ENERGY EFFICIENT AND THERMALLY COMFORTABLE APARTMENTS IN INDIAN COMPOSITE CLIMATE

Ph. D. THESIS

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JUNE, 2014

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A THESIS
Submitted in partial fulfilment of the
requirements for the award of the degree
of
DOCTOR OF PHILOSOPHY
in
ARCHITECTURE & PLANNING

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EXECUTIVE SUMMARY

India ranks fifth in primary energy consumption and accounts for about 3.5% of the world's commercial energy demand (*World Business Council for Sustainable Development, 2008)*. About 75% of this total energy-use (direct or indirect) is expended on Indian households *(S. Pachauri and D. Spreng, 2002).* Reports show that the cooling load of residential sector accounts for up to 45% of the total electricity consumption in India *(Energy Conservation Building Codes, 2007).* With the predicted rise in the growth rate of construction spending in housing (i.e. approx. 10% per annum from 2013-18) *(Asia Construction Outlook, 2013)* and high disposable incomes of the people *(A.B. Lall,2008;* D.C. Srivastava,2007*),* it is envisaged that the energy demand for better indoor thermal environment (through space heating/cooling) will continue to rise in the foreseeable future. Considering the highly variable climate of India, at macro and micro scale; the existing energy codes (i.e. the Energy Conservation Building Codes; ECBC) for naturally ventilated residential buildings are quite ambiguous and nonspecific. It follows a prescriptive component-based approach, where energy efficiency guidelines are applicable on only air-conditioned area of 1000 m^2 (or more) having a connected load of 500kW or more *(ECBC).* On the other hand, thermal comfort standards (as advocated by National Building Code; *NBC*) follows a narrow range of indoor temperatures in summer (23-26°C) and winter (21-23°C) and is based on Fanger's model, which overlooks the adaptive behavior & its effect on the thermal perception of the subjects. Field studies in tropical climate *(Humphrey, 1977; Sharma & Ali, 1986; 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.

This research has followed an integrated approach to evaluate the thermal performance of a naturally ventilated multi-storied apartments and the thermal perception of their residents in a composite climatic zone of north India. The fact that the conditions in naturally ventilated buildings is not quite comparable to those of the conditioned ones; the adaptive approach of thermal comfort has been employed. A Class II level longitudinal survey was conducted to analyze the thermal responses of the subjects, and to establish the temperature which people finds comfortable. In total, 54 apartment units are visited and 82

subjects were interviewed on a monthly basis for the year of 2012. The survey was fairly distributed between lower floors, middle floors and top floors, to analyze its effect on the thermal behavior of the buildings and its occupants. Chapter3 gives the detail of the study area, i.e. Chandigarh and Roorkee (composite climatic region of north India), along with the description of the longitudinal field survey that has been conducted for the studied period. The Design Builder's (DB) v.3.0.0.105 is employed to evaluate the energy performance and thermal behavior of the surveyed buildings. Measured data and real building information is used to assign the simulation input values for walls, roof, windows etc. The operation schedules for lighting, heating &cooling system (i.e. fan, A/c's, heater/hot blowers), occupancy etc. are also framed on the basis of responses received during the survey. The simulation arrangement of the baseline model is thoroughly explained and supported with the necessary statistical indices for validation. The Coefficient of Variation of Root Mean Squared Error (CV (RMSE) and Mean Bias Error (MBE) for the monthly electricity consumption is within the acceptable tolerances (as recommended by *ASHRAE Guideline 14-2002*), i.e. ±15% for CV (RMSE) and ±5% for MBE. This chapter can be referred for the dataset that has been used for the analysis of the thermal comfort of the subjects and the energy-use of the studied buildings.

Thermal evaluation of the occupants in warm climate has always been debated by the propagators of the thermal comfort models (i.e. Fanger's Model & Adaptive model). Fanger's model is premised on the assumption that the thermal response of the subject, to the given thermal environment, is proportional to the physics of the heat and mass exchanges between the body and the environment. However, it accounts for some degrees of behavioral adaptation, such as adjustments to the clothing and local air velocity. It still undermines the psychological dimension of adaptation and its effect on the thermal perception of the subjects. Earlier field studies have shown that PMV yields satisfactory results for thermal sensation in air-conditioned buildings but overestimates the subjective thermal responses in naturally ventilated buildings *(P.O. Fanger and J. Toftum, 2002).* The adaptive approach, on the contrary, advocates that a person is no longer a passive recipient of the given thermal environment, but instead an active agent interacting with the person-environment system via multiple feedback loops *(G.S. Brager and R.J. de Dear, 1998).* As the subject's experience of a place is a multivariate phenomenon *(A.K. Mishra and M. Ramgopal, 2013)*, it is important to understand the factors which stimulate the thermal sensation of the occupants. Chapter 4 is focussed on the estimation of the comfort temperatures, comfort range and evaluation of the behavioral adjustments of the occupants in response to the thermal discomfort. The adaptive use of various controls (‘*in-built controls’*, ‘*seasonal controls’* and *personal controls’*) with the change in the seasonal variations is elaborately discussed. It is observed that at extreme weather conditions subjects are switching to the energy intensive appliances (i.e. fans, A/c’s and heaters/hot blowers) or ‘*seasonal controls’* as oppose to the ‘*in-built controls’* (i.e. windows, balcony doors & blinds) or ‘*personal controls’* (i.e. changing clothing levels/ ‘clo’ and metabolic rates/‘met’). Fans, A/c’s and heaters work instantly at the discomfort hours and accentuate the feeling of degree of control of the subjects. With this feeling of control on the indoor conditions, the thermal perception of the occupants is elated which explains the high regression coefficient of the ‘*seasonal controls’*. The results have inferred that the efficient design of the building (i.e. ‘*in-built controls’*) is essential in order to minimize the dependence on ‘*seasonal controls* ‘and the resultant energy load.

Thermal comfort is related to the environmental and personal variables which are, in turn, dependent on the building parameters (both physical and thermal properties). 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 of the building. Chapter5 has evaluated the thermal performance of the surveyed multi-storied apartments (all five). The energy-use analysis is conducted, using a ‘*whole building calibrated simulation approach’ (ASHRAE 14-2002),* to assess the effect of heat flow through the building envelope, lighting system, heating/cooling systems etc. ECBC standard is referred for the resistance (R-value) and conductance values (U-value) of each of the assembly (wall, roof) or SHGC value of glazing unit to compare the changes. 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 loads and the indoor comfort conditions. This study has identified ‘*glazing’, ‘wall’* and ‘*lighting’* as the energy intensive predictors. Internal gains through *‘solar gains through exterior windows’* and *‘zone sensible cooling’* is observed to be maximum in the baseline models, whereas heat flows through the building envelope is maximum through ‘*glazing’, ‘walls’* and *‘air infiltration’*. The retrofit suggestions for the identified predictors are employed, one by one, keeping all other variables same as in the baseline model. It is observed that the any change to building component has consequently affected the overall heat conduction processes of the other structural elements. It is inferred from the results that a thorough understanding of the interactive processes between building components is important before suggesting any retrofits. Also, parameters like orientation, window to wall ratio, building form etc. significantly affects the thermal behavior of the building. Chapter 6 gives an insight to the questions like- *what* affects the thermal perception of the occupants? *Why* are the heat conduction flows so high in some buildings whereas moderately low in others? *How* the building-design affects the thermal behavior of the surveyed buildings? The derived adaptive model of thermal comfort is compared with the Fanger's PMV model. The discrepancies between the two is further extended by analyzing the demographic (age & gender) and contextual (seasonal variation & exposure to roof) variables. This basically established the, already accepted, concept that there are factors beyond the physical variables that affects the thermal perception of the occupants. It is notable that as the discomfort level surpasses the endurable thresholds of the human body it becomes important to take measures at the building level. Controlling the microclimate to reduce the effect of the outdoor temperature, reducing the direct or diffused solar gains and other heat gain/loss and allow cross ventilation, among all, are few of the significant ones *(R. Gupta and M. Gregg,2012).* In the later part of the chapter, therefore, parameters pertaining to the energy-use & thermal behavior of the surveyed buildings are evaluated with respect to its design. Building orientation, WWR and building form is observed to have significantly influenced the internal gains and the heat conduction gains through the building. The results presented in this study are merely a snapshot of *'how'* and *'what'* affects the thermal perception of the occupants along with the thermal behavior of the building. The present study has only focused on the composite climatic zone of India and, thus, the adaptive model of thermal comfort is applicable to multi-storied apartment (with similar construction strategies) in this climatic zone only.

ACKNOWLEDGEMENT

Working as a PhD scholar in Indian Institute of Technology, Roorkee was a magnificent as well as challenging experience to me. In all these years, many people, directly or indirectly, helped me in shaping up my academic career. It was hardly possible for me to thrive in my doctoral work without their precious support. I wish to express my sincere appreciation to those who have contributed to this thesis and supported me in one way or the other during this amazing journey.

First of all, I wish to thank my supervisor **Dr. P.S.Chani** and **Prof. S.Y.Kulkarni** for the support and guidance in my research. It was due to their valuable guidance, cheerful enthusiasm that I was able to complete my research work in a respectable manner. I owe my heartfelt appreciation to Dr. Chani for patiently providing the vision, encouragement and advice necessary for me to proceed through the doctoral program and complete my dissertation. I am thankful to the members of my SRC committee**; Dr. M. Mukherjee, Dr. M. Parida and Dr. G. Raheja**, for their insightful discussions and suggestions during the presentations. The staff members of the department of Architecture and Planning also deserve my sincerest thanks for their assistance.

My sincere gratitude is reserved for **M. Humphrey** and **Dr. Madhavi Indraganti** for their invaluable insights and suggestions during the conceptual stage of my research.

I take this opportunity to sincerely acknowledge the Indian Meteorological Department, Chandigarh and National Institute of Hydrology, Roorkee for providing me the data required for my research. My sincere thanks go to **Dr. M. Mukherjee** for allowing me to use the instruments from the Climatology Lab., Department of Architecture & Planning, IITR. I would like to acknowledge all who has directly or indirectly helped me to get the permissions of the concerned authorities.

I would like to express my appreciation to the residents of Hill View, Canal View, BhaimataDas, Trishla and Growmore apartments for allowing me to visit them for my field study. My humble thanks to all of you for patiently bearing my visits (sometimes unannounced) for the whole year. Especially, **Rekha Singh Ma'am** (you are always sweet to me), **Rashi Aunty, Minakshi Aunty and Raj Sharma Aunty**. The warm welcoming gestures from you were the source of encouragement during my field survey.

My time at IITR was made enjoyable in large part due to the many friends and groups that became a part of my life. Special thanks to- **Aanchal, Ila, Varinder, Rupali, Mausami, Rashmi, Mansi, and Pooja**. I am deeply indebted to my friends **Sugandha, Nirupama** and **Annamika** for being there to listen when I needed an ear. I would like to thank **Shaila Ma'am** for being supportive and a source of encouragement during the crucial stages of my research work. I appreciate the brainstorming discussions that we had during our tea-break. I also must mention the valuable support that I received from **Sonali** and **Tapasi** at the submission stage of my thesis. Thanks guys! My best buddies, **Abha** and **Priyanka**, stands out notoriously as they gave me the much needed escape from my research to the real world of silliness. My apologies if I forgot to mention anybody (too many to list here but you know who you are!).

This thesis is dedicated to my **dad** (*Dr.Harjeet Singh*) - the one whom I can look up to no matter how tall I grow, to my **mom** (*Suman*)**–** the bank, where I deposited all my hurts and worries, to my **brother** (*Kanwar*) – whom I can lean on, count on, tell on. The greatest gift I have ever had from God: I call them **family**.

Words cannot express the feelings I have for my parents and my brother. Thank you doesn't seem sufficient but I owe every bit of my success to them for their support, encouragement, care, understanding and precious love. I would not be here if it not for you. For every door slammed or opened during this journey, mom-dad your kind words always kept my moral high. Bhai you encouraged me and supported me in all the pursuits and sometimes gave me a much needed kick on my backside when I needed one.

"When the going gets tough, the tough gets going" – is what you all taught me. Love you for everything!

Last but not the least, and the one above all of us, the omnipresent God, for answering my prayers for giving me the strength to plod on despite my constitution wanting to give up, thank you so much Dear Lord.

Shailza Singh
IIT Roorkee
June, 2014

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ABBREVIATIONS

Aerated Concrete Block assembly	*'AAC'*
Air Conditioners	*'A/c'*
Air Temperature	*'Ta'*
Air Velocity	*'Av'*
Balcony Doors	*'BD'*
BhaimataDas Apartments	*'BMD'*
Blinds	*'BL'*
Canal View Apartments	*'CV'*
change in heat stored	'ΔS'
Clothing Insulation Level	*'clo'*
Computational Fluid Dynamics	*'CFD'*
Conduction	'C_d'
Convection	'C_v'
Correlation Coefficient	*'r'*
Dwelling Units	*'DU'*
Effective Temperature	*'ET'*
Energy Conservation Building Code	*'ECBC'*
evaporation heat loss	*'E'*
Extended model of PMV	*'PMVe'*
Extruded Polystyrene Insulation	*'XPS'*
Globe Temperature	*'Tg'*
Griffith's Neutral Temperature 1(using 0.31 regression coefficient)	'Tn_{G1}'
Griffith's Neutral Temperature 2(using 0.25 regression coefficient)	'Tn_{G2}'
Griffith's Neutral Temperature 3(using 0.21 regression coefficient)	'Tn_{G4}'
Griffith's Neutral Temperature 3(using 0.33 regression coefficient)	'Tn_{G3}'
Growmore Society	*'GMR'*
Heat conduction loss through glazing	*'SHG'*
Hill View Apartments	*'HV'*
Life Cycle Cost	*'LCC'*
Low Basal Metabolic Rate	*'BMR'*
Lower Floors	*'LF'*
Mean Age Air	*'MAA'*
Mean Bias Error	*'MBE'*
Mean Globe Temperature	*'Tgm'*
Mean of monthly energy consumption	'$\bar{y}$'
Mean Thermal sensation	*'TSm'*
Metabolic Level	*'met'*
Monthly energy consumption (measured value)	'$y_{measured}$'
Monthly energy consumption (simulated value)	'$y_{simulated}$'
Naturally Ventilated	*'NV'*
Net radiation	*'R'*
Neutral Temperature	*'Tn'*
Number of data points	*'n'*
Number of predictor variables	*'p'*
Operative Temperature	*'To'*

Outside Temperature	*'Toutside'*
Percentage Error	*'% error'*
Predicted Mean Voted	*'PMV'*
Predicted Percentage Dissatisfied	*'PPD'*
Radiant Temperature	*'Tr'*
Regression Coefficient	'R^2'
Relative Humidity	*'RH'*
Solar gains through exterior windows	*'HC'*
Solar Heat Gain Coefficient Through Glass	*'SHGC'*
Standard Effective Temperature	*'SET'*
Surface o Volume Ratio	*'S/v'*
Test Reference Year	*'TRY'*
Thermal Acceptance	*'TA'*
Thermal conductance,[W/m2C]	*'U.F' or '(U-Factor)'*
Thermal Preference	*'TP'*
Thermal resistance [m2.C/W]	*'R.V' or '(R-Value)'*
Thermal Sensation Votes	*'TSV'*
Top Exposed Floors	*'TF'*
Trishla Apartments	*'TR'*
Tropical Summer Index	*'TSI'*
Typical Meteorological Year 2	*'TMY2'*
VLT= Visual Light Transmittance.	*'VLT'*
Wet Bulb Temperature	*'Tw'*
Window to Wall Ratio	*'WWR'*
Windows	*'W'*

CHAPTER 1
INTRODUCTION

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 the year 2030 [1].It is a well known fact that economic development is directly associated with the energy consumption of any country. In India, to sustain the economic growth it is necessary to ensure the energy supply with the growth rate of 5-6% [2].

Considering the current status of the real estate industry, construction is one of the core sectors of India's economy. And with the growth rate of 9-10% [2], it makes a vital contribution to its socio-economic development by providing housing and infrastructure.

1.1 Energy-Use & Thermal Comfort : Current Scenario

India ranks fifth in the primary energy consumption and accounts for about 3.5% of the world's commercial energy demand [3]. About 75% of this total energy-use (direct or indirect) is expended on Indian households [4].Particularly; the construction spending in housing is expected to grow at a rate of 10% per annum from 2013-2018 in India [5]. The current status of residential sector clearly signifies its contribution to the economy and the resultant demand on the energy resources, and the focus required to deal with the same.

One important aspect of energy-use is the thermal behavior of the building envelope [6] which, further, influences the indoor comfort levels. Considering the highly variable climate of India, at macro and micro scale, the existing standards for designing energy efficient and thermally comfortable residential buildings are quite ambiguous for each of the climatic zone. National Building Code (NBC) [7] and the Energy Conservation Building Code (ECBC) [8] are the two regulatory bodies propagating thermal comfort and energy policies in India. The restricted scope of ECBC standards (covering only air-conditioned commercial buildings) overlooks naturally ventilated (NV) buildings that represent 80% of the typologies built in the cities [9]. Likewise, the narrow range of acceptable indoor temperatures in summer (23-26°C) and winter (21-23°C) period, as advocated by NBC [7], is based on Fanger's model [10] and neglects the adaptive behavior and its effect on the thermal perception of the subjects. Field studies in tropical climate have shown [9-26] a broader comfort range and high neutral temperatures as opposed to what is recommended by the operational standards.

Studies have revealed that thermal comfort is an important boundary condition while evaluating the effect of changes to the building design [27]. Rajat & Smita [28], integrated the 'Building Performance Evaluation' (BPE) with the 'occupancy-feedback' and suggested that the evaluation of occupancy behavior at the pre-retrofit period can help in framing low-carbon energy model for the buildings. So, in quantifiable terms, the thermal comfort is related to environmental and personal variables which are, in turn, dependent on the building parameters (both physical and thermal).

In this study, an integrated approach is followed to identify the predictors for energy load and thermal comfort in naturally ventilated multi-storied apartments in composite climate of north India.The most commonly used method to evaluate the thermal behavior of buildings and their impact on energy loads is by running simulations. Design Builder's software is, therefore, employed to evaluate the heat transfer through the structural components of the building. As the conditions in naturally ventilated buildings are not quite comparable to those of the conditioned ones, adaptive model of thermal comfort has been suggested in many field studies in the tropical climate [9-26]. Therefore, the adaptive approach is employed to analyze the thermal perception of the subjects and to identify the neutral temperature of naturally ventilated multi-storied apartments in composite climate.

1.2 Identification of the Problem

Energy loads are not just associated to the building design, material selection, or its heating &cooling systems but they also depend on the type of occupancy. A residential building, particularly, is a dynamic system in itself as it undergoes many changes during its life span. The domestic setup is far from any steady state air-conditioned commercial building, and the indoor environmental conditions can vary in a small scale of time [27]. Besides this, the dependence on contemporary design or construction strategies, which has led to low indoor comforts, has resulted in increased energy loads [29].

Thermal comfort in buildings is another important issue, especially, when people spend 80% of their life-time indoors [30]. It has been proved that poor comfort leads to high energy consumption and affects the user's health adversely. India witnesses predominantly four climatic seasons in a year [31] and the nation itself is divided into six climatic zones [32], with its maximum land coverage falling under composite climate. This seasonal and climatic diversity makes it quite essential to revise the current thermal comfort standards in India. On the contrary, National Building Code follows the narrow comfort range all over India [7,10-18], irrespective of the climatic zone it falls under. The applicability of such uniform indoor-comfort standards underestimates the human adaptability to indoor climates, typical in naturally-ventilated buildings. This not only affects the thermal comfort but also exhilarates the energy consumption of the building. Therefore, with the growing awareness for a need to reduce building's energy-use and to improve thermal comfort, it becomes increasingly important to seek ways to assess and control the same.

1.2.1 Need for study

As outlined, in a study by Steemers [33], there is a shift in the focus of scientific building research from energy and environmental oriented assessments towards occupancy-centered evaluation. Till now, many thermal comfort researches have been stimulated with the drive to achieve energy efficiency [34-36]. But, the documentation of field studies on thermal comfort in conjunction with the energy efficiency (especially residential buildings) in India is still not very profound. Only handful of studies are available on thermal comfort [9-18, 37-41] and energy efficiency [42-47] in India. In order to improve the building performance, it becomes increasingly important to seek ways to develop a framework for designing energy efficient apartments with enhanced thermal comfort in different climatic zones of India. This leads to:

- A need to identify the key parameters for enhancing the overall performance of naturally ventilated apartments and to recommend suitable measures not only to improve the energy efficiency but also thermal comfort.
- A framework to be drafted as a design guide for existing and upcoming apartment projects with optimum energy-use and thermal comfort.
- The results of the field studies to be documented and made available beforehand to the contractors, architects, engineers etc. to design appropriate strategies for the reduction in energy-use with optimum comfort conditions, while helping to mitigate the environmental impacts of the same.

1.3 Research Questions

1. *What are the energy intensive predictors that affect the energy-use in naturally ventilated (NV) multi-storied apartments?*
2. *Is there any possible relation between energy-use behavior of occupants and the perceived thermal responses?*
3. *What is the comfort range of occupants in NV multi-storied apartments and how does their adaptive behavior change with seasonal variations?*
4. *How thermal behavior of the building envelope affects the energy performance of the building.*

1.4 Aim

To evolve a framework for energy efficient apartments with enhanced thermal comfort in Indian composite climate.

