**	**StDev**
Tout	24.1	7.5	41.5	6.7	24.5	5.0	41.3	7.8
RH(%)	58.7	29.0	98.0	14.7	58.4	30.0	100.0	13.3

Tout- Mean Monthly outdoor temperature ; RH- Relative Humidity

2.1 Survey

A Class II level longitudinal survey was conducted to analyze the thermal responses of the subjects, and to establish the temperature which people find comfortable. In total 54 apartment units are visited and 82 subjects were interviewed on the monthly basis for the year of 2012. About 29 males (~35%) and 53 females (~ 65%) participated in the survey. The age group varied from 8-80 years having 11 young subjects (13%), 54 middle age subjects (65%) and 18 old age subjects (22%). This study collated a dataset of 984 in total. The male and female average age of subjects is 39.2 years and 39.8 years, respectively. All the subjects were living in the surveyed flats for over a period of year or more and were assumed to be naturally acclimatised to the climate.

The clothing patterns of people in India vary dramatically, mainly owing to the cultural diversities from region to region. In north India, females mostly wear 'salwar-kameez', whereas, men prefers shirt/T-shirt with trousers/shorts/pyjamas in summers. In winter period, insulation layers of sweater/jacket/shawl, caps, muffler & other woollen wears' are most commonly used. Figure 1a &b shows the typical winter and summer clothing of males and females in north India. New generation is mostly influenced by the western outfits, and thus the clothing patterns are progressively changing. The participant's metabolic rate (met) and clothing insulation (clo) were estimated using numerical met/clo values in accordance with the ASHRAE Standard 55. As the 'clo' value for salwar-kameez was not available it was estimated using: Icl = 0.00103W-0.0253 where, Icl = clothing insulation and W= weight of the garment in grams (g) (Indraganti, 2010). It is important to note that for Indian ensembles (mostly women clothing i.e. *sari* and *salwar-kameez),* the 'clo' values need to be scientifically validated and, therefore, the intrinsic errors involved with the estimated clo values needs to be explored for the same. The insulation of salwar-kameez was found to be

0.28 (cotton) and 0.47 (woollen). During the survey, the annual clo level ranged between 0.3 to 2.2 clo. Met level also ranged between 0.7 Met (sleeping/resting) to 2.0 Met (standing working) in this survey.

ASHRAE's seven point scale of thermal sensation, ASHRAE's nominal scale of acceptance & Nicol's five point scale of preference were used in this study (Raja et al., 2001). The questionnaire is based on Madhavi (Indraganti, 2010) and designed in English, as phrases with check boxes for response, refer (APPENDIX). Physical environmental variables, i.e., air temperature (Ta), relative humidity (RH), air velocity (Av) and globe temperature (Tg) are measured for all the occasions during the survey. MH 3350- Thermo Hygrometer is used to measure Ta (using TFS0100) & indoor globe temperatures using TYP101; whose probe was inserted in a black-painted table tennis ball (about 40mm diameter). Handheld Digital Vane Thermo Anemometer (Type 93460) is used to measure air movement. Fig2a shows the instruments used for the survey. In summer and monsoon period, fans are the main source for convective cooling, though; windows and doors are also effectively used. Therefore, the effect of air movement (fans or evaporative coolers in most of the cases) is measured with respect to the position of the subjects while conducting the interview. Vane anemometer is held perpendicular to the direct source of air movement to evaluate its effect on the thermal sensation of the subjects.

All the measurements were made close to the respondent and at 1.1m level, refer Fig2b. Local meteorological stations (IMD, Chandigarh) and observatories (National Hydrology Centre, Roorkee) were approached for the outdoor environmental data. In order to investigate the individual changes, only those subjects are included who participated for all the twelve months. In addition to the thermal responses and physical variables; the questionnaire focused on collecting data on hourly consumption of heating /cooling appliances, occupancy details etc. for creating the baseline models for the energy simulations.