1.5 Objectives

1. To develop adaptive model of thermal comfort for residential buildings.
2. To create baseline simulation models within acceptable statistical tolerances for energy-use analysis.
3. To identify key parameters which are conducive to energy efficiency and thermal comfort.
4. To analyze performance of the building system for the suggested alternative.
5. To draw inferences from the analysis for designing energy efficient and thermally comfortable apartments.

1.6 Scope & Limitations

- The scope of this research is to find the solutions to improve the overall performance of an apartment building in the composite climate of India.
- Comprehensive life cycle assessments and other parameters such as impact on land use and urban infrastructure falls outside the purview of this work. This study will not take into consideration the economic part of an apartment development.
- The psychological aspiration of the occupants on the overall thermal perception is also out of the scope.

1.7 Research Design

1.7.1 Methodology

This research follows a systematic methodology as shown in Fig. 1.1. The various steps followed in the investigation are the identification of problems and formulation of objectives followed by the data collection, estimation of total energy-use, simulation modelling, analysis and identification of key parameters that affect the energy-use and thermal comfort of naturally ventilated apartment building in a composite climate of India.

1.7.2 Data collection

Both secondary and primary sources of data have been collected and employed in the research.

1.7.2.1 Secondary data

Literature pertaining to this research is collected from different published and unpublished sources. The published literatures, such as related journals, reports, books, standards are used.

1.7.2.2 Primary data

An extensive primary survey has been conducted by employing a schedule, photographic survey and questionnaire survey of the occupants of the selected apartment buildings. The main objective of this survey is to understand the differential occupancy behaviour & annual household energy-use and to measure the indoor thermal comfort parameters (air-temperature, air-velocity, humidity etc.). Meteorological data and detailed drawings have been collected from the concerned authorities.

1.7.3 Survey tools & techniques

An appropriate schedule has been prepared to conduct the primary investigation. The schedule is questionnaire based - to collect the thermal sensation responses (ASHRAE seven-point scale) along with the use of the data-loggers for taking on-spot measurements of the environmental parameters; and to deduce the operational schedules of household appliances/occupancy etc..

1.7.4 Analysis tools & techniques

The collected data has been checked for the correctness and errors by using analytical tools and statistical indices as described below:

Optimal software’s like MS Excel is employed for compiling and undertaking analytical work. AutoCAD is used for the entire architectural documentation. Design Builder’s software has been used for simulating the energy performance of the building. Design Builder’s CFD is employed for simulating thermal performance and natural ventilation of the building.

1.7.5 Results and discussion

Results of all types of analysis such as, literature survey, primary surveys, model results, simulations, etc. is discussed in detail.

1.7.6 Conclusion & recommendations

The plausible findings or inferences are drawn for the energy efficient apartments with enhanced thermal comfort conditions in composite climate of India. Recommendations are made for the future scope of this research.

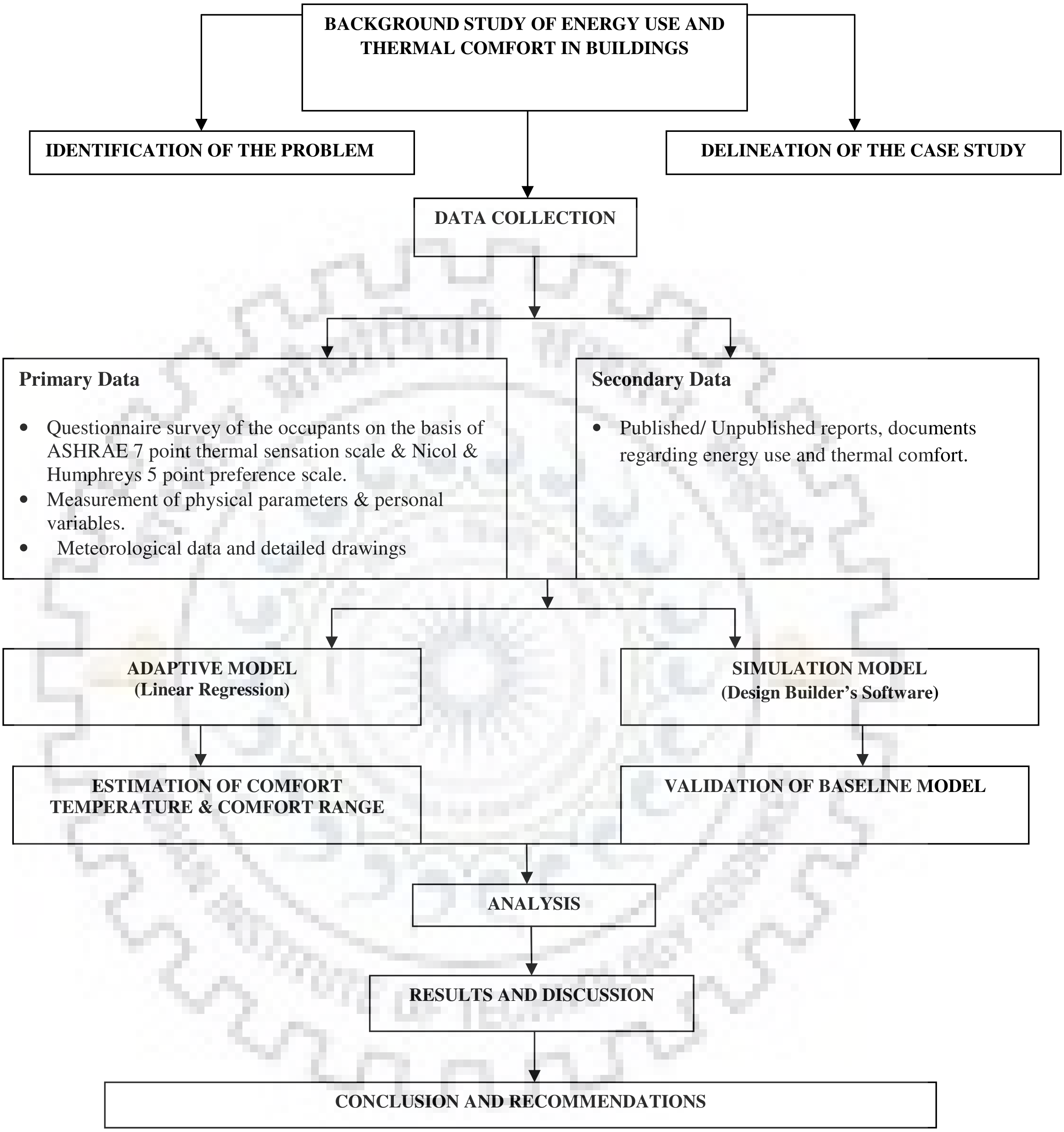


Fig1.1 Methodology

CHAPTER 2
LITERATURE REVIEW

2. INTRODUCTION

The International Energy Agency (IEA) estimated that the current trends of energy demand in buildings will stimulate about half of the energy supply investments by the year 2030 [1]. Although, the average per capita energy consumption of India is low as compared to the developed countries [1,4], but the projected figures are expected to rise by almost seven times by the year 2030 [1], (refer Fig2.1).Residential sector, especially, makes up a substantial share to the primary energy-use in most of the developing countries [4]. In India, it contributes nearly 23% of the total demand [2, 8, 46], *per se* making it the third largest energy-end user in the country after industrial and agricultural sectors (refer Fig2.2).

Considering the cultural, geographical and climatic diversity; the consumption patterns of energy in a building type varies widely across the country. The direct and indirect energy requirements of the Indian households have been reported to be progressively changing with the development in technology, income levels and lifestyles [4, 41, 46]. Construction quality, climate and the efficiency of the energy systems deployed are also suggested to be the significant predictors in the energy demand of a building [48]. But, in the current drive to achieve energy efficiency, somehow, the comfort requirements are neglected in a building design. Studies have proved that the thermal discomfort has a huge implication on the energy consumption of any building [49, 50]. Zain [6], in his study, has inferred that thermal comfort is an important consideration while adopting the strategies to conserve energy and, thus, must not be compromised at any level. It should be noted that a large part of the total energy is expended on making the indoor thermal environment comfortable, using space heating/cooling, in a domestic building [8,11]. Though, few studies are conducted on the thermal comfort [9-18, 37-41] and energy efficiency [42-47] in India. But a significant amalgamation of both the methodologies, to its full extent, has not been covered yet, especially, in naturally ventilated residential buildings.

The standards on thermal comfort and energy efficiency of buildings in India are quite ambiguous and nonspecific, especially, for residential buildings. The existing energy codes (i.e. the ECBC standards) follow a prescriptive component-based approach, where energy efficiency guidelines are applicable to only air-conditioned area of 1000 m^2 or more having connected load of 500kW or more [8,51]. Also, the operational thermal comfort standards are based on ASHRAE's-55 standard static model [7], which does not consider the adaptive behavior and its effect on the thermal perception of the subjects. In this view, the assessment of multi-storied apartments of India, in terms of energy consumption and thermal comfort, is quite valuable. It will assist policy makers to formulate the measures to optimize energy efficiency within the acceptable thermal comfort standards.

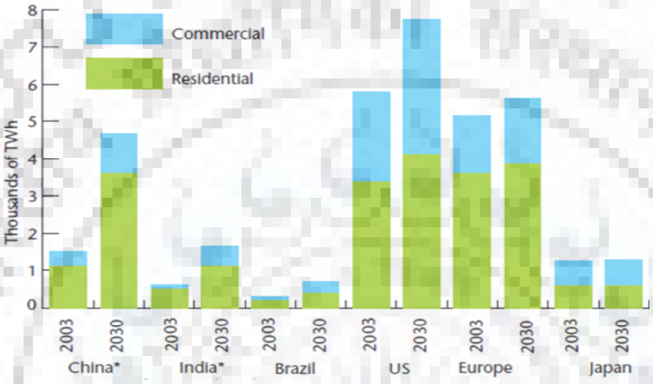


Fig. 2.1 Building Energy Projection by Region – 2003 / 2030 [1]

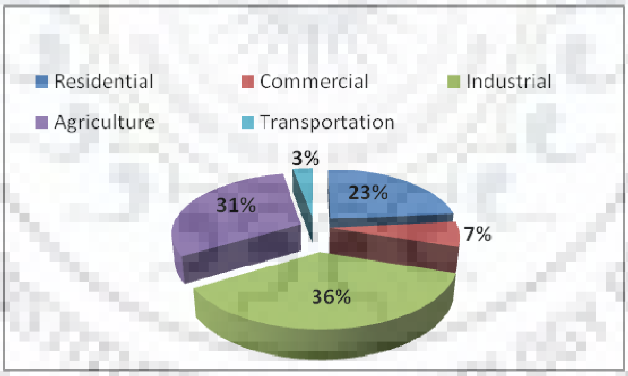


Fig. 2.2 Sectorial Energy Consumption in India [2]

2.1 Climatic Zones of India

Climate is a significant statistical predictor for assessing the energy end-use and comfort conditions of the buildings [32, 52]. The environmental surroundings, to which the buildings are exposed to, demand a case-specific approach depending upon the building type, climate, occupancy etc. [53]. Therefore, it is important to identify the climatic zone for which the analysis is being done.

The climate of India is strongly influenced by its unique geography and geology. Bansal and Minke [54] (1988) evaluated the mean monthly data from 233 weather stations and delineated six climatic zones of India. These zones are, namely; hot and dry, warm and humid, moderate, cold and cloudy, cold and sunny, and composite (refer Fig 2.3). The climatic zone of any place is assigned when the defined conditions are prevalent for more than six months; otherwise the area is called composite in climate classification.

Due to its geographical position and the climatic conditions, India witnesses different climatic seasons in a year .The Indian Meteorological Service divides the year into four seasons: the relatively dry, cold to cool winters from December through February; the dry, hot summer from March through May; the southwest monsoon from June through September when the predominating southwest maritime winds bring rains to most of the country; and the northeast, or retreating, monsoon of October and November [55].

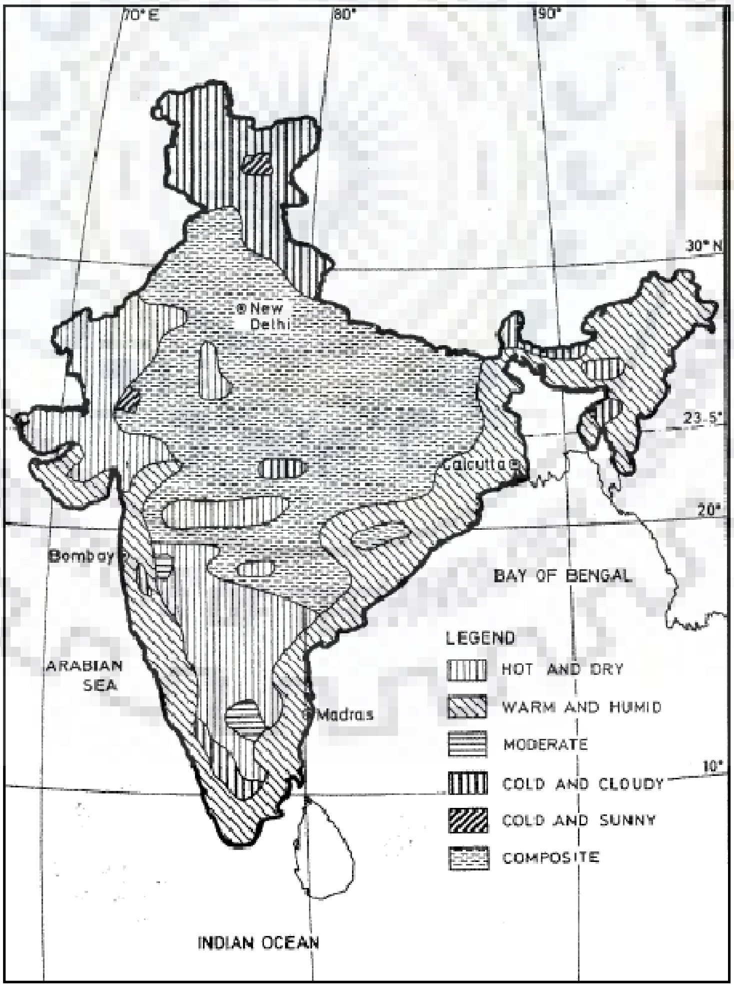


Fig. 2.3 Climatic zones of India [32]

2.1.1 Micro-macro climate: Implications on building design

Microclimate is mostly site-specific which affects the temperature, humidity, and wind around the building. There are various contextual factors (landforms, water bodies, vegetation etc.) that affect certain climatic elements, i.e., solar radiation, wind speed, temperature etc. [32]; which, further, influences the microclimate of a building. With the change in the climatic characteristics, the thermal behavior of the building changes and so does the design requirements to optimize the indoor comfort levels.

In a broader scale, macro climate is considerably affected by the density of the built environment and the percentage of vegetation cover. It is often observed that the surface temperatures in densely built urban areas are higher than the outskirt areas [32]; the phenomenon is termed as 'urban heat island'. In a study, high heat island intensities (i.e. temperature difference between city centre & outskirts) are observed to be higher in the metropolitan cities like; New Delhi, Mumbai Chennai & Kolkata [32 & 56]. GIS tools are widely used to identify the vulnerable areas with maximum discomfort [51] and to ascertain measures to be employed in the land use plan.

2.2 Earlier Thermal Comfort Studies in Buildings

Socrates (around 400 BC) and Vitruvius (1st century BC) were amongst the earliest researchers who raised their concerns about the importance of climate on building design in terms of thermal comfort [57]. Thermal comfort was not an issue in architecture, until 19th century when Heberden suggested that humidity, along with air temperature, significantly affects the thermal perception of the occupants. As the buildings are introduced to heating and cooling strategies, it becomes necessary to ascertain the design temperatures. The empirical and analytical works of Bedford (1936) and Gagge (1937) helped in framing the earlier thermal comfort models; Olgyay (1963) interpreted the interdisciplinary findings on thermal comfort with architectural relevance [57]. Table 2.1 gives the summary of the work on thermal comfort models in chronological order.

Table 2.1 Studies on Thermal Comfort Models in Chronological Order

Researcher	Location	Year	Inferences
C G Webb	Singapore & UK	1959	Worked on constructing an index of thermal comfort for office workers using multiple regression analysis.
Gagge et.al.		1967, 1986	Early pioneering work on heat balance model or 'static' or 'constancy' model is the basis of current thermal comfort standards.
Fanger		1970	He developed the first heat balance thermal comfort model and stated that skin temperature and sweat secretion lie within narrow limits to maintain the thermal comfort. Proposed Predicted Mean Vote (PMV) model to predict comfort votes of individuals for a given set of environmental conditions, clothing insulation and metabolic rate.
Nicol & Humphrey		1970	Thermal comfort should be predicted on the basis of its departure from the monthly mean value.
Nicol & Humphrey		1973	Suggested sensation of warmth as part of a self-regulatory system in which the means of regulation included both physiological and behavioural responses, and then formulated a model of thermal comfort along these lines
Humphrey		1978	In free running buildings, the comfort temperature was proved to be significantly related to the mean monthly outdoor air temperature.
Humphrey		1979	Time series analysis (using an exponentially weighted running mean as the mathematical model) showed that clothing might take up to a week to settle to an appropriate level following a change of temperature
Humphrey		1981	Explored the relation between the mean indoor temperature and the comfort temperature
Auliciem	UK & Australia	1984	Calculated the dependence of the comfort temperature indoors jointly on the mean outdoor temperature and the mean indoor temperature.

M. R. Sharma & Sharafat Ali	Roorkee	1986	A thermal comfort index has been derived using multiple regression analysis of thermal sensation with the environmental variables. The study was conducted in Roorkee for over a period of three consecutive summer seasons to evaluate the thermal comfort conditions for hot-dry and warm-humid conditions in India.
Nick Baker & Mark Standeven	Athens	1993, 1994	Proposed the term adaptive errors and adaptive increments and are suggested to be not random but biased in response to the thermal discomfort. Adaptive opportunities and Cognitive and evolved tolerance are referred to be extending the comfort limits of the subjects.
Nicol et al Humphreys			Field studies was conducted on office workers in five different cities covering all the climatic zones of Pakistan
de Dear and Brager		1998	Occupants in conditioned buildings are suggested to have different expectations than the occupants of naturally ventilated buildings.
Raja ,Nicol et.al	Oxford and Aberdeen	1996-97	The effect of outdoor temperature on indoor temperature and consequently on the adaptive use of the controls in peak summer is evaluated. It is also suggested that the adaptive behavior of the subjects (i.e. use of controls) is related to the thermal sensation of the subjects.
Fanger & Toftum		2002	It is observed that PMV model predicts thermal sensation well in the conditioned buildings but predicts warmer thermal sensation for field studies in warm climates in naturally ventilated buildings. Adaptive model has been proposed using regression analysis of globe temperature with the monthly mean outdoor temperatures. Overestimated metabolic rates and low expectations are suggested as the main reason for this difference. PMVe model with an expectancy factor is introduced as an extension of PMV model for non-conditioned buildings in warm climates.
de Dear and Brager		2002	Proposed a new thermal comfort standard for naturally ventilated buildings, leaving PMV as the standard for AC buildings.

2.3 Thermal Comfort Models

Comfort is not just a *response* to the thermal conditions, but a part of *interaction* between occupants and the building to regulate the indoor thermal environment. International thermal comfort standards; Thermal Environmental Conditions for Human Occupancy (ASHRAE 1992) and the ISO Standard 7730 (ISO 1994), have been formulated on the basis of heat-balance model and are characterized by the minimal recognition of the variations in the outdoor climate [39, 58, 59]. On the other side, the adaptive approach is based on the variable indoor temperature standards with the full consideration of the adaptive capabilities of the building occupants. The two proposed models for thermal comfort are entirely different in their approach to manage the indoor environmental parameters.

Factors like demographics (gender, age, economic status), context (building design, building function, season, climate), and cognition (attitude, preference, and expectations)[16, 60] are very important to assess the comfort conditions of any building. On the contrary, the contrived setting of climate chambers in Fanger's model, with a perceived control on the personal adjustments, [60] neglects the impact of these factors on the thermal perception of the subjects. Considering the dynamicity of the indoor conditions of naturally ventilated buildings, adaptive model has been widely adopted by the researchers in the field studies.

2.3.1 'Fanger's model' or 'Heat balance model'

The applicability of conventional thermal comfort model, as proposed by Fanger, is quite debatable when used in warm climate. The PMV/PPD index (based on Fanger's model) has been extensively used, since 1970, in buildings and vehicles to formulate the thermal comfort standards [61]. It predicts the thermal sensation as a function of clothing, activity and four environmental parameters (Ta, RH, Tg & Av) [61]. It is based on the experiments conducted in the controlled laboratory chambers, using North American and European nationals. Though, recent PMV studies are reported to be conducted in the tropical climate [61] but its applicability in naturally ventilated buildings in warm climate is still questionable [58,59]. Also, the universal application of this model, irrespective of the ethnic, climatic and geographic differences, has huge repercussions in the way the indoor environmental parameters are controlled and the resultant energy consumption. Earlier field studies have shown that PMV yields satisfactory results for thermal sensation in air-conditioned buildings, but in naturally ventilated buildings it overestimates the subjective sensation [61]. Low expectations of the subjects in warm climate and over estimated metabolic rate are suggested to be the possible explanation for this higher thermal sensation. In line with this concept, Fanger and Toftum introduced an extended model of PMV (PMVe) taking into account the expectations of the people based on local climate and popularity of mechanical conditioning [16, 61]. But the rationality of the expectancy factors, used in PMVe, is still debatable since it was proposed.