Figure1a. Winter clothing

Figure1b. Summer clothing

Figure 2a. Temperature Probes and Anemometer

Figure 2b. Instrument setup at 1.1m level

2.2 Simulation Arrangement: Baseline Model and Validation

Design Builder's (DB) v.3.0.0.105 is employed to evaluate the energy performance and thermal behaviour of the surveyed buildings. The consumption of energy in a building is related to the physical variables, occupancy schedules and operation schedules of various appliances (Haberl et al., 1996). In order to create a representative simulated environment for the surveyed buildings, a wide range of information was collected; including architectural drawings (with site details, construction details), monthly utility bills, hourly consumption of the appliances, occupancy details, tenancy details etc. Measured data and real building information is used to assign simulation input values for walls, roof, windows etc. The operation schedules for lighting, heating &cooling system, occupancy etc. are framed on the basis of responses received during the questionnaire survey.

2.2.1 Building Characteristics:

All the buildings were RCC structures with the infill of brick masonry (230mm) and cement plastering on both the sides of the wall. Roofs are typically reinforced concrete slabs with a layer of bitumen felt/ MW Glass wool with a thermal resistance of R=0.4-.48 (m^2 K)/W. Floors are typically concrete slabs with tile finish or stone chipping/marble finish/Kota stone finish. The windows are all clear, single pane glazing with an aluminum/wooden frame. Table 2 gives the detail of thermal properties of the structural elements of the surveyed buildings.

2.2.2 Model Validation:

The use of measured data and real building information avoids the chances of error. There are few limitations, though, to create a simulated environment that best represents the real one. The energy models are typically very complex and are time consuming & analyst-specific (Eisenhower et al., 2013; Reddy, 2006). It, therefore, becomes necessary to validate the baseline model using certain criteria.The 'Percentage error' is used to validate the baseline model for monthly as well as annual data using Equation (1):

% Error = (y simulated-y measured)/y measured x 100 (1)

Although, it is preferred to have hourly data for calibrating the baseline model but the system preferred in India for metering the consumption units is either monthly or bimonthly. So, monthly utility bills of all the buildings are collected from the concerned authorities (local government electricity board) for a maximum of two consecutive years. The billing data includes the monthly kWh consumptions of all the dwelling units (DU). The percentage error between the simulated energy consumption and measured data is within the acceptable tolerances of ±15% for annual data and ±25% for monthly data (Reeves et al., 2012) .

Table 2. Detailed summary of thermal properties of surveyed buildings

Parameters	GMR	TR	BMD	HV	CV
Glazing Type	#U.F=7.1 #SHGC=0.8 #VLT=.76	U.F=7.1 SHGC=0.82 VLT=.76	U.F=7.1 SHGC=0.8 VLT=.76	U.F=7.1 SHGC=0.8 VLT=.76	U.F=7.1 SHGC=0.8 VLT=.76

Wall Materials (External)	U.F= 1.9 , [#]R.V = 0.5	U.F= 1.9, [#]R.V = 0.5	U.F= 1.9, [#]R.V = 0.5	U.F= 1.9 [#]R.V = 0.5	U.F= 1.9 [#]R.V = 0.5
Internal Partition	U.F = 2.3 R.V = 0.43	U.F = 2.3 R.V = 0.43	U.F = 2.3 R.V = 0.43	U.F = 2.3 R.V = 0.43	U.F = 2.3 R.V = 0.43
Roof	U.F= 2.4, R.V = 0.42	U.F= 2.4, R.V = 0.42	U.F= 2.4, R.V = 0.42	U.F = 2.1 R.V = .48	U.F = 2.1 R.V = .48
	# U.F(U-factor)=Thermal conductance,[W/m2C] , R.V(R-value)=Thermal resistance [m2.C/W], SHGC=Solar Heat Gain Coefficient Through Glass				