It is important to understand that this model is premised on the assumption that the thermal response of the subject, to the given thermal environment, is proportional to the physics of the heat and mass exchanges between the body and the environment. However, it accounts for some degrees of behavioral adaptation, such as adjustments to clothing and local air velocity. It still undermines the psychological dimension of adaptation and its effect on the thermal perception of the subjects. This can explain the wider range of thermal tolerance of the tropical subjects, in the field studies, as compared to the one suggested by the International thermal comfort standards.The adaptive model of thermal comfort has been, therefore, introduced as an optional tool in assessing the performance of buildings in terms thermal comfort [62,63].

2.3.1.1 Basic principle:

Fanger’s model is based on the principle that the heat produced in the body is dissipated to the environment from the skin by radiation, convection, evaporative cooling etc. (refer Fig 2.4) [57]. Under comfortable conditions, the core temperature of the human body is 37°C, whilst the skin temperature varies between 31-34°C. As a response to the change in the environmental conditions (or in case of any discomfort), body responds accordingly to restore the body’s thermal equilibrium. For e.g. in warm conditions, the first response of the body to the discomfort is the expansion of the subcutaneous blood vessel to exhilarate the blood circulation and, hence, the heat dissipation. In the second step, sweating occurs to start the evaporative cooling. If the body still hasn’t achieved the equilibrium, or if the body’s core temperature reaches 40°C, heat stroke may develop. In cold conditions the response is just the opposite

Equation (1) explains the body's thermal equilibrium, on which the Fanger's thermal comfort model is based on.

The body's heat balance can be expressed as [57]:

$$\mathbf{M \pm R \pm C_v \pm C_d - E = \Delta S\ (W)]} \quad (1)$$

where

M = *metabolic rate*

C_v = *convection*

R = *net radiation*

C_d = *conduction*

E = *evaporation heat loss* ΔS = *change in heat stored*

If ΔS is positive then the body temperature has increased otherwise decreased.

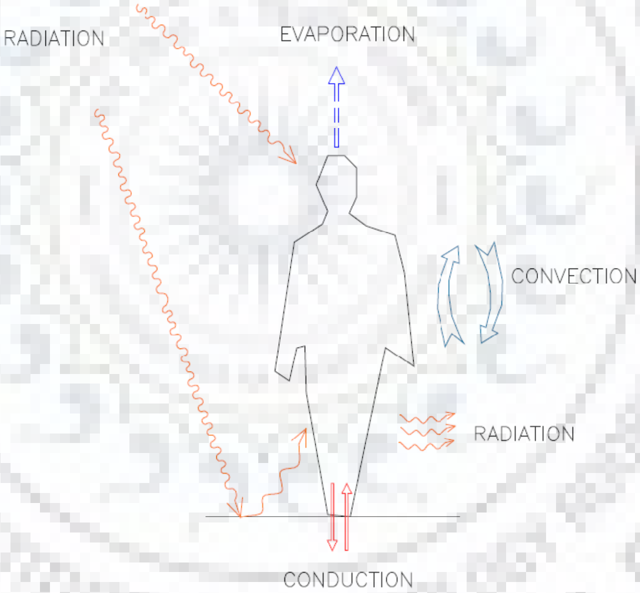


Fig.2.4 Heat exchange processes of human body with the surroundings [32]

2.3.2 Adaptive model

The Adaptive Model does not approach thermal comfort from the physics of heat exchange, but from the human behaviour [64]. It is based on the premise that a person is no longer a passive recipient of the given thermal environment, but instead an active agent interacting with the person-environment system via multiple feedback loops [60]. It is important to understand that there are factors beyond the physics of the body's heat balance, such as climatic setting, social conditioning, economic considerations and other contextual factors, that affects the thermal expectations of the subjects [60].The adaptive approach advocates a responsive environmental control algorithm with the enhanced comfort levels and reduced energy consumption [65]. Many studies in recent years have used the adaptive thermal comfort model as a tool for assessing the performance of buildings [66-68].

2.3.2.1 Thermal adaptations: Feedback loops

‘Adaptation’ is a generic term that can be interpreted as a gradual diminution of the organism’s response to the recurring environmental stimulation [65]. The natural tendency of a person to react to the thermal discomfort is expressed in term of ‘thermal adaptation’ [60]. The understanding of the feedback loops between the person-environment systems is very significant to evaluate the thermal adaptations [12, 60]. Thermal adaptation can be categorised into three different processes:

- Behavioural adjustment
- Physiological acclimatization
- Psychological habituation

2.3.2.1.1 Behavioural adjustment

Behavioural adjustments include all the modifications that a person might make, consciously or unconsciously, as a response to the thermal discomfort [60]. It offers people a wider range of opportunities to maintain their own comfort levels by altering their surroundings, clothing, metabolic activities etc. The extent to which one can behaviorally interact with their indoor climate depends on the contextual factors, i.e. the availability or the ease of use of the ‘adaptive opportunities’.

Fig 2.5 represents the feedback link between the people and the thermal environment using behavioral adjustments. In this, if a person feels uncomfortable, or even expects to become to, the thermal sensation of a person is immediately preceded with corrective actions, i.e. changing clothes, altering indoor environment etc.

Gail and de Dear [60] have classified behavioural adjustment into three sub-categories:

i. *Personal adjustment:*

   Responding to the indoor environment by changing personal variables such as - adjusting clothing, activity, posture, eating/drinking hot/cold food or beverages, or moving to a different location

ii. *Technological or environmental adjustment:*

Includes modifying indoor environment by opening/ closing windows, doors or shades ; turning on fans or heaters, blocking air diffusers; or operating other HVAC controls, etc.

iii. *Cultural adjustments*

It includes scheduling activities, siestas, adapting dress codes etc. In India, adaptive behavior of the people is significantly controlled by the social & cultural variables.

2.3.2.1.2 Physiological adaptation

Acclimatization is an unconscious feedback-loop mediated by the nervous system that directly affects our physiological thermoregulation set-points [65] (refer Fig. 2.6).

It can be divided into two categories:

i. *Genetic adaptation*

These alterations develops at a certain time scales (i.e. beyond that of an individual's lifetime)

ii. *Acclimation or acclimatization*

The thermoregulation system of a person is adjusted as per the thermal conditions it is exposed to for certain duration of time. The period of exposure to the thermal environment can be limited to days, weeks or even months; depending upon the fitness of the person [65].

2.3.2.1.3 Psychological feedback-habituation and expectations

The earlier work of McIntyre has been acknowledged for the role of expectations in thermal comfort. He stated that '*a person's reaction to a temperature which is less than perfect will depend very much on his expectations*' [60]. Studies suggest that building occupants becomes accustomed to the prevailing conditions sometimes as a result of exposure to the extreme conditions on a time scales of weeks to months. These synoptic and seasonal processes can explain the differences in the observed and predicted difference in the thermal sensation [60].

Fig. 2.7 shows the psychological feedback-loop as a response of the long exposure to the environmental changes in the form of socio-cultural practices or architectural & HVAC adjustments. The thermal sensation of a person, thus, alters as per his/her expectations and habituation to the surrounding environment.

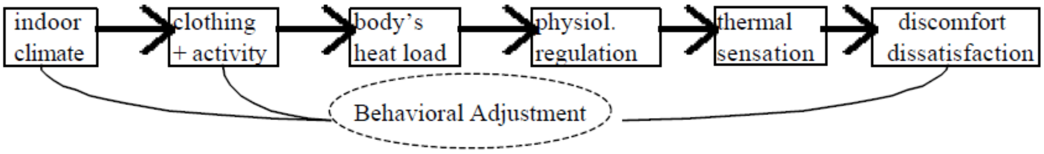


Fig. 2.5 Behavioral feedback loop [65]

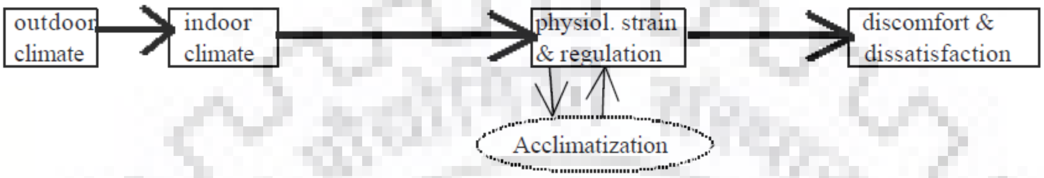


Fig. 2.6 Physiological feedback loop [65]

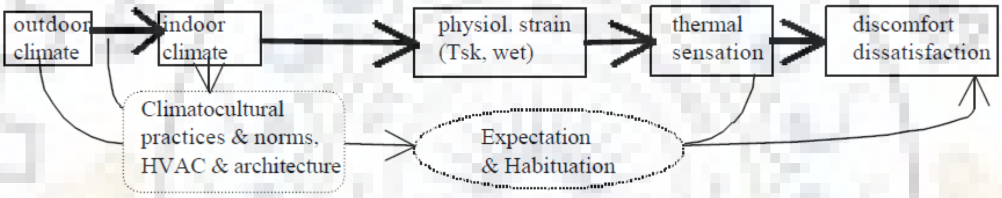


Fig. 2.7 Psychological feedback loop [65]

2.3.3 Thermal indices in thermal comfort

Field studies have shown an intriguing dependence of thermal sensation on the physical environmental parameters. Macpherson identified six factors that affect the thermal sensation of the people-

1. Air temperature
2. Mean radiant temperature
3. Humidity
4. Air speed
5. Metabolic rate
6. Clothing levels

Few of the indices that have been widely used to express the effects of thermal environment on human body are PMV, Effective Temperature (ET), Standard Effective Temperature (SET), Operative Temperature, Globe Temperature etc.

2.4 Building Design: Thermal Performance and Energy-Use

Building exchanges heat with the environment through various building components i.e. wall, roof, windows etc. by conduction, radiation; convection and evaporation (refer Fig.2.8). As shown in the Fig.2.9, the heat flow through the building broadly depends on four variables:

1. Weather (i.e. temperatures, solar radiation , wind speed etc.)
2. Design variables (like building configuration i.e. surface to wall ratio, window to wall ratio, building form, fenestration, etc.)
3. Thermo-physical properties (i.e. specific heat capacity, density, thermal conductivity etc.) of the building envelope that regulates the time lag and decrement factor (i.e. reduction in the amplitude of the heat waves) of the heat flow.
4. Usage data of a building (i.e. heat gain/loss due to occupants, lighting and equipment etc.).

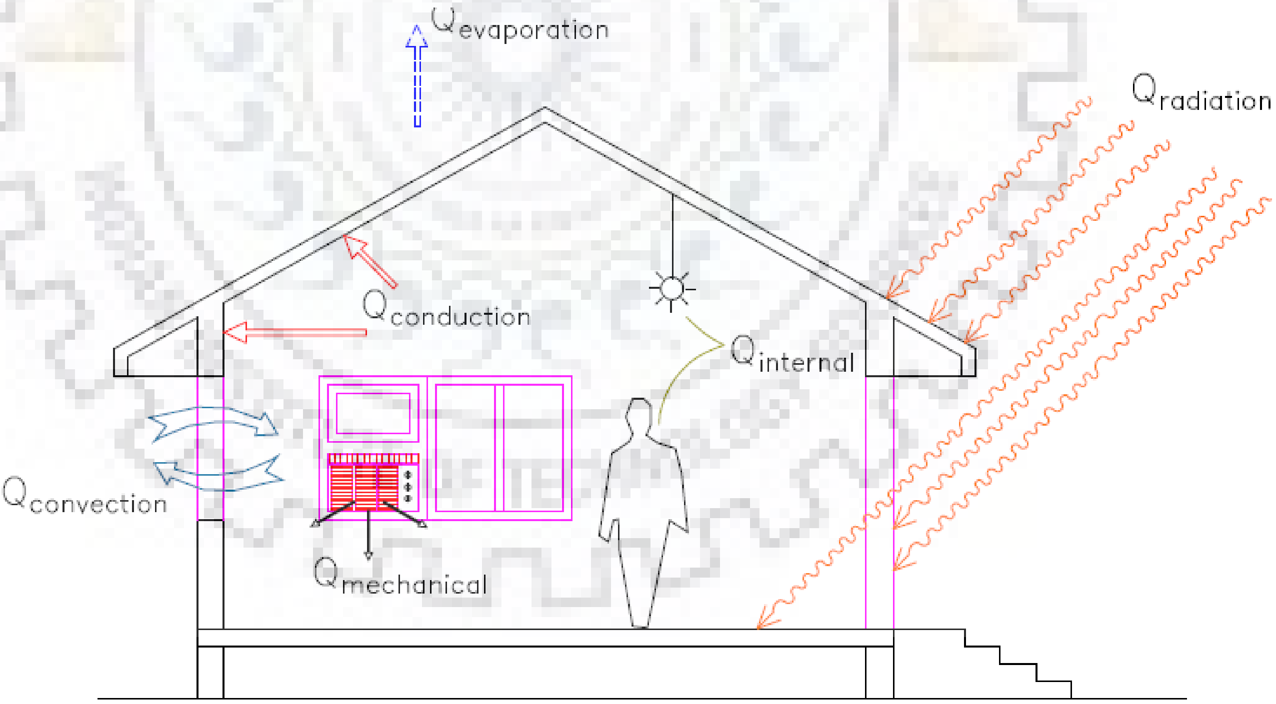


Fig. 2.8 Heat exchange processes of building with the surroundings [32]

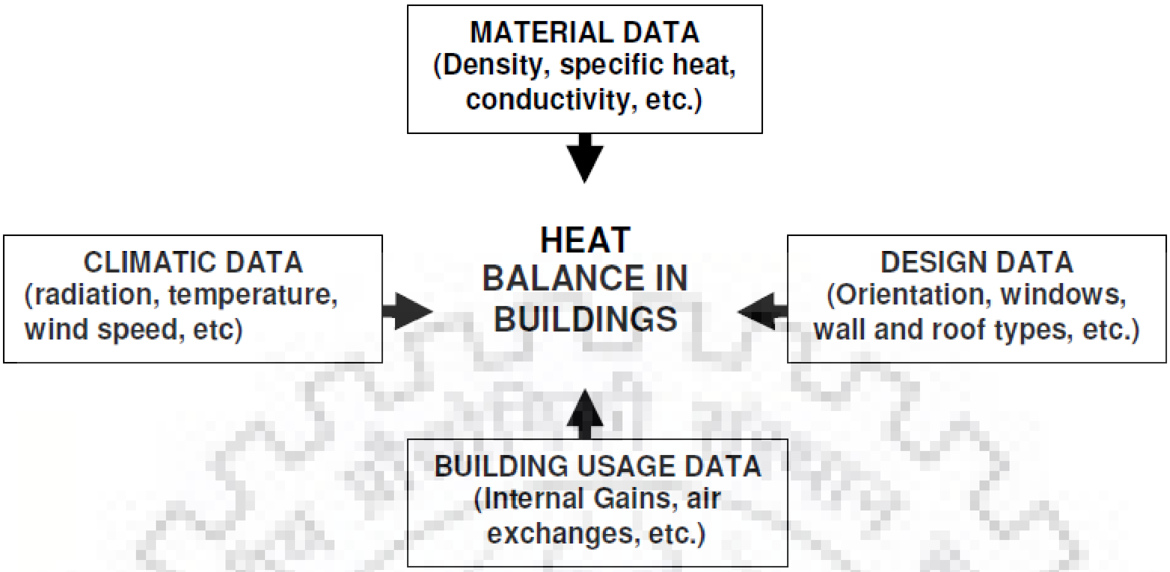


Fig 2.9 Thermal performance of building- Flow-paths [32]

Following section summarizes the parameters that are necessary to enhance the performance of the buildings:

2.4.1 Climate

Climate plays an important part in terms of maintaining thermal comfort conditions and the energy-use patterns of the building. Buildings located in different climatic region would have different cooling /heating requirements with different peak loads as well as total energy demands for the same level of indoor conditions. The climatic zone in which the building is built is crucial both in terms of weather conditions and architectural style, and therefore influences its energy behaviour [69].

2.4.2 Site

Landform, vegetation, water bodies, open spaces, setback from the surrounding built structures are some of the important elements of the site that needs to be identified and analyzed at the earlier stages of the design. By making use of the on-site elements, one can design a climate responsive building with a minimum impact on the surroundings. By integrating site-specific conditions one can enhance the indoor comfort conditions and the resultant energy consumption. Fig.2.10 gives few of the examples of the site-specific design considerations.

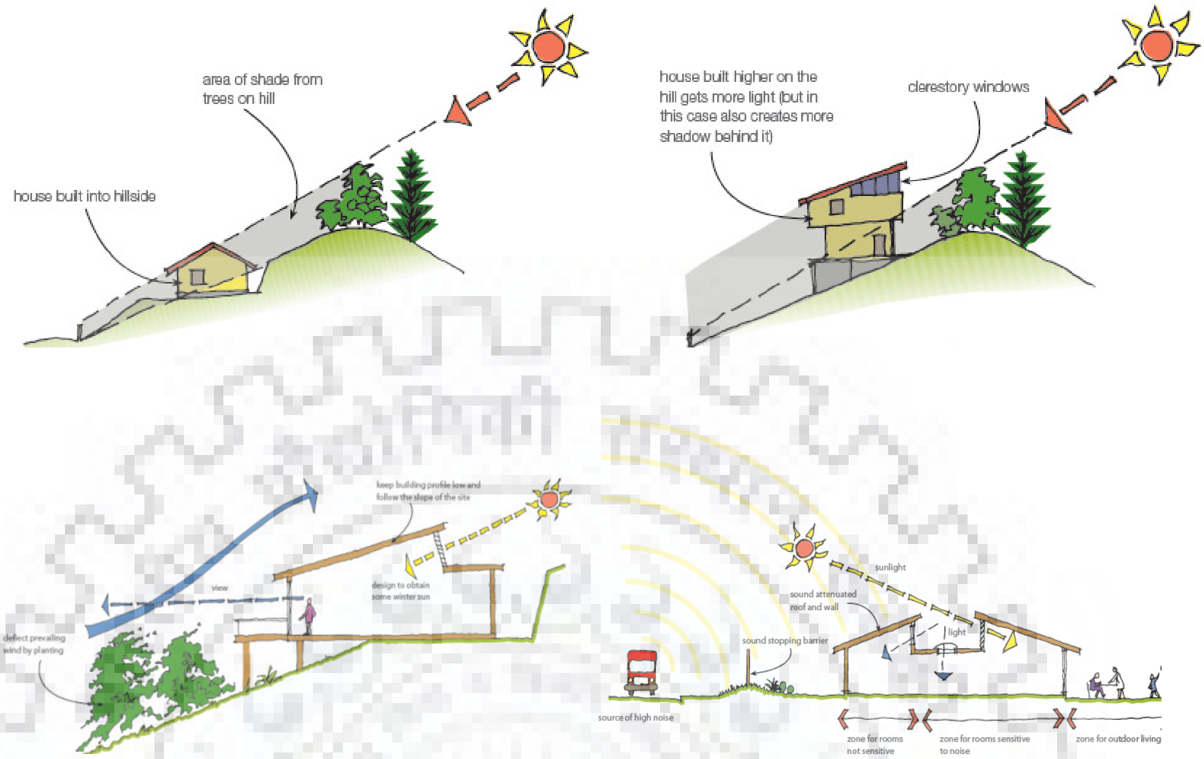


Fig 2.10 Examples of site specific design considerations [70]

2.4.3 Orientation

Sun path diagram is most commonly used to know the intensity of the solar radiation and the duration of the sunshine on the facades of the building envelope. Orientation of the building can significantly control the effect of solar exposure on the various building components and subsequently the heat conduction flows. Building should be so oriented to allow the maximum solar radiation in cold climate while preventing the same in the hot climate. ECBC [71] suggests, proper orientation can help to decrease the heat load by 5%. For example, if the longer side of the building in the composite climatic zone faces north and south and the short sides faces east and west, the heat load can be reduced. Fig2.11 illustrates the solar gains through the building envelope for east-west orientation. Further, orientation considerably affects the designing of the following building components:

- glazing
- types of walls and roofs
- shading devices

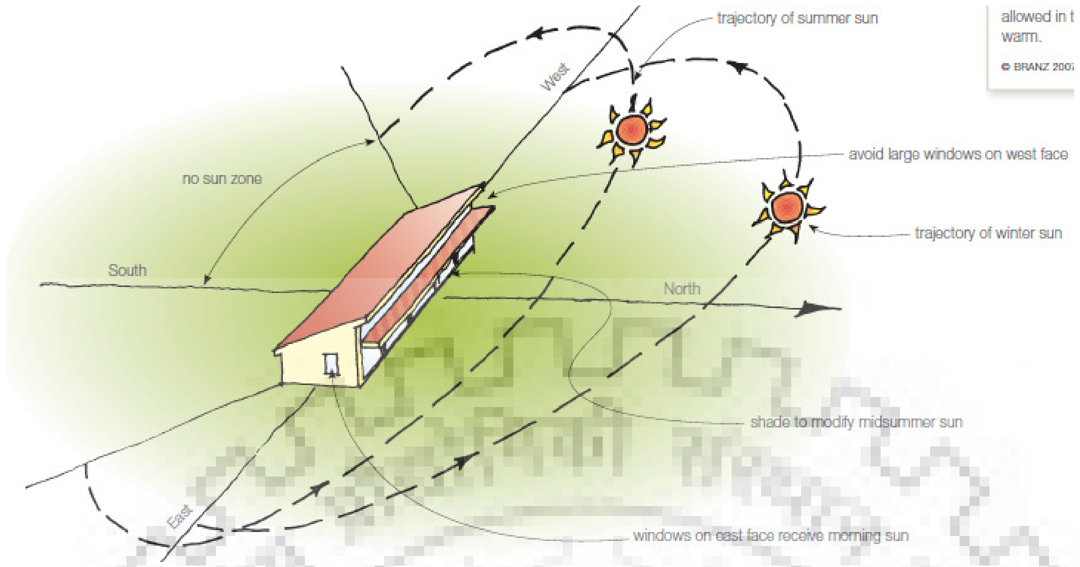


Fig2.11 Sun path diagram and the respective solar gains [70]

2.4.4 Building configuration

The geometry of the building and its components affects its overall thermal performance. The heat exchange processes and the cross ventilation is majorly regulated by its shape, arrangement of fenestration, shading devices, provision of buffer spaces etc. Following section elaborates the same:

2.4.4.1 Surface area to volume ratio (S/V ratio)

The amount of heat lost or gained depends upon the surface to wall ratio (S/V). If the S/V ratio is larger, so does the heat gain/loss for a given volume of space. A compact building gains less heat during the daytime and loses less heat at night. The compactness of the building is the ratio of its surface area to its volume, that is, Compactness = S/V (surface area/volume).