2. Result and Discussion

3.1 Thermal Comfort Analysis

3.1.1 Neutral Temperature

The thermal responses of the subjects are linearly regressed with the globe temperature (Tg) to develop an adaptive model of thermal comfort. A comfort temperature of 26.6 °C is obtained with a significant regression coefficient of 0.77. The broad comfort band of 22.5–30.6 °C, as compared to what is suggested by the current thermal comfort standards in India (i.e. 23-26°C in summer and 21-23°C in winter), suggests that residents are well adapted to their thermal environment as oppose to narrow comfort range as recommended by the National Building Code (NBC). The regression equation obtained for the current study is:

TSV=.209Tg-5.556

The gradient of the slope indicated that occupants will experience a 1 unit change in their thermal state for every 5.0 °C change in Tg. The outdoor temperature, as assumed, has also shown a significant regression coefficient of 0.8 with TSV. The seasonal evaluation of the thermal responses have indicated that subjects are least sensitive to changes in globe temperatures in winters (with a lower regression slope of 0.148/°C) as compared to other seasons. The observed differences might be explained by the seasonal variability in the usage pattern of controls as a response to changes in the temperature. Also, the thermal acceptability of the subjects is observed to be high even when the comfort votes were low or while voting discomfort (i.e. ‘hot’ or ‘warm’ in summer & monsoon and ‘cool’ or ‘cold’ in winters).

The adaptive behaviour of the occupants is an important consideration while assessing the thermal comfort temperatures of naturally ventilated residential buildings. The superfluous comfort temperatures (-1.5°C, 8.2°C, -11°C etc.) can, thus, be aptly ascribed to the variable use of adaptive controls, as mentioned in the studies previously (Indraganti, 2010; Nicol et al., 1999; Rijal et al., 2010). Griffith’s method, as suggested by Nicol (Rijal et al., 2010) is used to modify these unreliable comfort temperatures for each subject using mean comfort vote and mean temperatures. Table 3 gives the detailed summary of estimated Griffith’s neutral temperature of all the surveyed buildings. Four Griffith’s constants, as obtained by Indraganti (0.31), Nicol et.al. (0.25 &0.33) and finally the one obtained in this study (0.21), are used for the analysis.

Table 3. Griffith's Comfort Temperature

Building	Regression		Mean		Griffith's			
	Tn	r	Tgm	TSm	TnG1	TnG2	TnG3	TnG4
					0.31	**0.25**	**0.33**	**0.21**
HV	24.5	0.9	26.1	0.1	25.8	25.8	25.8	25.7
CV	27.3	0.9	26.7	0.0	26.7	26.7	26.7	26.7
BMD	25.1	0.9	26.6	0.0	26.5	26.5	26.5	26.4
TR	28.3	0.9	26.4	-0.1	26.6	26.6	26.6	26.7
GMR	25.9	0.9	26.7	0.0	26.7	26.7	26.7	26.6

3.1.2 *Comparison of PMV and TSV*

Fanger's predicted mean vote (PMV) is estimated using CBE's comfort calculator (CBT, Thermal Comfort Tool) to compare the results with the subjective thermal responses (TSV). In most of the observed events, PMV was always higher for the warmer period and lower for the cooler period than the actual sensation. Conceivably, the regression of Tg with PMV, for the annual data, yielded a lower comfort temperature (25.9°C) but with a marginal difference of 0.6°C only, refer Table4. However, seasonal evaluation of the TSV-PMV difference was fairly significant for the winter and summer period, i.e. 5°C and 1.1°C respectively, refer Table4. The reliability of the difference can be argued with the inherent errors involved in clo and met estimations, as mentioned in studies before (. It should be noted that, owing to the exposure to extreme temperatures, the adaptive behavior and the thermal expectations of the subjects has adjusted to the wider range of temperature. This has subsequently affected the distribution of the comfort votes when accounting the annual data.

To analyze the strength of the relationship between TSV and PMV, a scatter diagram is plotted between the two, refer Fig 3. It is observed that when the TSV is equal to 0 (or neutral), the predicted thermal sensation is +.13 & + .26 for summer and monsoon and -1.3 for winters, refer Table5. The results, thus, support the argument that the traditional PMV model overestimates the thermal sensation, similar to the findings of previous studies (Indraganti, 2010; Rajasekar et al., 2010; Beizaee et al., 2011; Kotbi et al., 2012). It should be noted that the higher discrepancy is observed in the winter period and this can be attributed to the lower thermal sensitivity (as mentioned in the previous section). Humphreys (Heidari, 2002) has mentioned that the lower values of the slope from field studies suggests the adaptive control of the thermal environment by the occupants. In the winter period, closed doors (60%) and windows (90%) along with the heater usage (approx. six hours) minimised the adverse effect of outdoor environmental conditions. Also, the estimated clo variability is observed to be higher when subjects voted on the cooler side of TSV scale, similar to the observations drawn by Schiavon and Lee (Schiavon, 2013). It, is thus deduced from the above findings that the adaptive behaviour of the subjects significantly affects their thermal perception in naturally ventilated buildings.

Table 4. TSV-PMV Seasonal Evaluation

				0.21	Griffith's Tn
	Tom	**Tgm**	**Tn**		**PMV residual (°C)**
			Observed	Predicted	
Winter	15.6	18.6	26.3	31.5	5.2
Summer	28.8	30.1	25.4	26.5	1.1
Monsoon	28.6	30.8	27.7	28.7	0.9
ALL	24.3	26.5	26.6	25.9	-0.6

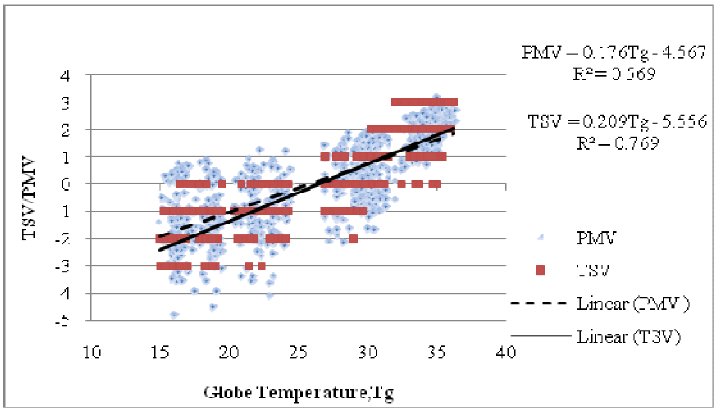

Figure 3. Variation of TSV and PMV with Tg

Table 5. PMV Residual for all seasons

	PMV: TSV	**TSV**	**PMV residual**
Winter	PMV=-0.098TSV-1.3	0	-1.3
Summer	PMV=.782TSV+.129	0	+.129
Monsoon	PMV=.507TSV+.263	0	+.263

3.1.3 Thermal sensation as a function of measured variables

The adaptive use of the controls is a key variable in the thermal evaluation of the subjects. The choices made by the subjects in response to the thermal discomfort are directly or indirectly influenced by the physical and personal variables (Nicol and Humphreys, 2002; Baker and Standeven, 1996). Thermal sensation of the subjects is, therefore, evaluated as a function of the measured variables (i.e. Tg, Av, RH, met, clo) to identify the significant predictors. Table 6 gives the summary of correlations of the measured variables with TSV.