In a hot-dry climate, the S/V ratio should be as low as possible to minimize the heat gain. In a warm humid climate, the prime concern is creating airy spaces. This would require a higher S/V ratio [8]. N.K. Bansal et.al. [72], in his research has shown a parametric equations between surface to volume ratio (S/V) and energy load, taking into account the effect of increasing height as well as increasing length and width of a building in a composite climate of India. The study concluded that the energy consumption slightly increases with increasing S/V for both un-insulated and insulated building.

2.4.4.2 Shape of the building

Building shape controls the indoor air flow pattern by creating positive pressure on the windward side and negative pressure on the leeward side [32]. Building form can also lead to self shading (especially in H-type or L-type as oppose to the simple cube) or can modify the airflow pattern around the building. Bostancioglu [73], studied the impact of building shape on construction cost and life cycle cost (LCC) in multi-storied residential building in Turkey. Results showed that the increase in energy cost due to orientation is 0.86% and increase in costs due to changes in building shape reaches up to 26.92%.It is concluded that if area to volume (A/ V) ratio increases, the construction cost, energy and LCC increases.

2.4.4.3 Shading

The affect of solar radiations on the external surfaces can be controlled by shading devices. Exposed surfaces of the buildings are usually shaded with the help of horizontal & vertical shading devices, extruded balconies, awnings etc. A drop of 4.6°C has been observed in a low rise residential building (Ahmadabad) by employing a horizontal shading device of 0.76m depth [32].

2.4.4.4 Buffer spaces

Balconies, courtyards, verandahs can provide a shaded buffer area and can help in reducing the ambient temperatures of the indoor spaces in warm areas.

2.4.4.5 Arrangement of openings

Cross ventilation can be regulated by providing window openings so as to connect the high pressure areas with the low pressure areas (refer Fig.2.12). Nguyen et.al.[74] in his study , showed that the distribution and configuration of the openings should be adjusted to improve the natural lighting and ventilation. Hassan et al. [75] conducted a study on CFD simulations and wind-tunnel experiments to investigate the affects of window positions on ventilation characteristics of a simple single room. It was concluded that single-sided ventilation with two distant openings (one far left and one far right) performed better than the two adjacent openings (centre-located).

Gao et.al. [76] used field measurements and CFD simulations to study the affect of opening configurations on overall natural ventilation performance of a residential unit. It was found that better natural ventilation performance could be achieved when the two openings were positioned in opposite directions or perpendicular to each other. The concept of MAA (mean age air) was adopted to represent natural ventilation performance in both field measurements and CFD simulations. Trace gas technique is used to measure the MAA in the field measurements (where CO_2 is taken as the trace gas) for CFD model validation. The concentration decay method was used to compute MAA at various predefined samples positions in the chosen residential unit. It was concluded that mean age air (MAA) is most sensitive to varying window positions followed by building orientation and door positions.

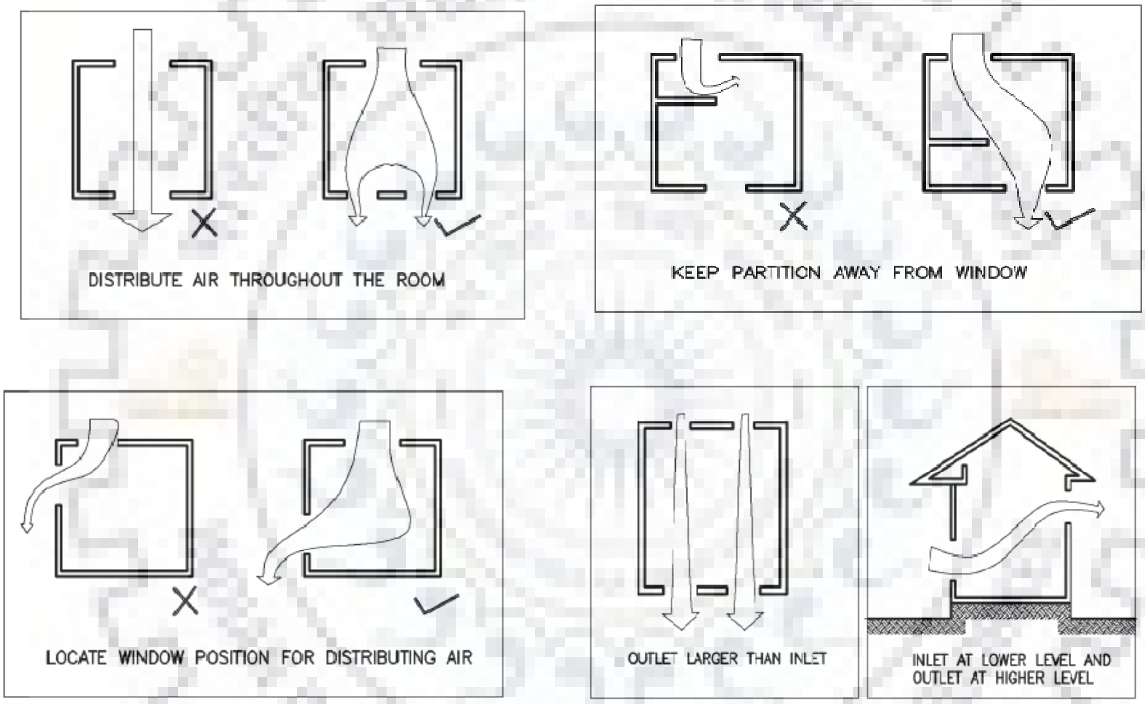


Fig.2.12 Window arrangements for cross ventilation [32]

2.4.5 Building components

The thermal properties of the building components determine the heat flow (gains/losses) processes and the comfort conditions of the indoors. Following are the some of the building elements that affects the heating and cooling load or the overall energy use profile of any building:

1. Roof
2. Walls
3. Fenestrations

4. External color and texture

In a study, walls and windows are observed to be accounting for 80% of the cooling load in residential buildings in major cities of India [32]. Maximum cooling load was observed for windows, i.e. 52.9% -64.7%, followed by heat conduction through wall (i.e. 26.5-36.4%). Bouchlaghem [77] also presented a computer model, which simulated the thermal performance of a building by taking into account the design variables related to the building envelope and by optimizing window-shading devices. A research project, titled ‘Standards of Collective Housing Projects’ supported by Tubitak engineering research group[73], addressed the residential building standards with a focus on design, economy and physical environment control conditions of spaces. The study has compared both the construction cost and the heating cost of the residential buildings. It was found that although the window sizes had some affect but a marked relation is observed between F/V (external facade area to building volume) ratios and the heating load.

Liping [78] investigated the impact of various ventilation strategies and facade designs on indoor thermal environment for naturally ventilated residential buildings in Singapore. Parametric studies of facade design on orientation, window to wall ratios and shading devices were performed for two typical weeks by coupled simulations between ESP-r and CFD (FLUENT). In total, 26 various facade design scenarios were investigated and 52 cases were simulated for indoor thermal comfort evaluation. It was found that north- and south-facing facades can provide much comfortable indoor environment than east- and west-facing facades in Singapore. It is recommended that optimum window to wall ratio of 0.24 can improve the full-day ventilation and 600mm horizontal shading devices are needed for each orientation in order to improve the thermal comfort.

Favarolo et al. [79] also adopted CFD simulations and laboratory experiments to analyze the influence of openings configuration on natural ventilation performance. It was concluded that when dealing with single-sided ventilation, ventilation performance was most affected by the vertical position and the width of the openings. For cross ventilation, Tantasavasdi et al. [80] explored the potential of natural ventilation in the houses of Thailand and concluded that the inlet aperture area should be around 20% of the floor area to achieve adequate natural ventilation for an acceptable comfort level; and Yin et al. [81] reported that the ventilation performance was most influenced by the relative vertical positions of the two window openings.

Majumdar [82], reported some conceptual ideas in reducing the energy use in buildings especially for heating, cooling, ventilation and lighting in different climatic zones of India. She presented 41 case studies of buildings designed by various architects incorporating energy saving features in the design, without quantifying the energy savings/ consumption in these buildings. She concluded that in a typical naturally ventilated building in India, lighting accounts for maximum energy consumption but in an air-conditioned building, 40-50% of the total electricity consumption is accounted for HVAC system, followed by lighting system (20%). Other load (pumps, equipments etc.) contributes to 20-30 %.

2.5 Evaluation Tools for Energy Efficiency

The best approach to analyze the building performance and to efficiently optimize the energy use is by using a computerized tool or energy software tool [83]. A simulated environment is created by integrating the thermal properties of the building envelope, internal loads, weather conditions and most importantly the operation schedules of various appliances and the occupancy. U.S Department of energy has enlisted 416 building energy software tools for evaluating energy efficiency of the buildings. These tools are broadly divided into following categories:

- Whole Building Energy Performance Simulation
- Validation & Testing
- Standard Compliance

To comprehend the dynamic interactions of the building requires a sophisticated computer based tools and software's. It makes it easier to comprehend the energy and thermal performance of the building for various alternatives, especially at the conceptual stage of the building. *Energy-Plus, DOE, e-Quest, Design Builder's* etc. are few of the simulation software's which are widely used by energy consultants through-out the world.

However, it has its limitations as in most of the cases significant differences are observed between the simulated and measured results [83]. These differences have been accepted by the researchers as the inherited uncertainties, which should be within the acceptable statistical tolerances as recommended by various statuary bodies. The international performance measurement and verification protocol (IPMVP, 2010) and ASHRAE guideline 14, 2002 [84] has framed the guidelines for measuring and evaluating the energy performance of the building. The *'whole building calibrated simulation'* approach gives the best result when the overall performance is to be assessed. It helps in creating a model for the pre-retrofit conditions by calibrating it against actual data. The calibrated model is, then, used to estimate the energy savings for the retrofit measures.

2.6 Inferences

- Indoor and outdoor environmental parameters strongly influence the energy consumption profile of a building along with the thermal sensation of a person.
- Adaptive model of thermal comfort is more ideal for identifying the comfort levels of the people in naturally ventilated buildings in tropical climate.
- PMV model has shown satisfactory results for conditioned buildings but the scope of its application, in naturally ventilated buildings, in warm climate still needs to be proved with appropriate alterations.
- Thermal adaptations in the form of behavioral adjustments, physiological and psychological adjustments are very important in thermal comfort evaluation.
- Comfort temperature is directly proportional to the mean outdoor temperature. The occupants of naturally ventilated buildings have wider range of comfort level as compared to the occupants of air conditioned buildings. This indicates that thermal comfort requires a case by case approach. Adaptive approach as suggested by researchers (Nicol& Humphreys and de Dear) is very suitable for naturally ventilated buildings especially in a country like India.
- Natural ventilation is most sensitive to the change of windows position, followed by building orientation. Door position incurs very little influence on the overall natural ventilation performance.
- The uniform standards adopted in India underestimates the human adaptability and has serious energy implications on the way environmental controls/ energy efficient strategies are designed, installed, and used.
- The orientation and the shape of a building significantly affect the construction cost, energy cost and LCC of buildings in terms of solar gains.
- Façade designs- WWR and shading devices helps in improving the thermal performance of naturally ventilated buildings.

- In composite climate of India, energy consumption increases with the increase in area to volume ratio (A/V ratio).
- Occupants can dramatically affect the energy demand and this is mostly stimulated in response to the indoor environmental conditions (air temperature, air velocity, humidity etc.).

CHAPTER 3

STUDY AREA, FIELD SURVEY AND SIMULATION ARRANGEMENT

3.INTRODUCTION

A field survey is conducted in the year of 2012 in five naturally ventilated (NV) multi-storied apartment buildings. The selection of the case studies was solely made on the basis of factors like climate zone, building type, income group, no. of floors, floor areas/ dwelling units (DU) and most importantly clearance from the concerned authorities i.e. the president of the societies and the approval of the occupants to be surveyed. Two buildings i.e. Hill View Apartments (HV) and Canal View Apartments (CV) are located in Roorkee and the other three buildings i.e. Grow-more Society (GMR) and Bhaimata Das Society (BMD) and Trishla (TR) are located in Chandigarh.

This chapter gives the detail of the study area along with the description of the longitudinal field survey that has been conducted for the studied period. The simulation arrangement used to construct the baseline models is also supported with the necessary statistical indices for validation. The assumptions that are made at the earlier stages of the research have also been illustrated. This chapter can be referred for the dataset that has been used for the thermal comfort analysis and the energy-use of the studied buildings, as discussed in chapters 4&5.

3.1 Study Area: Location & Climate

3.1.1 Chandigarh

Chandigarh is located in the foothills of the Shivalik hill ranges of the Himalayas in the northwest India. It covers an area of approximately 114 km² and shares its borders with the states of Haryana and Punjab. The exact cartographic co-ordinates of Chandigarh are 30.44°N & 76.47°E. It has an average elevation of 321 meters (1053 ft). May and June are the hottest months of the year with the mean daily maximum & minimum temperatures around 37°C & 25°C, respectively. January is the coldest month with mean maximum and minimum temperatures being around 23°C and 3.68°C respectively [85]. The annual rainfall ranges between 700 mm to 1200 mm.

3.1.2 Roorkee

Roorkee is situated at the foothill of the Himalayas, in Hardwar district, within the state of Uttrakhand [86]. It lies in 29^0 51'N latitude, 77^0 53' E longitude at an altitude of 274m, with the temperatures ranging from above 40^0C in summer to below 5^0C in winter [87]. Temperature begins to rise from March (29.1^0C) and reaches to its maximum point in May (39.2^0 C). The temperature begins to fall with the commencement of monsoon season i.e. around mid-June. During the winter season, i.e. from November to February, the temperature ranges between 10.5^0C to 6.1^0C. The relative humidity is highest in the monsoon season (i.e. 85% in the morning and 79% in the evening). The lowest humidity is observed during the month of April and May i.e. 24% (in evening) and 40% in May (in morning) [86]. The total annual rainfall is about 2600 mm (102 in).

As per climate classification proposed by Bansal and Minke (1988) [32], Chandigarh and Roorkee both fall under composite climatic zone (refer Fig.3.1).

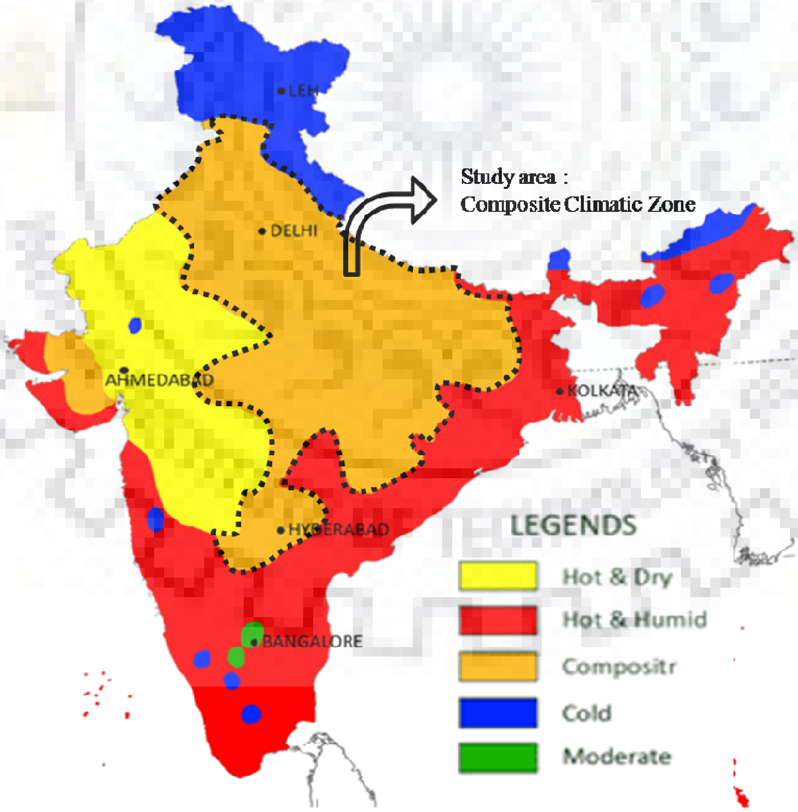


Fig 3.1a Climatic zones of India [48]

3.2 Field Survey

3.2.1 Data collection

A longitudinal field study is conducted in the year of 2012, such that the thermal responses of all the subjects are recorded for each month, to investigate the change in the thermal perceptions with the changing physical environment. Indoor physical environmental variables, i.e. the air temperature, globe temperature, air velocity, and relative humidity, are measured (at the level of 1.1m) along with the personal variables (i.e. 'clo'; clothing levels and 'met'; metabolic levels) for each occasion when the thermal questionnaire is conducted ; defined as Class II level survey in RP-884; [65]. The thermal responses recorded in these surveys are coherent to the physical and the personal variables of the subjects and are, therefore, useful to establish the adaptive behavioral patterns.

Five naturally ventilated multi-storied apartments (6-9 storeys) are studied on a monthly basis for the whole year. Two buildings, i.e., HV & CV are located in Roorkee whereas other three buildings are located in Chandigarh (GMR, BMD & TR) (refer Fig 3.2 and Fig. 3.3a, b, c, d & e for details). The survey was fairly distributed between lower floors, middle floors and top floors; to analyze its effect on the thermal behavior of the buildings and its occupants. Table3.1 gives the detailed summary of the surveyed buildings**.** Table 1.1 in Appendix-1 gives the distribution of the surveyed apartments in different levels.

Table 3.1 Detailed Summary of the surveyed buildings

Apartment	Location	No. of floors	Flats per floor	Floor area of flat (m^2)	Ventilation Type	Orientation	Building Proximity	Construction Type	Building Layout
GMR	Panchkula	G+9	6	132.1	*NV	NE-SW	RC	[b] Standard	Open
TR	Zirakpur	G+6	12	119.2	NV	NE-SW	OFC	[b] Standard	Closed
BMD	Panchkula	[a] G+8	4	155.5	NV	NE-SW	OF	[b] Standard	Open
HV	Roorkee	G+7	4	173.7	NV	[c] E-W	RA	[b] Standard	Open
CV	Roorkee	G+6	3	162.5	NV	N-S	GCM	[b] Standard	Closed

[a] the top floor has a two pent houses, [b] RCC framed Structure on Stilts with Brick Masonry , [c] Orientation of each block
RC- Residential complex and Construction Site, OFC- Open Field and Construction Site , OF- Open Field, RA- Residential and Academic Buildings , GCM- Ganga canal and main road
** NV- Naturally Ventilated*

Fig 3.2a Location of the surveyed buildings (Hill View Apartments, HV; Canal View Apartments, CV; BhaimataDas Apartments, BMD; Growmore Society, GMR & Trishla Apartments, TR) in the composite climatic zone of India.