Globe temperature (Tg), air movement (Av) and clothing (clo) have significantly correlated with TSV (refer Table 6). Air velocity is observed to be linearly increasing when subjects have voted on the warmer side of TSV scale (refer Fig 7). This suggests that subjects are controlling the air flow using mechanical ventilation (fans, evaporative coolers etc.) or natural ventilation (door, windows etc.) to combat the thermal discomfort. The socio-cultural constraint has considerably affected the adaptive use of clothing. Clo level is also observed to be decreasing with increase in warmer sensation, till it reaches a minimal acceptable limit. The variability in 'clo' level increased as subjects voted for discomfort on a TSV scale (i.e. -3,-2, 2&3). As shown in Fig.8, less variation is observed in 'clo' level when subjects voted on the warm side of the TSV scale (i.e. from 1 to 3) as compared to when subjects voted on the cooler side of TSV scale. Relative humidity has shown a moderate correlation, but the results are assumed to be generic in nature and needs to be explored in monsoon period on hourly basis. Met level has not shown any significant relation with any of the physical variable or with the comfort votes. Based on the above findings temperature, air velocity and clo are identified as the predictors for thermal evaluation in naturally ventilated buildings.

Table 6. Correlation of Measured variables with TSV

	TS: Tg	TS: clo	TS: Av	TS:RH	TS: met
Winter	0.4	**-0.5**	-0.1	-0.2	-0.1
Summer	**0.8**	**-0.6**	**0.7**	0.1	0.1
Monsoon	**0.8**	-0.2	**0.5**	0.2	0.0