Fig. 3.3a Hill-View (HV)


Fig. 3.3b Canal-View (CV)


Fig. 3.3c Bhaimata Das (BMD)


Fig. 3.3d Growmore (GMR)


Fig. 3.3e Trishla (TR)

The questionnaire is based on Madhavi [10] and designed in English, as phrases with check boxes for the response (refer Appendix-2). Survey sheet included interviewee's demographic information, thermal sensation votes, clothing level, activity level and adaptive use of environmental controls at the time of voting. 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 [88]. Besides this, questions related to the tenure of stay, number of family members, household appliances & the hourly consumptions of fans, A/c's, heater/blowers etc. are also included in the questionnaire. Table 3.2 and Table 3.3 gives the brief description of the collated data and the sources from where the data is collected, respectively.

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. "SIKA" MH 3350-Thermo Hygrometer has been used to measure relative humidity (RH) and Ta (using sensor probe TFS0100) & indoor globe temperatures is measured using sensor TYP101; whose probe was inserted in a black-painted table tennis ball (about 40mm diameter). Digital Vane Thermo Anemometer (Model: 93460) is held perpendicular to the source of ventilation (in this case, mostly fans or air coolers) to measure the air movement. The effect of natural ventilation (through doors, windows etc.) was not marked, with respect to the position where the subject was seated during most of the occasions, and, therefore only included when the cross ventilation is observed. All the instruments are calibrated during each session and are positioned close to the respondent at a level of 1.1m (refer Fig3.4a.b&c). The participant's metabolic rate ('met') and clothing insulation ('clo') were estimated using numerical 'met'& 'clo' values (as specified in ASHRAE 55 Standard) for typical activities & clothing, (refer Table1.2 a& b of Appendix-1). Local meteorological stations (IMD, Chandigarh) and observatories (National Hydrology Centre, Roorkee) are approached for the outdoor environmental data. Detailed summary of the measured physical variables, thermal responses and the 'clo' level & 'met' levels of all the subjects is given in the Table 1.3 a, b & c in Appendix-1.

Fig 3.4a MH 3350- Thermo Hygrometer (with temperature probes) and Handheld Digital Vane Thermo Anemometer

Fig3.4b Instrument setup at 1.1m level

Fig3.4c Subject during survey

Table 3.2 Brief Summary of the Collected Data

Comfort Analysis	
Outdoor Parameters	Ambient Air Temperature, RH , Wind Speed
Indoor Environmental Parameters	Ta,Tg,RA & Av
Personal Parameters	Clo & met
Thermal responses	Thermal sensation, thermal preference & thermal acceptance
Controls (Adaptive Opportunities)	Use of doors, windows , fans , A/c's heater/hot blowers etc.

Energy Analysis	
Utility Bills	At max. 2 consecutive years for validation of simulated model *[ASHRAE-14]*
Building Plans	Occupancy density
Occupancy hours	Activity schedules
Hourly consumption of equipments	Equipment schedules
Architectural Drawings & site visits	Construction Details

Table 3.3 Brief Summary of the Instruments	
Physical Environmental Variables (Indoor)	
➢ Air temperature (Ta)& Relative Humidity (RH)	"SIKA"MH 3350 (Digital Thermo-hygrometer) with TFS 0100 (sensor) temperature probe
➢ Globe Temperature (Tg)	TFS100E (sensor) whose probe was inserted in a black-painted tennis ball (about 40mm diameter)
➢ Air velocity(Av) :	Handheld Digital Vane Thermo Anemometer
Personal Variables	
➢ Met & clo	Estimated using checklist from ASHRAE 55 for corresponding activities & clothing
Outdoor Environmental Data	
➢ Local meteorological stations & Observatories	IMD, Chandigarh and National Hydrology Centre, Roorkee

On the first visit, occupants were deliberately explained about the research and the survey to be conducted. However, few subjects refused to participate after sometime, bringing down the total number of subjects from 122 to 82. Subjects were hesitant and sceptical with the frequent visits in a day, so it was decided to conduct the interviews once a month for all the subjects. In order to investigate the individual changes between the seasons, only those subjects are included who participated in all the twelve months. So, finally 55 apartment units & 82 subjects of five different buildings were studied for 12 months in the year of 2012. This study collected a data-set of 984 in total.

3.1.1 Sampling

Out of 82 subjects, 29 males (~35%) and 53 females (~ 65%) participated in the survey (refer Table 3.4). The average age of male and female subjects is 39.2 years and 39.8 years, respectively. The subjects were distributed in the age groups of young (≤7-17 yrs), middle (≤ 20-50 yrs ≥) and old (≥50yrs) categories. Approx. 13.4% were young subjects, 64.6% belonged to the middle age group and 22% falls under old age group, (refer Table 3.5a & b). 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. An insulation of 0.04clo for undergarments and 0.15 clo for upholstery (if subject was seated or found resting) was also added to the insulation.

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

Table 3.4 Detailed Profile of Subjects

Apartment	No. of Subjects		Weight (Kg)				Height (mt)				Age			
	Males	Females	Males		Females		Males		Females		Males		Females	
			Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
GMR	10	10	67.3	12.3	63.8	10.9	1.7	0.1	1.6	0.1	42.3	20.8	39.3	12.1
TR	5	10	59.2	17.9	59.7	7.9	1.6	0.2	1.6	0.1	29	21.3	33	3.3
BMD	4	9	63.3	8.2	64.8	11.9	1.7	0.1	1.6	0.1	51.3	17.2	32.1	10.4
HV	5	10	61.4	14.3	68.9	11.5	1.7	0.1	1.6	0.1	38.4	23.1	47.7	17.6
CV	5	14	59.6	20.2	59.4	11.2	1.6	0.2	1.6	0.1	34.6	26.9	44.2	16.7
TOTAL	**29**	**53**												

Table 3.5a Gender-wise Sample Distribution

	Males	Females
	35%	65%
Average Age	39.24yrs	39.77yrs

Table 3.5b Age-wise Sample Distribution

Young	Middle Age Group	Old
≤7-17 yrs	≤ 20-50 yrs ≥	≥50yrs
13.4%	64.6%	22%

Fig3.5 Clothing Ensembles of Male and Female Subjects in North India

most commonly used. Fig 3.5 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, but the 'clo' value for salwar-kameez was not available and it was estimated using following equation:

$$\mathbf{Icl = 0.00103W - 0.0253}$$

where, Icl = clothing insulation and W= weight of the garment in grams (g) [10]. 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.

3.1.1 Physical environmental parameters

3.1.1.1 Outdoor environmental conditions

- *Summer (mid March to mid June):* Maximum temperature observed was 41.3°C & 41.5°C for Chandigarh and Roorkee respectively. Table 3.6 gives the annual outdoor environmental summary of the studied regions. Diurnal range was high in summer as compared to other seasons with standard deviation of 5.8 for Chandigarh and Roorkee. Mean temperature was 30.01°C in Chandigarh and 27.31°C in Roorkee. Relative Humidity (RH) varied moderately with the mean of 61% (standard deviation, StDev= 3.2) in Chandigarh and 64.9% (StDev=2.69) in Roorkee. Detailed summary of the outdoor environmental conditions for all the seasons are presented in Table 1.4a of Appendix-1.
- *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 (StDev= 2.1). For Roorkee the figures didn't vary much with the mean of 16.2°C and StDev of 1.6 (min.=7.5°C & max.=26°C). RH varied moderately with the mean of 42.8% (SD= 3.9) in Chandigarh and 40% (StDev=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 1.4a of Appendix-1), paired with high humidity made the environmental conditions quite stuffy in this season.

Table 3.6 Annual Summary Outdoor Environmental Conditions for the Surveyed Period

	Chandigarh				Roorkee			
	Mean	**Min**	**Max**	**StDev**	**Mean**	**Min**	**Max**	**StDev**
Toutside	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

Toutside : Outside Temperature
RH : Relative Humidity

3.1.1.2 Indoor environmental conditions

- *Summer:* Maximum Tg observed in summer period was 36.2°C with the mean of 30.1°C. Lowest RH is observed during this period i.e. 22.8% (mean=38%). Measured air velocity ranged from 0.0 to 1.2 (StDev of 0.31). The airflow measured during this season was mainly attributed to the ventilation through fans or evaporative coolers. Table 3.7 gives the annual indoor environmental summary of the studied regions and refer Table 1.4b of Appendix-1 for the seasonal data.
- *Winter:* Mean globe temperature observed for winters is 18.6°C with a min. of 14.9°C and maximum of 24.3°C (StDev=2.6). RH was within the range of 42.1% to 70.8% with a StDev of 6.1. Air velocity measured was less as compared to summer & monsoon period, mainly because the doors and windows were kept closed to keep indoors warm.
- *Monsoon:* Mean globe temperature ranged between 26.8°C to 35.2°C with the mean of 30.76°C in monsoon. Relative humidity was highest during this period with maximum value of 84.8% (mean=61.77%) and StDev of 10.46. Air velocity measured during this period was significantly high with a value of 2.5 (mean=0.8).

Table 3.7 Annual Summary Indoor Environmental Conditions for the Surveyed Period

	Chandigarh				Roorkee			
	Ta	**RH**	**Av**	**Tg**	**Ta**	**RH**	**Av**	**Tg**
Tmean	26.1	52.6	0.4	26.6	25.9	52.4	0.4	26.4
Tmin	14.2	23.6	0.0	15.0	14.1	22.8	0.0	14.9
Tmax	35.9	84.8	2.5	36.2	35.7	81.8	1.8	35.8
StDev	6.8	13.1	0.4	6.7	6.4	13.8	0.4	6.4

Tmean : Mean Indoor Temperature ; Tmin : Minimum Indoor Temperature ; Tmax : Maximum indoor Temperature ; StDev : Standard Deviation

3.2 Simulation Arrangement: Model Validation

Simulation models are created to conduct the energy-use analysis of the surveyed buildings. It is important that the simulation environment created by the baseline model represents the existing conditions. Following steps have been employed to validate the simulation model:

- Construct a baseline model using construction details, occupancy schedule, operation schedules, weather data etc.
- Analyze the preliminary results for debugging.
- Calibrate the simulated values against the monthly utility bills.
- Model validation using Percentage (%) Error, Coefficient of variance of the root mean squared error (CV RMSE) Mean Bias Error (MBE).

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. The collated data has been referred throughout the simulation process, i.e., at the early stage to create the baseline model & to calibrate it and, in the later stages, to compare the efficiency of the recommended measures in the retrofitted models.

3.2.1 Data

3.2.1.1 Building plans

The as-built building plans are obtained from the architect's office or concerned authorities of the apartment developers. Refer Appendix-3 to check the key plan and the floor plans of all the surveyed buildings. Site visits are conducted to cross check the data and to make any additions, if some detail is missing. Properties of windows, glazing type, shading from the nearby buildings, contextual details of the site are few of the other details that are also collected.

3.2.1.2 Utility bills

Although, it is preferred to have hourly data for calibrating the simulation 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 (i.e. government electricity boards) for two consecutive years (refer Table

1.5a,b,c,d &e Appendix-1). The billing data includes the monthly kWh consumptions of all the dwelling units (DU). Also, the installation of data loggers with minimum intrusion and maximum precision is found to be not only expensive but also impractical in a domestic setup. And, considering the skepticism of the occupants with the frequent visits, it is decided to conduct the survey on a monthly basis.

3.2.1.3 On-site survey & interview

Structural and construction details only provide the information about the thermal mass of the building envelope. But, heat conduction gains/loss through the building is a very complex system and depends upon factors like lighting system, occupancy, heating and cooling systems etc. Therefore, one-to-one interviews were conducted with the residents of the buildings to collect the data variables that are significant for framing the operation schedules. Data related to the number occupants/DU, tenure of tenancy, type of lighting system, hourly consumption of various appliances (fans, A/c etc.) is collected to assign the following schedules:

- Activity/occupancy schedule
- Operation schedule of appliances (which directly or indirectly affects the heating and cooling load)
- Type of ventilation and heating/cooling systems for each zone.
- Window operation schedule

3.2.1.4 Spot measurements

The spot measurements are made to record the indoor environmental variables (air temperature, Ta; globe temperature, Tg; relative humidity, RH & air velocity, Av) of the surveyed apartment units. This basically helped in evaluating the comfort analysis of the simulation software with the measured data. The selection of the surveyed apartment units is done so as to evenly cover the top exposed floors (TF), middle level floors and lower floors (LF).

3.2.1.5 Weather data

The role of any simulation is to predict the behavior of energy load and heat flow in a real time situation for the existing building. Also, it is used to evaluate the thermal environment and energy usage for the suggested alternatives/ ECM's in the retrofitted model. So, it is important to use the weather data that closely represents the physical environment to which the building is exposed to. In case of non availability of 'epw' file (Energy Plus weather) for the respective place, it is recommended to use the existing 'epw' file which is within 20-30 miles (30-50 km) and within a few hundred feet (100 m) of elevation [89].The climate zone is also an important consideration before selecting the epw file [84]. In the current study, epw file of 'Saharanpur' is used for Roorkee and 'Delhi' for Chandigarh, as both fitted the respected studied areas in terms of climate classification (i.e. composite) or the minimum range as suggested for using a certain 'epw' file. The use of single year data (i.e. the year of 2012 in the current case) or the Test Reference Year-type (TRY) weather data is avoided as it cannot represent the typical long –term weather patterns. Therefore, Typical Meteorological Year 2 (TMY2) and Weather Year as used for Energy Calculations 2 (WYEC2) in Energy-Plus are adopted.

3.2.2 Baseline model

Design Builder's (DB) v.3.0.0.105 is employed to evaluate the energy performance and thermal behavior of the surveyed buildings. The consumption of energy in a building is related to the physical variables, occupancy schedules and operational schedules of various appliances [90]. Measured data and real building information is used to assign the 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. The input details of simulation for the as-built baseline model are explained in the section below. Fig1.1 a, b, c, d & e of Appendix-1 gives the geometrical illustrations of the baseline models of the surveyed buildings.

3.2.2.1 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.V=0.4-.48 (m^2K)/W. Floors are typically concrete slabs with either tile finish or stone chipping/marble /Kota stone# finish. The windows are all clear, single pane glazing with and aluminum/wooden frame. Table 3.8 gives details of thermal properties of the structural

 # Kota Stone: a fine grained limestone, quarried at Kota, Rajasthan (India).

elements of the surveyed buildings. Fig 1.2a-i in Appendix-1 illustrates the construction details of the wall, roof and floor that are assigned to the baseline model.

Table 3.8 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

3.2.2.2 Operation schedules

Zones are usually aggregated (merged) in simulation models; such that the multiple zones with similar operation schedules are represented as a single large zone in the model. This approach (i.e. ‘5 zone’ per occupied floor having one core zone and four perimeter zones) has been the benchmark for the simulation results in the previous studies [83, 91]. Such simplifications and approximations in the model can lead to the inaccuracies or uncertainty errors. It is important to note that the thermal processes depend on the function of each zone, its position with respect to the exterior and the method used to condition the space [83]. In the study, therefore, the occupancy schedules, lighting loads and conditioning type are assigned on a zone-to-zone basis. The simulation input values for operational schedules are assigned on the basis of questionnaires conducted in 55 apartments in all the five multi-storied apartments. The section below explains the operational schedules that are assigned for the simulation model in this study.

3.2.2.2.1 *Lighting*

On the basis of responses received during the survey, lighting schedule is assigned to all the building models. A list of lamp types and number of lamps per zone is created to estimate the lighting power density of each zone. In most of the cases, the usage was predominantly around the late evening hours. In the present study, the schedule for lighting system is assumed to be running from 7am to 9am and 5p.m. to 12a.m (a standard family time when the occupancy is high and also the lighting is essential). It is notable that the lighting schedules vary in a domestic setup. Therefore exemptions made for the typical cases:

- During winters, with the early sunset and late sunrise, the lighting use varies.
- People who work late at night require a specific lighting schedule.

3.2.2.2.2 *Occupancy*

The number of working and non working occupants is used to estimate the occupancy density per zone in a building. The number of occupants in the studied buildings is graphically presented in Fig3.6 and as it can be seen more than 60% of the houses have 2–4 occupants. An average of '3' family members per dwelling is estimated in all five buildings. It must be noted that the dwelling with no occupancy at all or where the dwelling unit is unoccupied for a period of month or more are identified using monthly utility bills. Different schedules were assigned for these apartments units. Table3.9 shows the assigned schedules for each zone.

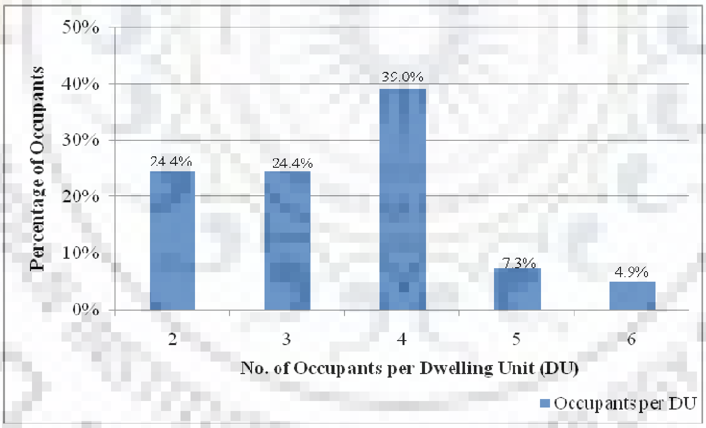


Fig 3.6 Distribution of number of ocupants per dwelling unit (DU)

Table3.9 Operation Schedules for different zones

Occupancy/Lighting	Assumed Schedules
Bed Room	7p.m to 7a.m & 9p.m to 6a.m
Living Cum Dining	9a.m to 7p.m
Kitchen	7a.m to 9p.m
Lights	7a.m to 9a.m & 5p.m to 11p.m

3.2.2.2.3 *Fan, A/c, heater/blower, hot water geyser*

Based on the data collected during monthly visits, running hours of each of the equipment is noted and the schedules are assigned on the basis of the average consumption hours for each of the building. The number of appliances and running hours varied for some cases as the disposable income level and the social stature varied for few of the surveyed occupants. But it is not marked enough to make any considerable changes within a building as the subjects, more or less, belong to the same income group (middle income group). Table3.10 shows the running hour details of all the buildings.

3.2.2.2.4 *Other daily-use appliances*

The average running hours of T.V, washing machines, computer/laptops for each of the building is assigned as per the responses of the surveyed subjects, summarized in Table3.10. It must be noted that appliances with the constant wattage, like refrigerators are not occupancy dependent where as daily use appliance like T.V, Fans, A/c, washing machine etc. are occupancy dependent. In case of refrigerators with 24X7 usages, only the operation cycle varies throughout the day (depending upon the cooling load or the indoor thermal load). The schedule for refrigerators are, thus, so assigned that its operation cycle is high in the afternoon hours and low in the morning and evening hours (in summer months) with similar usage-profile but less efficiency in winter months. Also, the rate power per equipment is assigned on the basis of equipment labels or internet product searches.

Table3.10 Average Hourly Consumption of Appliances in surveyed buildings (in hours)

	AC	Fans	Water Heater	Heater/ Blowers	Computer	Laptop	T.V	Washing Machine
CV	2	9	1	1	1	2	3	5
HV	3	9	1	2	1	1	4	2
BMD	2	9	1	1	1	2	5	4
TR	2	10	0	2	1	1	5	3
GMR	2	10	1	1	1	2	4	4

Once the simulation input values are defined and readily entered to create the simulation model, the results are compared with the monthly metered data. In the beginning stages, the desired tolerances are not achieved and the anomalies between the simulated and metered data are analyzed to identify and eliminate the input errors, the process being called debugging. The changes made during debugging are based on the earlier simulation input /output checks with the collated data(or measured data), as also suggested by Kaplan et.al. [92]. It includes, zone typing, external surface/structural characteristics, operational schedules for fan, lighting, A/c, heater/hot blower, ventilation selection etc.

3.2.3 Uncertainties and model calibration

The ‘errors’ or ‘uncertainties’ in any simulated model are either attributed to the behavior of the occupants [93], personal bias of the modeler [83,94] or the input variables representing the operational schedules of a building. In case of residential buildings, the indoor thermal environment, occupancy and the operational schedules of the equipments are erratic, making it quite difficult to define these uncertainties. Therefore, it is necessary to calibrate the simulation results with the actual data so as to reduce the risk of compromising the results.

The international performance measurement and verification protocol (IPMVP, 2010) and ASHRAE guideline 14, 2002, endorse the *whole-building calibrated simulation approach* for measuring and verifying the energy savings achieved in the existing buildings [95].It is recommended to collect utility bills spanning at least a year or 12 continuous months for calibrating the simulation outputs with the actual data. In this study, metered data of monthly electricity consumption of two consecutive years is used for the calibration. Fig 3.7a, b, c, d & e shows that the monthly energy-use curve of simulation results closely resembled the contours of the curve created by the measured data. The monthly comparison of the simulated and measured electricity consumption is given in Table 1.6 a,b,c,d &e in Appendix-1. But it is still necessary to check for the accuracy of the simulation results using certain statistical indices within defined acceptable tolerances.

3.2.3.1 Acceptable tolerance limits

The use of measured data and real building information reduces the chances of error. Therefore, the calibrated model should meet the acceptable tolerance for the statistical indices that are applied for the validation. Table3.11 outlines the acceptable tolerances defined by the guideline standards. In the study, following three statistical indices are used to validate the baseline model:

- Percentage Error
- Coefficient of variance of the root mean squared error (CV RMSE)
- Mean Bias Error (MBE)

Equation (1),(2) and (3) are used to calculate the % error, CV(RMSE) & MBE [96].

$$\%\ \text{Error} = (y\ \text{simulated} - y\ \text{measured})/y\ \text{measured} \times 100 \tag{1}$$

$$\text{CV RMSE} = 1/\ \bar{y}\ \text{measured} \times \{\sqrt{\ } [\textstyle\sum(y\ \text{simulated} - y\ \text{measured})2\ ]\ /\ (n-p-1)\} \tag{2}$$

$$\text{MBE}\ (\%) = [\textstyle\sum(y\ \text{measured} - y\ \text{simulated})/\ \sum y\ \text{measured}] \times 100 \tag{3}$$

where:

y simulated = monthly energy consumption (simulated value)
y measured = monthly energy consumption (measured value)
$\bar{y}$ = mean of monthly energy consumption
n =number of data points
p =number of predictor variables

Table3.11 Acceptable tolerances defined by Guideline Standards

Index	ASHRAE 14 (%)	IPMVP (%)	FEMP (%)
CV(RMSE)	± 15	± 5	±10
% Error			
MBE	± 5		

The estimated percentage error between the simulated energy consumption and measured data is observed to be within the acceptable tolerance of ±15% for annual data and ±25% for monthly data (refer Fig 3.8a & b), as suggested in similar studies previously [93]. Percent error for monthly energy consumption between measured data and simulated results ranged from -24.5% to 14.1% for CV, -25.3% to 14.8% for HV, -14.6% to 11.3% for GMR, -16% to 15.1% for BMD and 7% -24.3% for TR (refer Table 1.7 a&b in Appendix-1). The positive values indicated that the simulations have overestimated the results whereas the negative values mean that the simulations have underestimated the results as compared to the measured data. The model has shown slight variations in few cases with an absolute difference 0.5%. But, considering the intricacy involved to calibrate the simulation model for residential buildings, the analysis has been preceded with the obtained models tolerances only.

The Coefficient of Variation of Root Mean Squared Error (CV (RMSE) and Mean Bias Error (MBE) for the monthly electricity consumption is obtained within the acceptable tolerances, as defined in the ASHRAE Guideline 14-2002 [84,97]. Fig3.9 illustrates the estimated CV (RMSE) and MBE for the baseline model of all the surveyed buildings.

The focus of the study is to evaluate the thermal environment and its impact on the energy consumption. Therefore, the physical variables of the indoor environment obtained through the simulation outputs are also compared with the measured data. By doing so, the calibrated model not only represented the energy consumption of the whole building but also the thermal environment of the indoor space. It is observed that the % error for Ta, Top & Tr is within the acceptable limits for summer months and have marginally crossed the tolerances for winter months (especially November & December). Relative Humidity (RH), however, has shown major differences when compared with the measured values. It is important to note than in naturally ventilated buildings conditions can change dramatically for many reasons (weather, occupancy, etc.) and such differences are conceivable. Table 1.8 a, b, c& d in Appendix-1 shows the statistical validation of the baseline models for indoor environmental variables. On the basis of the above statistical validation it is assumed that the baseline models represent the existing thermal environment and energy consumption of the surveyed buildings.

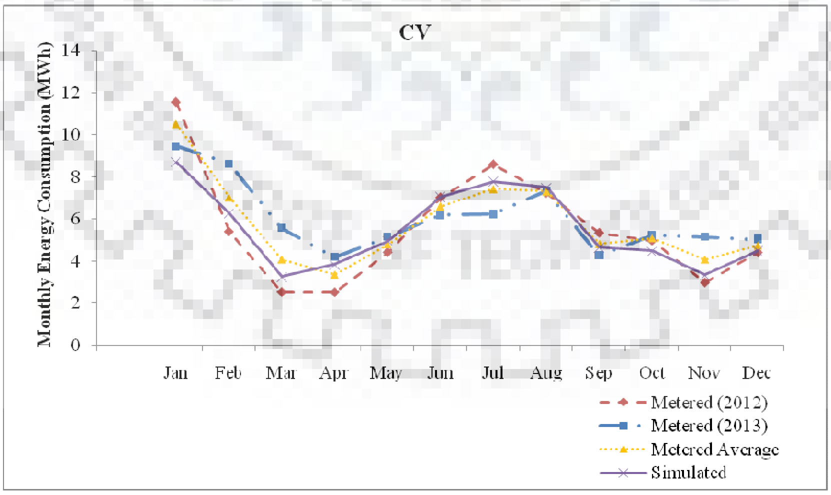


Fig 3.7a Monthly energy-use curves of baseline models and measured data, CV

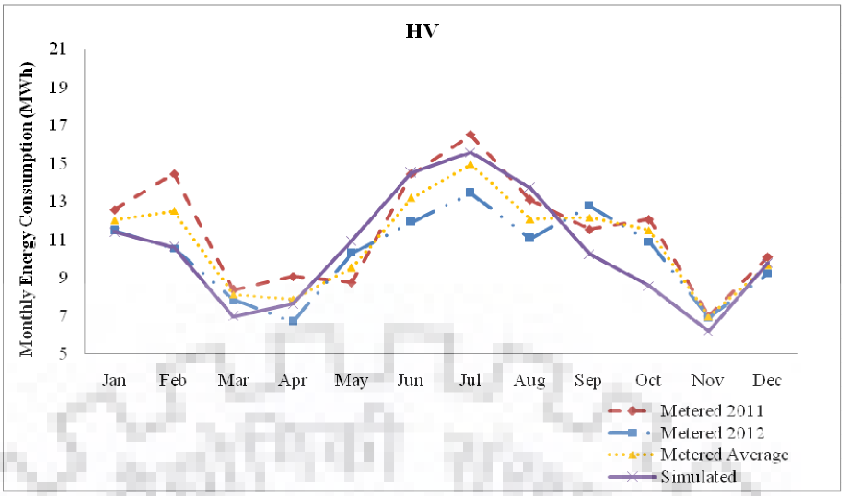


Fig 3.7b Monthly energy-use curves of baseline models and measured data, HV

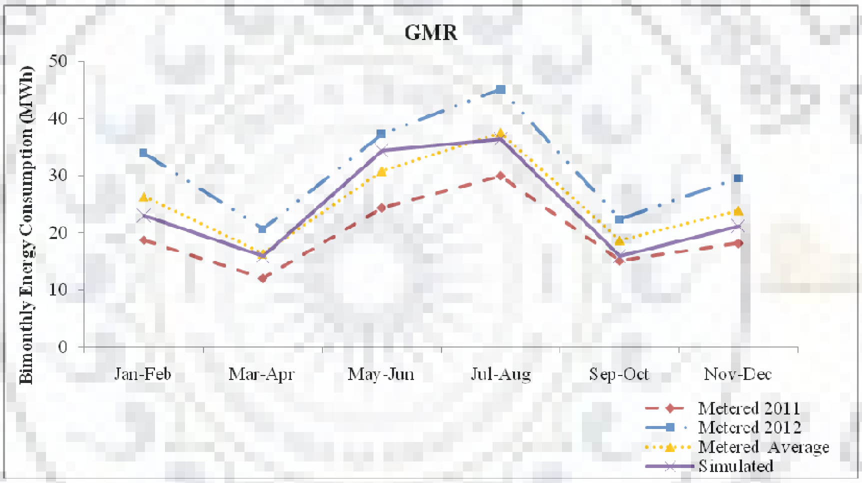


Fig 3.7c Monthly energy-use curves of baseline models and measured data, GMR

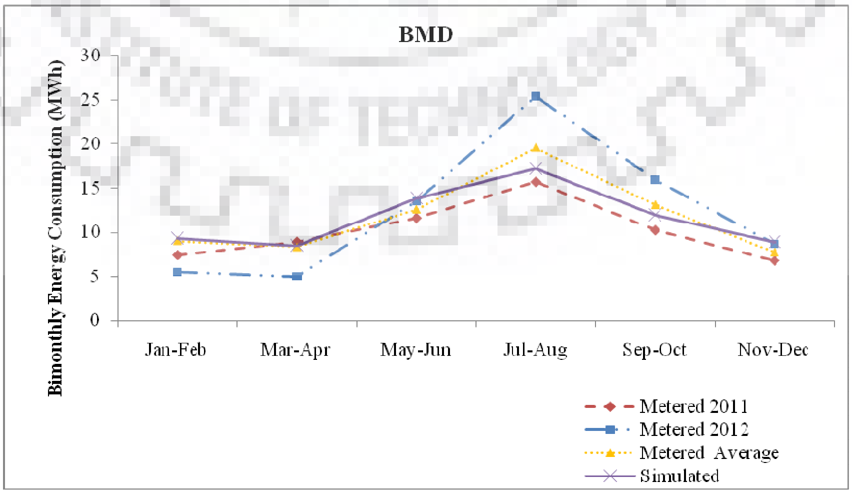


Fig 3.7d Monthly energy-use curves of baseline models and measured data, BMD

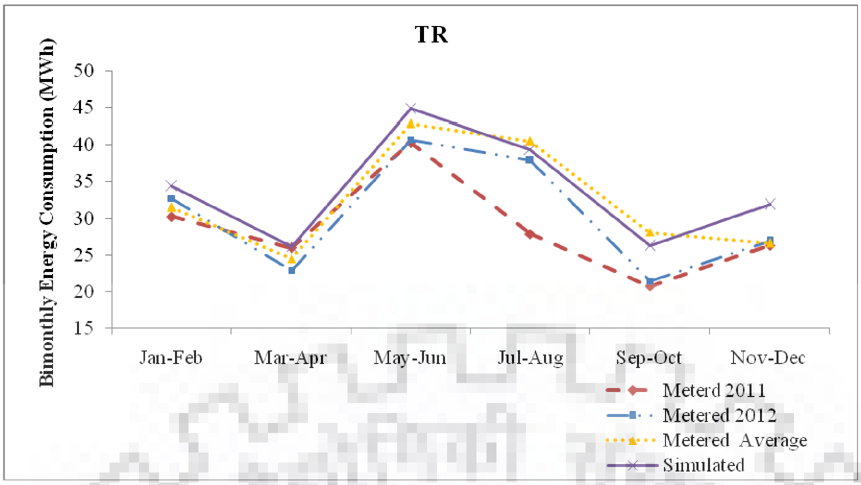


Fig 3.7e Monthly energy-use curves of baseline models and measured data, TR

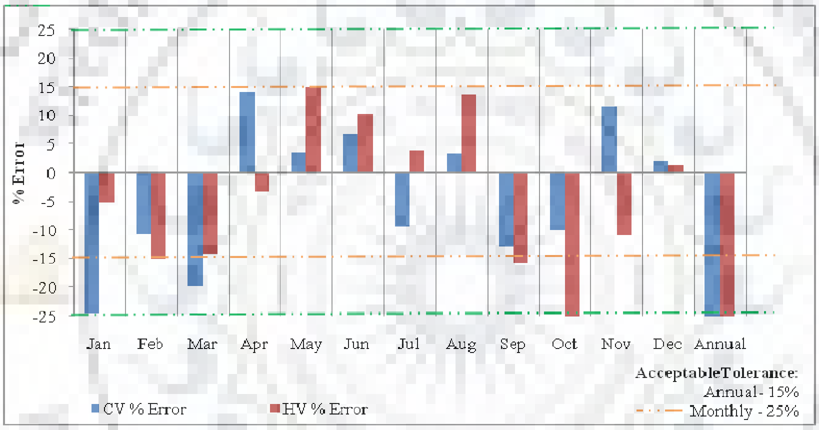


Fig 3.8a Percent differences (PD's) between simulation results and measured data for annual and monthly data (HV & CV)

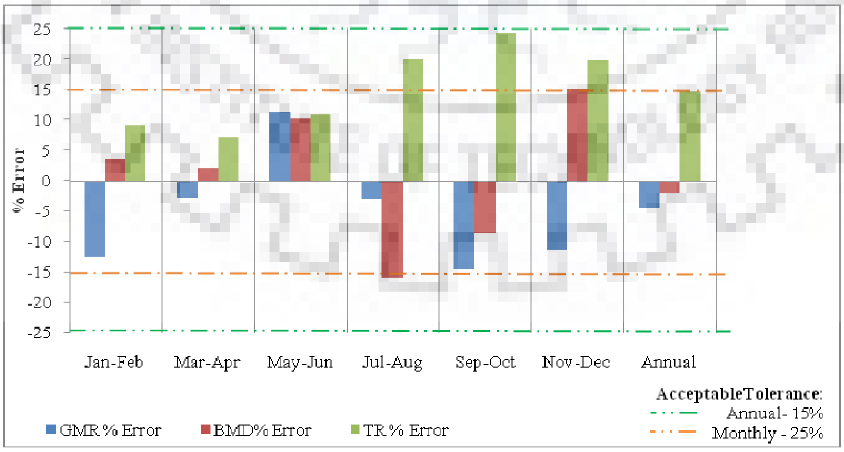


Fig 3.8b Percent differences (PD's) between simulation results and measured data for annual and monthly data (GMR,BMD & TR)

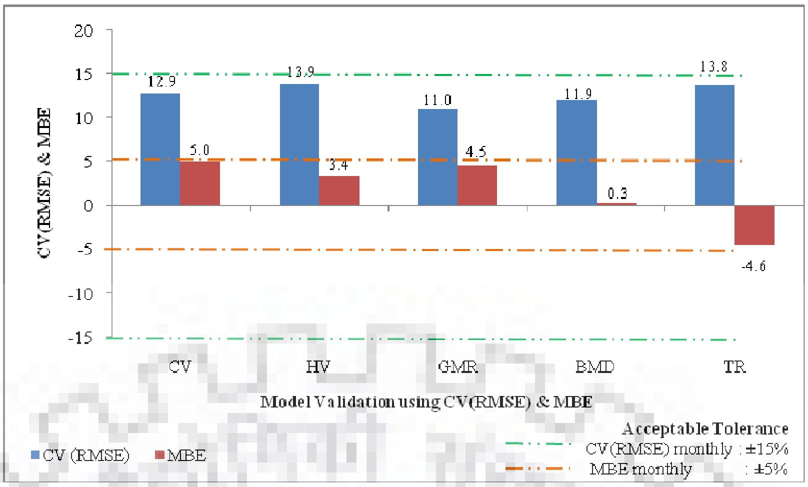


Fig3.9 CV (RMSE) and MBE between simulation results and measured data for monthly data

3.3 Inferences

- Climate significantly controls the overall performance of the buildings and the thermal expectations of the occupants. Therefore, it is important to collect data on outdoor and indoor physical variables.

- Distribution of the data sample should cover all the age groups and genders. It is important to include the demographic variables while developing the adaptive model of thermal comfort.
- Necessary Steps in Model Validation Or Calibration
  a. Construct a baseline model using construction details, occupancy schedule, operation schedules, weather data etc.
  b. Analyze the preliminary results for debugging.
  c. Calibrate the simulated values against the monthly utility bills.
  d. Model validation using Percentage (%) Error and CV (RMSE).

- The estimated percentage error between the simulated energy consumption and measured data is observed to be within the acceptable tolerance of ±15% for annual data and ±25% for monthly data.

- The Coefficient of Variation of Root Mean Squared Error (CV (RMSE) and Mean Bias Error (MBE) for the monthly electricity consumption is obtained within the acceptable tolerances of ±15% and ±5% respectively, as defined in the ASHRAE Guideline 14-2002.

CHAPTER 4

THERMAL COMFORT ANALYSIS

4. INTRODUCTION

Thermal comfort is famously described by ASHRAE Standard 55 as '*that condition of mind which expresses satisfaction with the thermal environment'* [16,98]**.** As the subject's experience of a place is a multivariate phenomenon [16], it is important to understand that what stimulates the thermal sensation of the occupants?

The fundamental assumption of adaptive model of thermal comfort is: *'if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort'* [58]. It embraces the notion that people play an important role in creating their own thermal preferences through the way they interact with the environment; or modify their own behaviour, or gradually adapt their expectations to match the thermal environment [60]. Adaptive behavior as a response to thermal discomfort also has a huge implication on the energy consumption of any building [49,50]. Steemers [33], in his study has justified this point with the detailed monitoring of 12 case studies (office buildings) in U.K and India. Climate is another prime contextual variable in the adaptive model of thermal comfort [58]. It strongly controls the thermal perception of the people and the way a building is to be designed. Previous studies [27, 88, 99, 100] have proved that the temperature (indoor/outdoor), among all other parameters, strongly influences the comfort preferences and the control use behaviour of the respondents. It suggests that the seasonal variations in the climate have a huge repercussion on the way occupants perceive and respond to the environmental changes. Brager and de Dear [60] reported a link between personal control of environmental conditions (temperature & ventilation) and work performance. Iftikhar [88] also inferred that the change in indoor temperature is about one-third of the outdoors when occupant controls the indoor.

This chapter is focussed on the estimation of the comfort temperatures, comfort range and the analysis of the thermal perception of the occupants. Highlights of this chapter are as follows:

- Developed an adaptive model for multi-storied apartments in a composite climate of North India.

- Analyzed the impact of seasonal changes on the thermal perception and control use of occupants.

4.1 Thermal Evaluation of Occupants

4.1.1 Neutral temperature (Tn)

Neutral temperature (Tn) is the indoor air temperature when subjects most likely to vote ‘0’ or ‘neutral’ on ASHRAE’s seven point thermal sensation scale. The proportion of subjects reporting comfortable (i.e. voting –1, 0, +1) were regressed with Tg as shown in Fig.4.1a. The regression equation obtained for the current study is:

TSV=0.21Tg-5.56

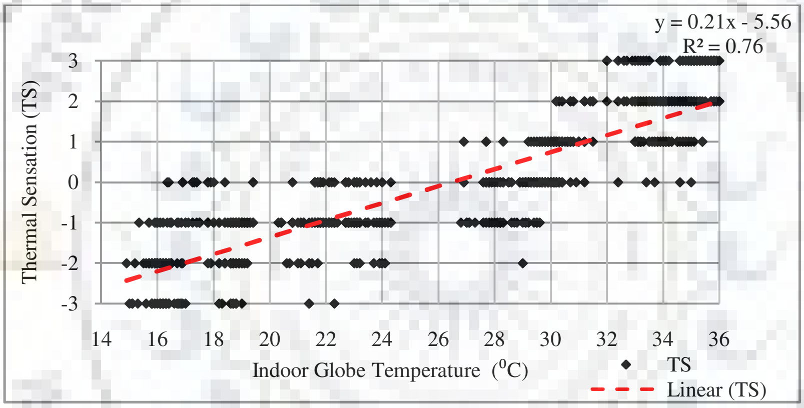


Fig.4.1a Linear regression of TSV with Tg

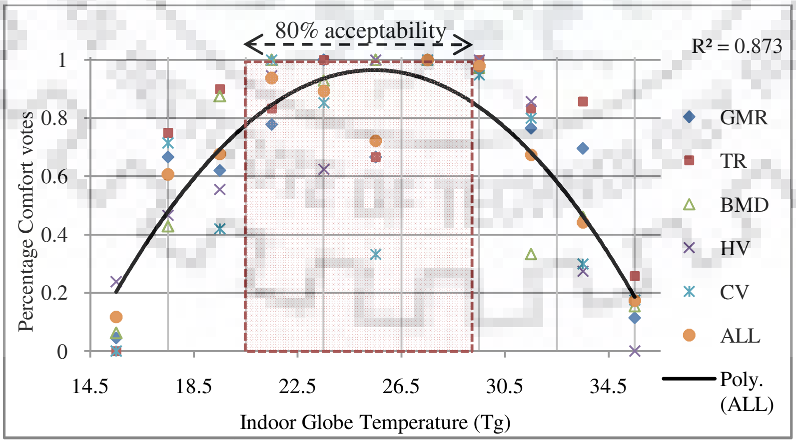


Fig.4.1b Proportion of comfort votes within comfort band

The derived linear regression model is found to be statistically significant with a regression coefficient value of 0.76 & a comfort temperature of 26.6 °C. The gradient of the slope, representing the thermal sensitivity, indicated that the occupants will experience a 1 unit change in their thermal state for every 5.0 °C change in Tg. Fig.4.1b. shows that little or no discomfort was experienced by 80% of the subjects when the indoor temperature was within a range of 22.5–30.6 °C.

However, for some subjects Tn turned out to be superfluous (-1.5°C, 8.2°C, -11°C etc.), (refer Table 1.9 a, b & c in Appendix-1). It is observed that subjects having very poor correlation between Tg and TSV (winter period showing more of such values as compared to other two seasons) are the one with these erratic values. Similar results were observed by Indraganti & Rijal et al. [10,101]. As suggested in previous studies, TS is not primarily dependent on Tg [101] and there are other variables responsible for the thermal perception of the occupants. The comfort temperature is found to be varying slightly in all the seasons. It suggests that seasonal variability in the usage pattern of controls, as a response to changes in the temperature, affects the comfort temperature, also mentioned in previous studies [59,101]. Researchers [20,101, 102] have also inferred that simple regression analysis for estimating comfort temperature is not a very reliable approach, especially when the adaptive behavior of the occupants is active. Therefore, Griffith's method, as suggested by Nicol [20] is used to calculate comfort temperature for each subject using mean comfort vote and the mean temperatures as follows:

$TnG = Tgm + (0 - TSm)/a$

where, TnG: neutral temperature by Griffiths' method, Tgm: mean globe temperature , TSm: mean thermal sensation vote, a: regression coefficient.