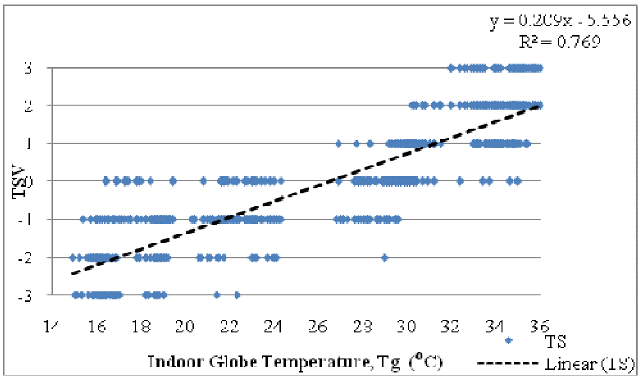

Figure 6. Tg vs TSV

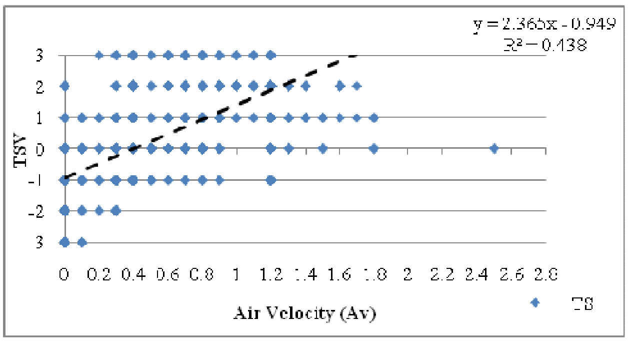

Figure 7. Air velocity vs TSV

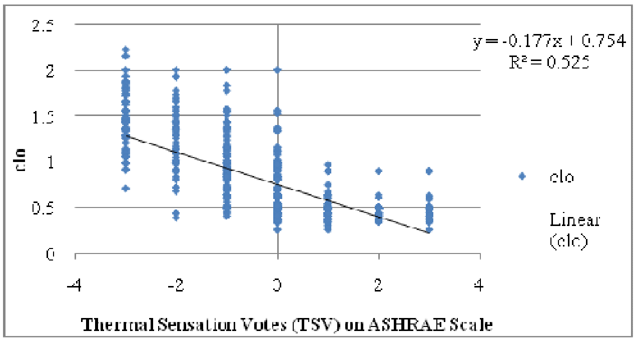

Figure 8. Clo vs TSV

3.2 Energy-use analysis

3.2.1 Thermal behavior of Building Envelope

Major amount of energy in buildings is consumed to either flush out the extra heat or to restore heat. Thus, it is vital to control the rate of heat flow through the building envelope to maintain the zone temperature within the comfort limits. In composite climate, cooling load is maximum and the major amount of energy in naturally ventilated building is used to regulate the convective cooling (using fans, doors, windows etc.) or to cool down the indoors (using A/c). The simulation results have indicated that the source of heat gain/ loss can help in identifying the design parameters that needs to be focused to optimize energy use and thermal comfort. Solar gains through exterior windows and zone sensible cooling have shown the maximum internal gains in the baseline models. Whereas, the heat flows through the building envelope in the baseline was maximum through glazing, walls and air infiltration. As the baseline models have already been validated using percentage error (for monthly data); the results are assumed to be the representing the existing thermal environment of the surveyed buildings. Fig 9&10 shows the distribution of the internal gains and the heat conduction gains of the baseline models.

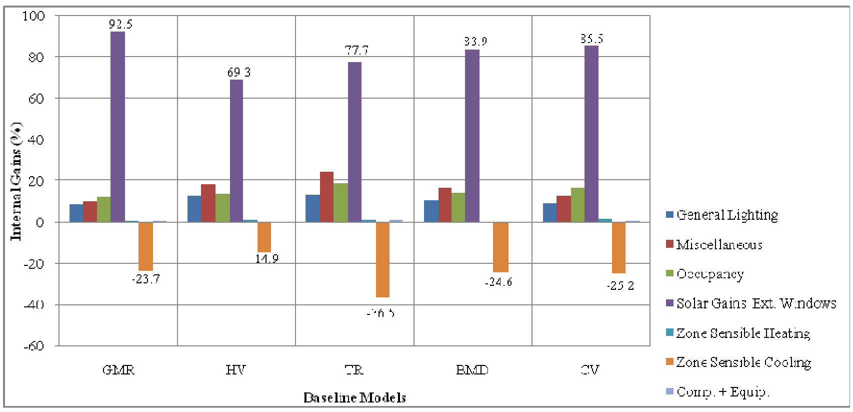

Figure 9. Distribution of internal gains in the baseline models

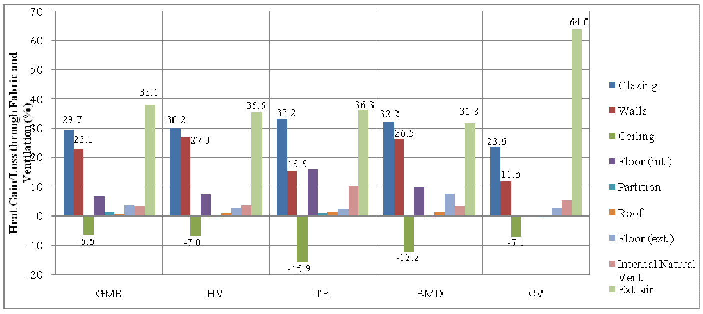

Figure 10. Distribution of heat gain/ loss through builing envelope in the baseline models

3.2.2 Building Design :Effect on heat gain/loss

a.Orientation

Orientation is an important consideration while evaluating the solar gains through the building envelope, as the heat flows through the facade facing different directions is unequal (Sustainable Building –Design Manual Volume II).The analysis has shown that the building orientation and the window to wall ratio (WWR) for the corresponding direction have significantly affected the heat flows through the building envelope and the resultant energy loads. GMR has shown the highest and HV the lowest solar gains through the ext. windows. The E-W orientation with an overall WWR of 0.4 explains the lower gains for HV, refer Table 6. The solar gains through ext. windows in HV are, thus, allowed only when required (winter period) and restricted in the warmer period, refer Fig11, an ideal case for composite climate.