Four Griffith's coefficients; as obtained by Indraganti in her Hyderabad study (.31) , Nicol et.al in Pakistan study (.25 & .33) and finally the one obtained in this study (.21) are used for the analysis. TnG_1, TnG_2, TnG_3 & TnG_4 are the Griffith's neutral temperatures (refer Table 4.1) obtained using regression coefficients 0.31,0.25,0.33 & 0.21, respectively. Table 1.10 a,b,c&d in Appendix-1 gives the detailed summary of the estimated Griffith's neutral temperature. The basic purpose is to modify the unreliable values of neutral temperature using Griffith's analysis.

As mentioned earlier, this variation is directly dependent on the TSm value of the subjects. The difference is observed to be increasing as the subjects are voting away from '0' (or ‘neutrality’); whereas the difference is receding as the TSm value is close to '0'. The difference between TnG$_4$ (current study) and TnG$_1$, TnG$_2$ &TnG$_3$ is observed to be smaller for monsoon and summer period (within a range of 0 to 3.0) as compared to winter period (from .6 to 4.8). The proportion of ‘neutral’ votes is higher in summer and monsoon period and, thus, explains the smaller difference. On further analysis, top exposed floors (TF) are observed to have higher Griffith’s neutral temperatures than the lower floors (LF). This difference between LF & TF is more pronounced in the monsoon period, as more subjects have voted for neutrality in the ‘LF’ (0.5%) as compared to ‘TF’ (0.3%). The results are in alignment with the one obtained by Indraganti [10].

Table 4.1 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

The results obtained in this study are in alignment with the previous studies.Table 4.2 gives the summary of the adaptive models obtained by the researchers in similar field studies in tropical climate [9, 10, 15, 21, 103, 104]. It is observed that the studies conducted in India [10, 15] have presented the closest match with the current study. Indraganti and Rajasekar have obtained a regression slope of 0.31 & 0.34 which is slightly higher than the one obtained in the current study (0.21). The temperature range for which the study was conducted by Rajasekar (23^{0}C to 41.5^{0}C) and Indraganti (24.1^{0}C to 40.4^{0}C) was comparatively narrow as compared to the current study [15^{0}C to 41^{0}C]. Another notable difference is the socio-cultural diversity which has a huge impact on the way clo insulation varied. In Hyderabad study [12], *‘sari’* (with the clo level of 0.65) is the clothing ensemble of the female subjects, whereas ‘*salwar- kameez’* (with the clo level of 0.28) is the common attire of females in the current study. Pellegrino’s Calcutta study, differed in terms of building type & climate which explains the starkly high difference in the regression slope and neutral temperature (refer Table 4.2). The above findings signify the impact of outdoor conditions, cultural aspects and the survey period on the thermal comfort model.

Table 4.2 Comparison with Previous Studies

	Madhavi (Hyderabad)[10]	**Pellegrino (Calcutta)[9]**	**Rajasekar (Chennai)[15]**	**Feriadi (Indonesia) [103]**	**I A. Raja (Pakistan) [21]**	**Heidari (Iran) [104]**	**Current Study (North India)**
Climate	Composite	Tropical, warm & humid	Hot & Humid	Tropical, hot & humid	Tropical to sub tropical	Sub tropical to sub polar	Composite, humid subtropical climate
Study Period	May, June & July	May	Summer (April-May) Winter (Nov- Dec)	Dry season (Apr- Jun) Rainy Season (Nov Jan)	July & January	Jan - Dec	Jan -Dec
Building Type	Residential (NV)	University Building (NV)	Residential (NV)	Residential (NV)	Offices (NV)	Offices (NV)	Residential (NV)
Regression equation	TSV= 0.31Tg-9.06	TSV= 0.65Top-20.3	TSV = 0.34Tg – 9.72	TSV = 0.59*OT - 17.2	Tc= 0.38To +17.0	Tn = 0.76Ti + 5.54	TS= 0.21Tg-5.56
Comfort Temperature	29.23^{0}C	30.9^{0}C	29.0^{0}C	29.17^{0}C	_	28.4^{0}C (Hot season) 20.8^{0}C (Cold season)	26.06 ^{0}C
Comfort Band	26 to 32.45 ^{0}C	29.4^{0}C to 32.5^{0}C	26°C to 31.8°C	_	_	25.1–32.8^{0}C	21.8 to 31.37 ^{0}C

4.1.2 Comparison with tropical summer index (TSI)

A thermal comfort index, Tropical Summer Index (TSI), is derived using multiple regression analysis of environmental variables on thermal sensation. The study evaluated the subjective thermal responses of 18 young adults for three consecutive summer seasons at the CBRI, Roorkee [40]. This index is derived in line with the adaptive behavioral patterns, living styles & eating habits of the Indian subjects. Owing to the similarity in the-study area and other socio-cultural constraints, it is considered essential to compare the results using this index.To do so, a simple regression is employed for the comfort votes with TSI calculated. Tropical summer Index for the current study is calculated for each subjects using following equation:

TSI= 1/3Tw + 3/4Tg -2 (Av) ½

where, Tw is the wet bulb temperature, Tg is globe temperature & and Av is the air velocity. Table 1.11 in Appendix-1 gives the detailed summary of estimated TSI.

A significant correlation of 0.86 is observed for TSI & TSV. A comfort range for 80% acceptability was found to be 22.0°C -29.8°C (referFig.4.2), which fairly varied from the one obtained by Indraganti, Rajasekar & Sharma & Ali [10, 15, 40].The inconsistency in the results can be attributed to the difference in the time period for which the survey was conducted. The current study has conducted a yearly survey for all the seasons, where as the other two studies (Sharma & Ali and Indraganti), are predominantly covering the summer period of the year. The difference is mainly in the lower limit of the comfort range for 80% acceptability, upper limit has marginally differed in all the results (refer Table 4.3). In case of Sharma & Ali, the divergence is also due to difference in the built environment under which subjects were studied (office), activity, subjects (only males were surveyed) and adaptive measures employed. In case of Madhavi, cultural and sociological differences has affected the clothing pattern (instead of sari, '*salwar-kameez'* was the main attire of most of the female subjects and instead of '*lungi*' and shirt males in the current study wore shirt-trouser/short.

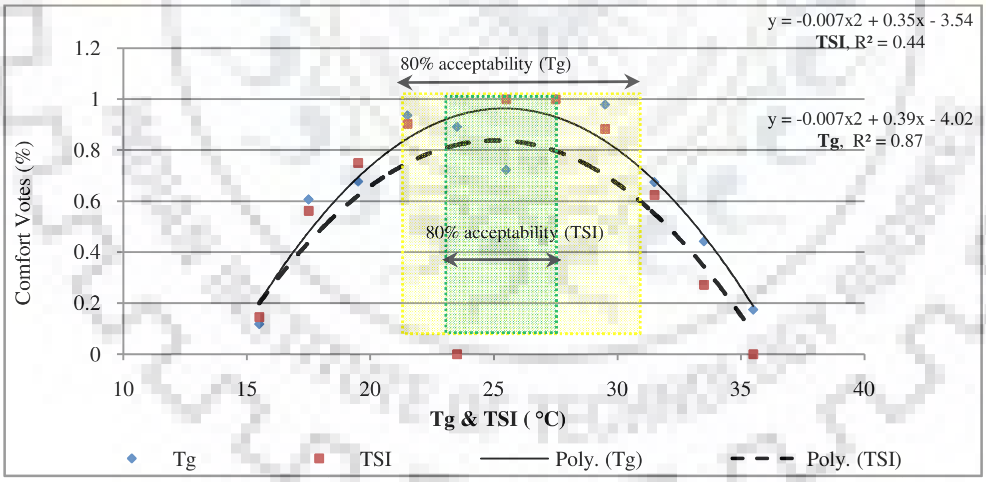


Fig.4.2 Comparison of linear regression of TSI &Tg with comfort votes (TSV)

Table 4.3 Comparative Results for TSI Analysis

Comparative Studies	80% acceptability
Sharma & Ali (Roorkee study)	25.0°C -30°C
Indraganti (Hyderabad study)	27.5°C -30°C
Rajasekar & Ramachandraiah (Chennai study)	26.8-31°C
Current Study (All Data)	22.0°C -29.8°C
Current Study (Roorkee data in May, June & July)	21.91°C -29.3°C

4.1.3 Thermal acceptance (TA)

Thermal Acceptance or 'TA' has negatively correlated with the thermal sensation in summer (-0.6) and the monsoon period (-0.5) where as it showed positive correlation (0.5) in winters. 'Acceptability' has been synonymously used with 'satisfaction', and that 'satisfaction' is associated with the thermal sensation of feeling 'slightly warm' (+1), 'neutral' (0), and 'slightly cool' (-1) among thermal comfort research community [105]. Thermal acceptance was highest in the monsoon period (84%) whereas winter & summer period marginally differed in TA votes (79% & 77% respectively). An interesting point to be noted is the low percentage of comfort votes (-1,0,+1) in the respective seasons i.e. 17% in winter, 21% in summer & 27% in monsoon in spite of high thermal acceptable votes. Fig 4.3a gives the overall distribution of the acceptable, unacceptable and comfort votes for the respective seasons. This clearly contradicts the general conception that people voting within the comfort band find conditions to be thermally acceptable [14]. Another notable fact is the percentage of thermally acceptable votes were fairly significant even when the subjects voted for discomfort (i.e. '3 & 2' in summer & monsoon and '-2 & -3' in winters). Fig.4.3b illustrates the distribution of total acceptable votes for the events when the subjects are voting uncomfortable (for e.g. "cold" or "-3" and "hot" or "+3"on TSV scale. During monsoon period, 75% of the subjects voted in the comfort band and out of this almost 6% still felt the environment thermally unacceptable. Lower expectations, difference in the psychological attitudes & health issues have been pointed out, time and again, to explain the same [14, 60].

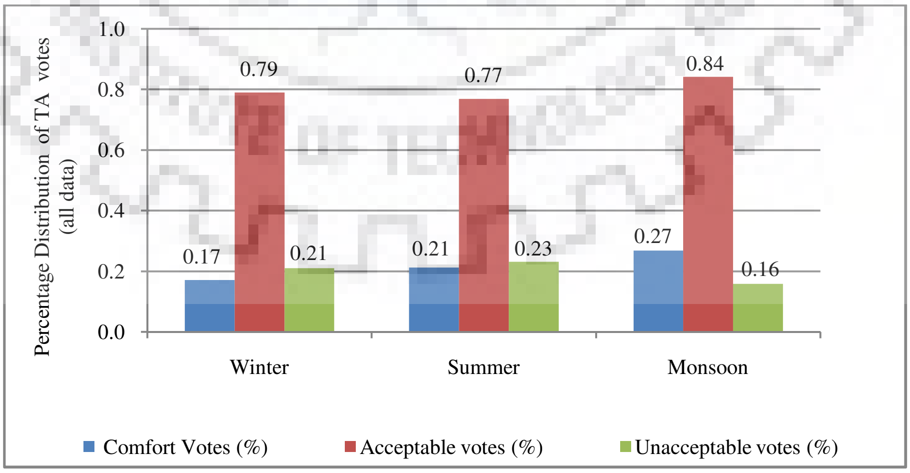


Fig.4.3a Percentage Distribution of Acceptable, Unacceptable and Comfort votes for all data

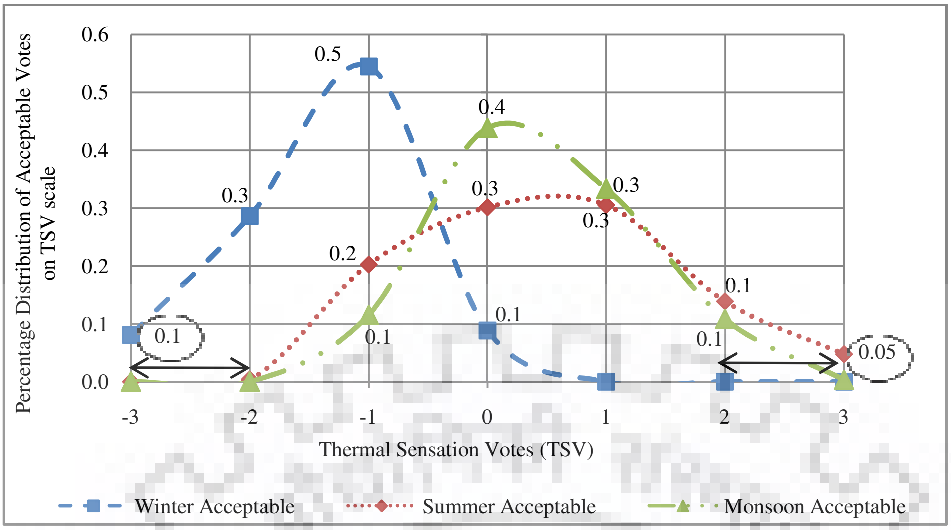


Fig.4.3b. Percentage Distribution of Acceptable Votes for Respective Thermal Responses TSV scale (0.1 & 0.05 % is the percentage of subjects found conditions acceptable, when the subjects are voted for discomfort on TSV scale i.e. “cold” or “-3” and “hot” or “+3” on TSV scale, respectively.

4.2 Adaptive Use of Controls

Controls are employed by the subjects either to restore the comfort conditions or to achieve the same [106]. These decisions are partially based on outdoor/ indoor temperatures and partially on the personal expectations [60]. People consciously and unconsciously respond to the thermal discomfort by changing activity [14,107], clothing /posture [12, 14, 108] or thermal environment. In naturally ventilated buildings, the usual controls available to regulate the thermal environment are doors, windows, blinds, fans, A/c’s & hot air blower etc. [99]. Opening of doors or windows enhances the natural ventilation; fans provide forced convective cooling & blinds/ curtains reduce the glares as well as the heat gain from direct solar radiation [88].

Temperature (outdoor & indoor) is the key statistical variable in predicting the use of control. But studies have confirmed that it is the immediate environment that stimulates the instincts of the subject to use the available controls [99].So, the proportion of controls used during the survey period is plotted against the globe temperature (Tg) for regression analysis. Seasonal variation is observed in the ‘opening’ or ‘closing’ pattern of windows (W), balcony doors (BD) & blinds (BL). For analysis, ‘window open’, ‘door open’, ‘blind drawn’, ‘fan on’ and ‘A/c on’ were coded as `1' and otherwise as `0'. The relative frequency of “open” and “close” event for each of the control is calculated separately for indoor (Tg) and outdoor instantaneous (To) temperature. The personal variables (i.e. ‘clo’ and ‘met’ level) for comfort conditions slightly varied from person to person but on generalizing the results, a distinct pattern is observed in the seasonal use of controls.

In order to better understand the adaptive use of W, BD & BL it is further expanded in the questionnaire as: Open Mostly -1, Closed Mostly-2, Half open/Half closed -3, Open only morning & evening -4, Open only during daytime-5.

In the study, it is observed that the behavioral adaptations of the subjects have considerably varied for summer, winter and monsoon period, in response to the recurrent seasonal changes. The adaptive use of controls is broadly evaluated under following three categories:

- *In-built Controls/ Designed controls*
- *Seasonal Controls/ Energy Intensive Controls*
- *Personal Controls*

4.2.1 In-built controls

Balcony doors, windows, blinds, external doors etc. are the in-built features of the building which are adaptively used by the occupants to control the indoor thermal environment. To analyze the behavioural change in the use of ‘*designed controls’*, Tg is regressed with the proportional use of BD, W & BL. Windows has shown the highest and blinds the weakest regression coefficient with the globe temperature. Balcony doors are being used, more or less, in the same manner throughout the year. External doors are found to have a weak correlation with the variables and, thus, not included in the study.

4.2.1.1 Windows

Window (W) is one of the most commonly used controls in a building. It is observed that the proportion of opened windows crossed 40% at a temperature ranging between 20^0C - 34^0C, whereas only 20% of the windows are recorded to be opened during extreme winter and summer period (refer Fig4.4a). Simulation results, as discussed in Chapter 5, have shown that exterior windows and walls contributed significantly to the ‘*solar gains’* and the ‘*heat gains/losses through external air or infiltration’*, which explains the restricted window opening behavior of the subjects during extreme summer and winter months. It should be noted that, in winters, to maintain the indoor warmth, closing of doors and windows is the easiest, effective and economically viable control to isolate the indoors from the outdoor chills. It fairly explains the strong correlation of ‘W-use’ with the Tg in winters as a response to cold discomfort. While in summer and monsoon, alternate controls like fans & A/c’s are more effective and are excessively used by the subjects to control the indoor environmental conditions & ventilation rates. Similar window opening behavior is observed by Indraganti & Rijal [11,109]. Factors like ‘*dust*’ & ‘$^{\#}$*loo and fog*’ have also attributed to the hampered use of the windows, regardless of its effectiveness to regulate the natural ventilation (refer Fig4.4b). A significant proportion of occupants have voted ‘dust’ & ‘loo/fog’ for not opening the doors and windows. And this explains the comparatively weak correlation with Tg for summer and monsoon period. Window has, thus, not only helped in regulating the natural ventilation but also acted as a key barrier to the contextual adversities. The adaptive use of windows, surely, needs to be considered while designing the buildings, so as to provide ample opportunities to the occupants to restore the indoor comfort conditions.

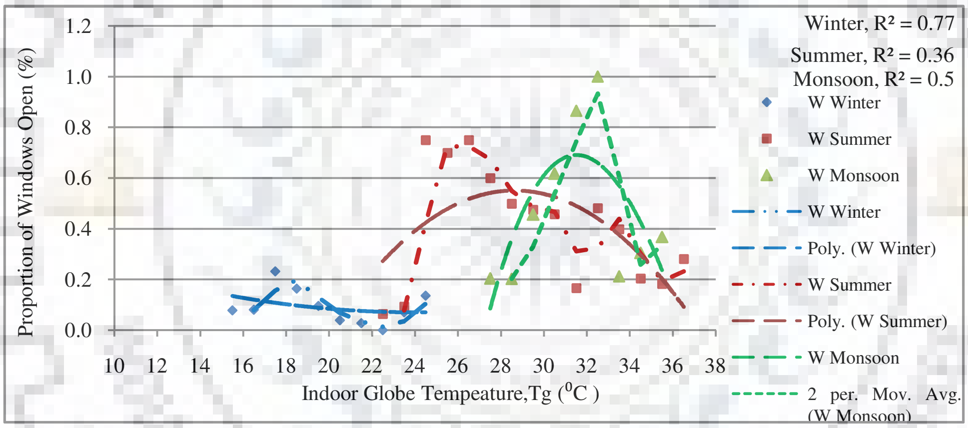


Fig4.4a Seasonal Variation of Window-use as function of Tg

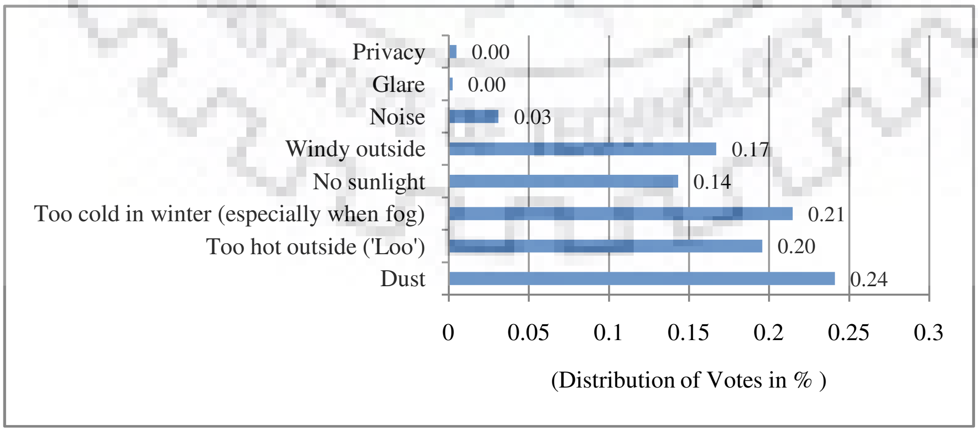


Fig4.4b Percentage distribution of votes (not opening doors & windows)

#Loo is a strong,hot and dry summer afternoon wind from the west which blows over the Gangetic Plain region of north India (temperatures ranging between 45°C – 50°C)

4.2.1.2 Balcony doors

Balcony doors (BD) are observed to be used in a wider range of temperatures and more uniformly as compared to any other control. The proportion of 'BD-use' gently rises from 40% at 19°C to 80% at 32°C. Fig4.5 shows the seasonal changes occurring in the 'BD-use' when plotted against Tg, with a maximum usage in the monsoon months. Also, the 'BD-usage' is observed to be maximum when the Tg is within the comfort band, i.e. indoor temperature ranging between 22.5– 30.6°C. Most subjects reasonably expressed their preference for open doors and windows not just for the allowance of cross ventilation but because it gives the feeling of '*freshness*' and '*openness*'. The expectations in terms of '*freshness*' and '*openness*' with the opening of windows and doors have considerably played a very important role in the thermal responses and the comfort preferences.It is imperative to note that out of the total responses (984), 419 responded to be not using the balcony spaces and still 'BD' is the most preferred control in all the seasons.