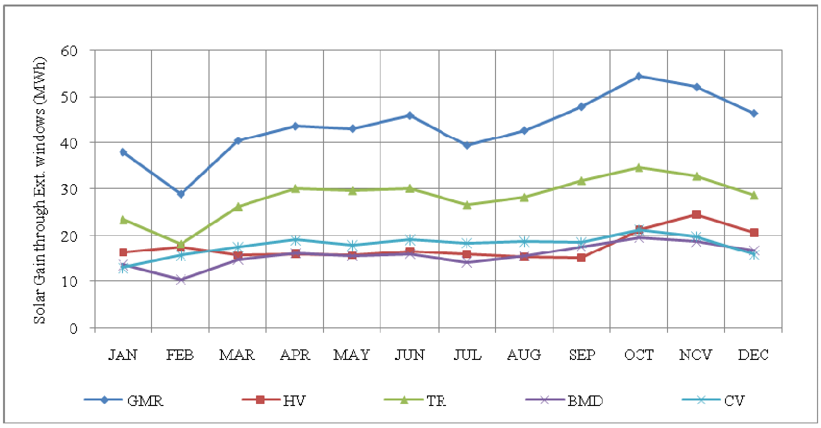

Figure 11. Solar Gain through Exterior Windows

Table 6. Summary of WWR and S/V ratio of surveyed building

	Wall Area	Volume	Window Area	S/V	WWR
BMD	3806.4	10627.2	526.4	0.4	0.5
CV	2499.7	9048.8	502.7	0.3	0.8
TR	2816.6	17238.2	839.9	0.2	0.9
HV	4841.3	12976.3	560.3	0.4	0.4
GMR	6470.6	17382.9	964.3	0.4	1.9

On the other hand, the higher solar gains in GMR can be attributed to its building form. The CFD analysis (using an extended Design Builder's application) is employed to analyze the difference in the heat flows for each block. Fig 12a shows the key plan of GMR, divided into four blocks (i.e. Aa, Ab, Ba & Bb) on the basis of orientation of the longer axis. The block 'Ba' & 'Bb' with the orientation along N-S & E-W axis, respectively, has shown the major effect of exposure to solar radiation with respect to its orientation, refer Fig 12 b, c, d, e. Heat conduction gain in 'Ba' block is higher than block 'Bb', owing to the exposure of longer facade to the east direction (having maximum solar radiation in summer). The average zone temperature of 'Ba' is approximately 1°C higher than the block on E-W axis, i.e. Bb, for both the floor levels, refer Table7. The zones facing the prevalent north westerly winds are observed to be cooler in blocks 'Ba' and 'Bb'.

Table7. Average zone temperature of LF and TEF of GMR

	Bb TEF	**Bb LF**	**Ba TEF**	**Ba LF**	**Ab TEF**	**Ab LF**	**Aa TEF**	**Aa LF**
Average Zone Temperature	36.5	36.3	37.5	37.2	37.3	37.0	37.1	36.9

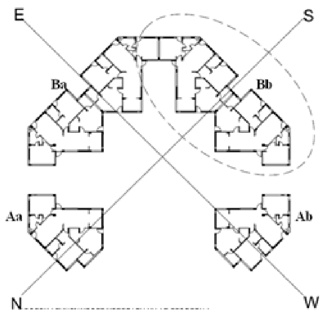

Figure 12a. Key Plan of GMR

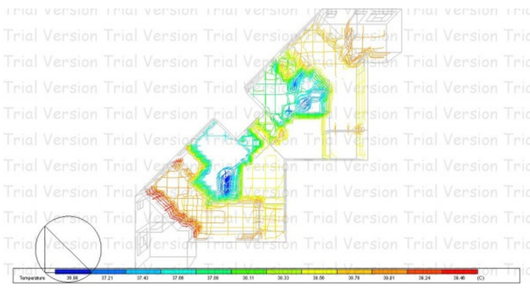
Figure 12b. GMR Ba Block (LF)

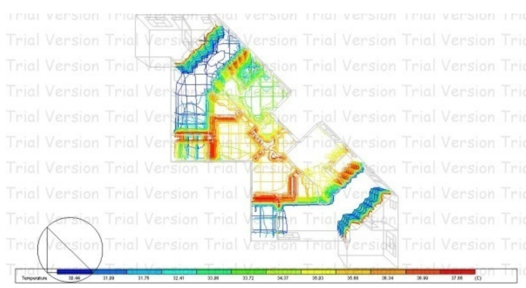
Figure 12c. GMR Bb Block (TEF)

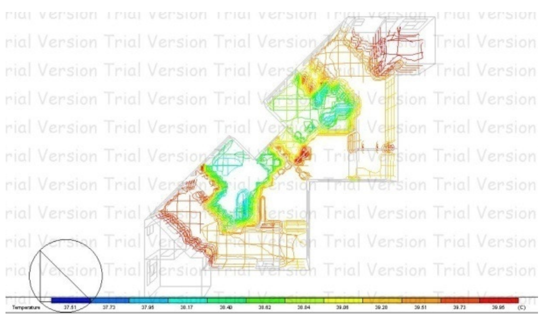
Figure 12d. GMR Ba Block (LF)


Figure 12e. GMR Bb Block (TEF)

b. Glazing Area: WWR

In tropical climates, north orientation has a brief exposure to solar radiation (early mornings and late afternoons) whereas east & west receives the maximum solar radiation during summer (Sustainable Building –Design Manual Volume II).Therefore the WWR for the façade of respective directions, i.e. with maximum solar radiations, have been summarized in the Table 8. It is important to note that the type of glazing used in the surveyed building is mostly single-pane unit with wooden frames. This has not only contributed to the solar gains and heat conduction gains (refer Fig 6 & 7) but has significantly affected the heat gains through external air or infiltration. As all the buildings are naturally ventilated, the heat gain through external air is estimated using 'Calculated Natural Ventilation' option in Design Builder's software. CV, among other buildings, have shown the highest values (refer Fig 7) and the observed difference can be attributed to its high WWR (0.8). The WWR of east and west facades (recipient of maximum solar radiation) in CV is also comparatively higher, refer Table8. Therefore, the amount of heat entering through the windows is more for a given a volume of the space, which is less in case of CV.

Table 8. WWR of facades with maximum solar radiation

	E	W	NW	NE	SE	SW
BMD			0.16	0.07	0.16	0.07
CV	0.23	0.22				
TR			0.44		0.44	
HV		0.05				
GMR	0.22	0.23	0.12	0.20	0.30	0.20

4 Conclusion

The study has been conducted W14103with a prime focus to identify predictors that affects the energy loads and thermal comfort of naturally ventilated multi-storied apartments in composite climate of north India. By inculcating two different approaches of building evaluation, the study has fairly achieved the same. A comfort temperature of 26.6 °C with a comfort band of 22.5–30.6 °C has been derived. This suggests that the residents are well adapted to their thermal environment as oppose to narrow comfort range as recommended by the National Building Code (NBC). PMV is also observed to be overestimating the thermal sensation as oppose to the actual thermal sensation votes. The TSV-PMV difference was observed to be fairly significant for the winter and summer period, i.e. 5°C and 1.1°C respectively whereas marginally differed for the annual data i.e. 0.6°C.. Temperature (globe temperature), air velocity and clo are identified as the predictors for thermal evaluation in naturally ventilated buildings. Building orientation, WWR, building form has significantly influenced the internal gains and the heat conduction gains. GMR has shown the highest and HV the lowest solar gains through the ext. windows. The E-W orientation has shown the minimum solar gains and heat gains whereas, east & west has shown the maximum. Building form has also considerably effected the orientation of the building; which further has affected the exposure to solar radiations of longer facades.The average zone temperature of ‘Ba’ (along N-S axis) is observed to be 1°C higher than the block on E-W axis, i.e. Bb.WWR has not only effected the solar gains but also the heat gains through infiltration. CV with significantly high WWR and low S/V ratio has shown maximum heat gains through external air.

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