Balcony spaces, with shaded buffer space provide better options for cross ventilation over windows, as also mentioned in a study by Indraganti [11]. The role of balcony doors in the thermal perception of the occupants clearly suggests that the efficient design of the balcony spaces in naturally ventilated buildings can optimize the indoor thermal environment.

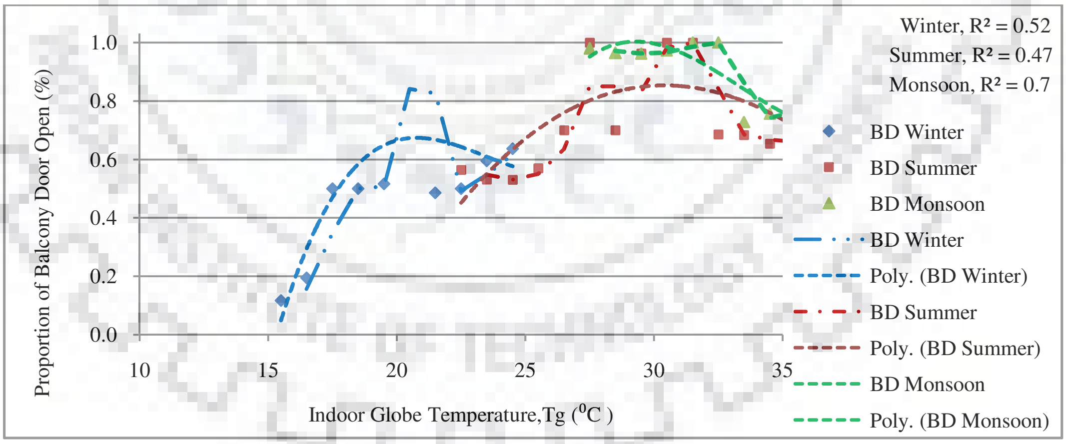


Fig4.5 Seasonal Variation of Balcony Door (BD) as function of Tgm

4.2.1.3 Blinds

The overall usage behaviour of blinds or 'BL' has weakly related to Tg (r^2=.46) as compared to other controls. But, the seasonal regression analysis of the proportional use of blinds with Tg has exhibited a very strong relationship (winter, r^2=0.9; summer, r^2=0.74;

monsoon, r^2=0.8, refer Fig4.6). Indoor globe temperature (i.e. Tg) and outdoor temperature has strongly correlated in the study (0.96), which implies that any change occurring outdoors has a direct or indirect influence on the indoor environment. During peak summer and winter periods, 'BL' is preferred to be drawn in order to maintain a barrier between extreme outdoor conditions and to restore the indoor comfort levels. In winters, the mean outdoor temperature in Chandigarh and Roorkee drops to around 5-7^{0}C. Blinds in combination with the heater/hot blowers has acted as a good insulator and helped in reducing heat loss through windows. Similarly, in summer period, outdoor temperature rises up to 41^{0}C and blinds are preferred to be drawn in combination with the closed doors & windows (and/or air conditioners 'on') to keep the '*loo*' & glare out.

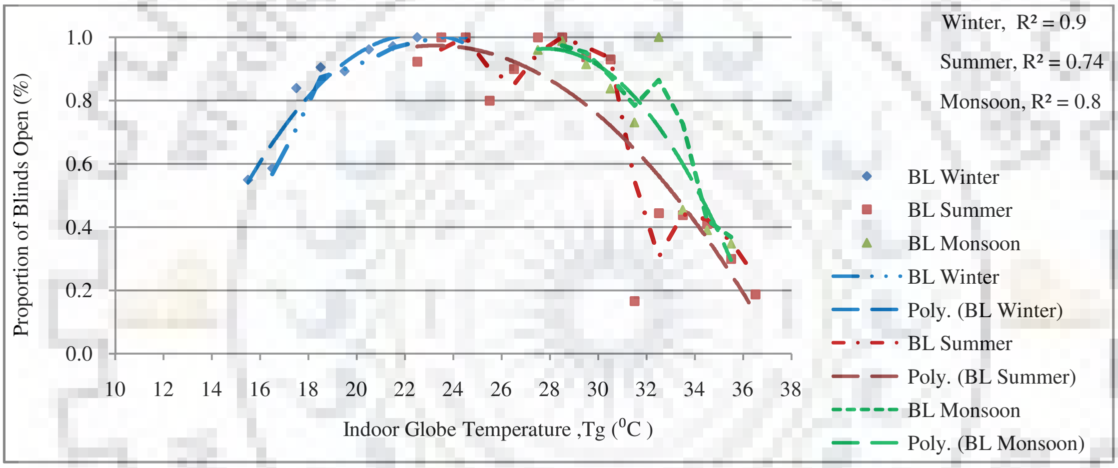


Fig4.6 Seasonal Variation of Blind use as function of Tg

4.2.2 Personal Controls

When the thermal discomfort persists even after employing the in-built controls (i.e. windows, doors etc.), subjects tend to shift to the personal controls. Changing clothing level or activity level, drinking tea or cold drink, changing posture etc. are some of the personal controls. In the present study, clothing level and 'met'levels are analyzed for evaluating the personal controls.

4.2.2.1 Clothing

Clothing adjustment is one of the most common adaptive behaviour that covers a wide range of temperature. The regression analysis depicted in Fig4.7a, suggests that indoor temperature is an important determinant of clothing as an adaptive control. Studies have also reported that building occupants modify their clothing several times a day in naturally ventilated buildings [110,111]. But in residential buildings, people know what kind of thermal environment to expect and easily avail the adaptive opportunities, resulting in minimal clothing adjustments over a day [16]. The annual 'clo' variability observed during the survey ranged from 0.3 to 2.2 'clo', indicating the flexibility available in the clothing adjustments in north India. The choices made by the subjects in 'clo' level are directly or indirectly driven by the physical environmental parameters and primarily indoor /outdoor temperatures [60,111]. Globe temperature & air velocity have exhibited a strong correlation with the 'clo' level (r= -0.84 & r= -0.6, respectively), whereas, relative humidity (RH) has weakly correlated, r=0.2 (refer Table 4.4a). The results obtained in this study are in alignment with the one established by Heidari [104]. Below is the derived regression equation:

$clo=2.053-0.049*Tg$, $r^2=0 .696$

where, clo is clothing level; Tg is globe temperature (in ^{0}C)

Seasonal variations in the clothing adjustments have shown a strong linear dependence on indoor globe temperature in summer (r= -0.7) & winter (r= -0.7) period and weak correlation in the monsoon period, r= -0.3 (refer Table4.4b). With the increase in temperature, 'clo' level decreases till it reaches a minimal acceptable limit. Beyond this level no further changes are observed due to socio-cultural constraints, termed as 'adaptive saturation' [16]. As the minimal acceptable 'clo' level has already been crossed in summer time, occupants opt for easier and more effective controls to enhance the convective cooling (i.e. fans, A/c, windows, doors etc.) in monsoon period. A weak regression coefficient for 'clo' with RH is also the resultant of 'adaptive saturation'. When 'clo' level is regressed with the Av, a moderately strong correlation is established in the summer period (r= -0.5) as compared to winter (r= 0.2) and monsoon (r= -0.2) period (refer Table 4.4b). The reduced 'clo' level with the increased air velocity suggests that clothing adjustment is an effective control measure in summer period (refer Fig4.7b). Also, that it tends to work well when the ventilation rates (through fans, doors and windows) are adaptively used by subjects.

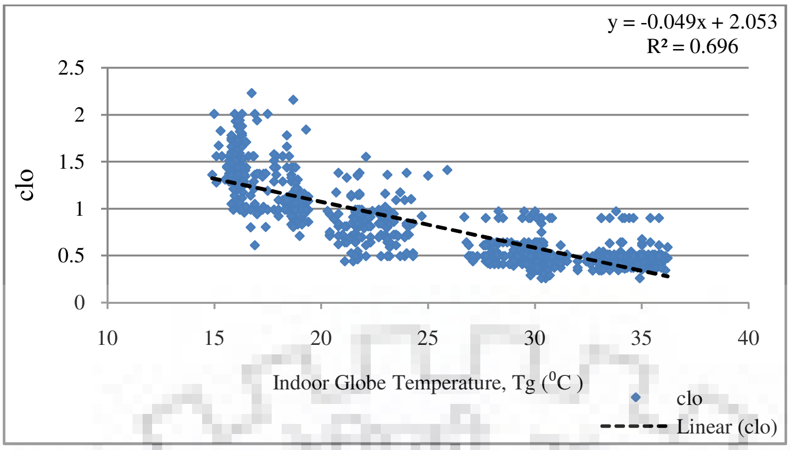


Fig4.7a Linear regression of ‘clo’ with Tg

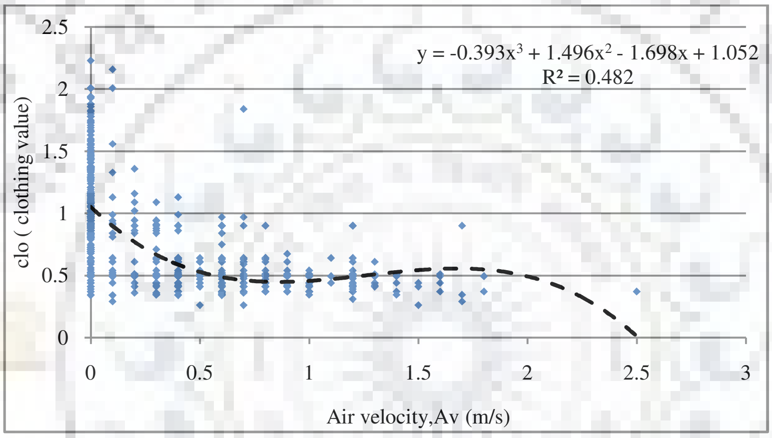


Fig4.7b. Linear regression of ‘clo’ with Air velocity (Av)

Table 4.4a Correlation of clo with variables

	clo: Av	clo : RH	clo:Tg	clo:TSV	clo:met
correlation	-0.60	0.2	-0.84	-0.72	-0.02

Table 4.4b Seasonal Variation in correlation of ‘clo’ with variables

	clo:Av	clo:RH	clo:Tg	clo:TSV	clo:met
Winter	0.2	0.1	-0.7	-0.5	0.0
Summer	-0.5	0.0	-0.7	-0.6	-0.2
Monsoon	-0.2	-0.2	-0.3	-0.2	-0.1

4.2.2.2Metabolic activities

Metabolic activity has shown no correlation with any of the physical variable or with the comfort votes of the subjects, similar results were drawn by Nicol [11]. Indraganti has reported [11] that people lower down their metabolic rate as an adaptive measure in response to the discomfort on the warmer side. In this study no such observations are made as the monthly survey, with one time visit to the subjects, could not reveal any significant variations. Seasonal analysis has not revealed any significant correlation with any of the physical variables. Although, clothing has shown a fairly negative correlation (-0.2) with 'met' in the summer period, (refer Table 4.5a). Similar observation was made by Indraganti in Hyderabad study [11].This implies that with the increase in temperature, subjects prefer to keep their clothing to low (within acceptable limits) if they are involved in heavy activities or vice versa. The gender-wise analysis of 'met' rates has clearly shown that female subjects are more involved in heavy activities as compared to the male subjects. Almost 33% of the female subjects were observed to be involved in heavy activities as oppose to only 8% male subjects (refer Table 4.5b). This difference in the metabolic activities, to some extent, has affected the thermal comfort perception of the two genders.

The current methods for evaluating the 'met' level are debatable as the factors like psychological stress, transient effects of earlier activities, or the vigour with which a given activity is performed [60] are not fully considered. A detailed research with prior focus on the relevance of physical environmental variables on daily metabolic activities can help to fill these voids.

Table 4.5a Seasonal variation in correlation of 'met' with different variables

	met:Tg	met:TSV	met:Av	met:clo	met:RH
Winter	-0.01	-0.09	0.04	0.02	-0.02
Summer	0.04	0.08	0.03	-0.18	-0.04
Monsoon	-0.06	0.01	-0.07	-0.08	-0.02

Table 4.5b Gender-wise distribution of subjects involved in light and heavy activities

	Activity	met	Female (%)	Male (%)	Female	Male
Light Activities	Sleeping	0.7	6	4	67%	92%
	Sitting (Passive Work)	0.8	33	40		
	Sitting (Active work)	1	23	40		
Heavy Activities	Standing Relaxed	1.2	5	8	33%	8%
	Walking about	1.7	2	2		
	Cooking	1.6	23	4		
	House Cleaning	2	8	2		

4.2.3 Seasonal Controls

Most of the surveyed subjects are observed to be leveraging on the electrical controls [12] for instant relief from the discomfort. Rapid urbanization has increased the disposable income [41]; and also the dependence on energy intensive controls. It is evident that the cooling load is predominant in composite climate and reports show that almost 48% of the energy is expended on ventilation controls in residential buildings in India [8,12]. It is also observed that when the weather is at the extremities subjects begin switching to the energy intensive controls (i.e. fans, A/c's and heaters/hot blowers) termed as *'seasonal controls'* in the study as oppose to the use of 'W', ' BD' & 'BL' or *'designed controls'*. The proportional use of a fans, A/c's and heaters/hot blowers were observed to be adaptively used as the indoor /outdoor temperature shifted from the comfort range (refer Fig. 4.8).

4.2.3.1 Fans

The overall proportional use of the fan is comparatively low as compared to 'W', 'BD' and 'BL', but has shown a strong regression coefficient, $r^2 = .91$, when plotted against Tg (refer Fig4.8).A notable observation is the increased air velocity when subjects voted 'slightly warm' or 'hot' on TSV scale (refer Fig 4.9). The hourly consumption of fans, ranged between 14 to 21 hours in summer and monsoon period, also exhibited a strong relationship with outdoor ($r^2=0.8$) and indoor temperature ($r^2=0.9$). 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, similar to the results of previous studies [88, 99]. A marked rise is observed in the proportional use of fans between 23^{0}C (approx. 20% usage) & 29^{0}C (approx. 80% usage), with practically all the fans running above 31^{0}C, similar to the results obtained by Nicol et.al. [20].

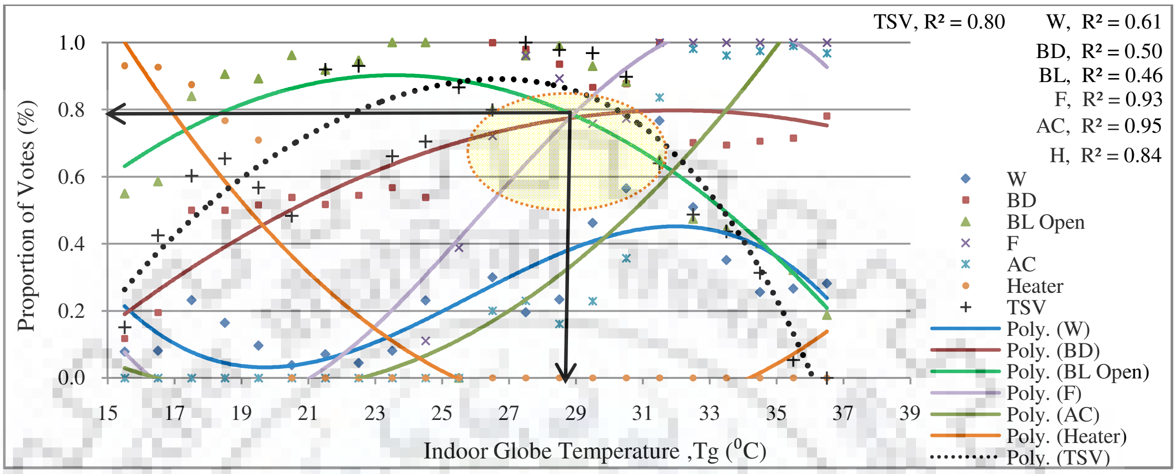


Fig4.8 Proportional use of control as and comfort votes a function of Tg

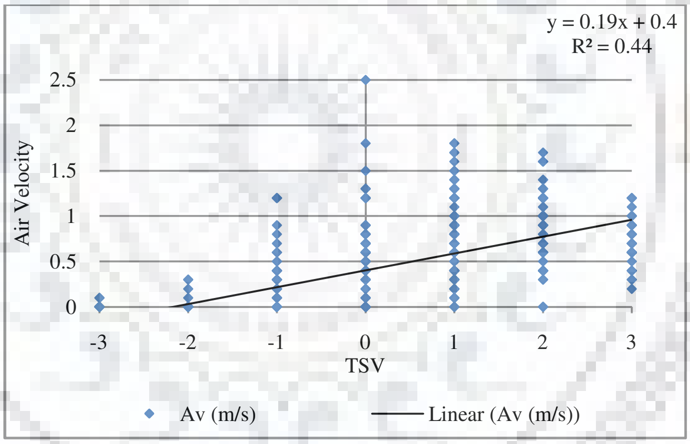


Fig4.9 Linear Regression of Air velocity with TSV

4.2.3.2 Air conditioners (A/c's)

The statistical summary of the proportion of air-conditioner usage is very similar to fans (refer Fig4.8). It exhibited a strong relationship to indoor and outdoor temperatures (r^2=0.89 & r^2=0.85 respectively) and are observed to be used only at the peak summer period, within a narrow range of temperature (27^{0}C to 33^{0}C). A significant rise is observed in the proportional use of A/c's from 20% at 27^{0}C to 80% at 33^{0}C (refer Fig4.8). As mentioned in a paper by Asit [17], choice of adaptive adjustments by occupants is governed by three criteria: ease of use, effectiveness, and economy -the three E's. It is observed that although fans were being used 24x7 but the usage of A/c's are only limited to the hours when subjects are either resting or sleeping (i.e. in the afternoon or at the night time). Subjects were observed to be deliberately pushing their comfort limits to the extent it is bearable, in order to control their electricity expenditures. As explained by Brager & de Dear [60], "*Thermal perception of subjects is beyond the physics of the body's heat balance, such as climatic setting, social conditioning, economic considerations and other contextual factors*". In this study, subjects were found to be more conscious about the electricity expenditure, and this has directly affected the A/c usage even during the peak discomfort hours.

4.2.3.3 *Heaters*

Heater /hot blowers have also revealed a strong relationship with indoor /outdoor temperatures. As expected, heaters/hot blower's usage increased with descending temperature. At 17^{0}C almost 80% of the subjects are using heaters/hot blowers and as the temperature increased its usages also drops down to 20% at 21^{0}C (refer Fig4.8).

Fig4.8 shows the regression plot of the '*proportional use of all the controls*' and the '*comfort votes*' with the indoor globe temperature. It is observed that, at the point of intersection of polynomial curves of all the controls (coinciding at approx. 29^{0}C), almost 80% of the subjects voted comfortable. It suggests that occupants in naturally ventilated buildings are more comfortable when the available adaptive opportunities are readily accessible for use. Fans, A/c's and heaters work instantly at the discomfort hours and accentuate the feeling of degree of control of the subjects. With this feeling of control on the indoor conditions the thermal perception of the occupants is elated, which also explains the high regression coefficient of seasonal controls as oppose to the designed controls.

4.3 TSV in Response to Seasonal Control-Use

Thermal expectations of the people tend to shift gradually with the change in season. This is evident from the difference in the neutral temperature for summer, winter and monsoon period, as shown in Table 4.6. This difference in the thermal sensation, as explained before, is attributed to the adaptive measures employed by the subjects to restore the comfort conditions. It suggests that seasonal variability in the usage pattern of controls, as a response to changes in the temperature, affects the comfort temperature, as also mentioned in the studies previously [59,101]. Thermal sensation votes (TSV) of the subjects are evaluated in response to the adaptive use of the windows, balcony doors, blinds, fans, A/c's and heaters/blowers.

'W'-use' is observed to be not used extensively as compared to the other controls but has shown a strong regression coefficient with the mean thermal sensation votes (TSm); r^2=0.64. Fig.4.10a, illustrates that the proportional use of 'W' is maximum (i.e. above 50%) when the subjects voted 'slightly warmer' on TSV scale. When the proportional use of 'BD' is regressed with TSm, up to 80% voted between '0' (or 'neutral') and '1' (or 'slightly warm') on TSV scale (Fig.4.10b). By comparing Fig 4.10a & 4.10b, it is clear that maximum subjects preferred to open balcony doors over windows in response to the thermal discomfort in warmer side. Balconies are usually shaded and thus lowers the ambient temperature whereas windows are directly exposed to the solar gains and adds to the glare and indoor temperatures.

Table 4.6 TSV-PMV Seasonal Evaluation

	Tom	Tgm	Tn
Winter	15.6	18.6	26.3
Summer	28.8	30.1	25.4
Monsoon	28.6	30.8	27.7
ALL	24.3	26.5	26.6

'BL'-drawn is observed to be minimum when subjects voted 'neutral' and observed maximum rise as the TSV shifted to either side of the neutrality i.e. feeling 'slightly warm' or 'hot' & 'slightly cool' or 'cold' (refer Fig4.10c). More than 80% of the blinds were open when the globe temperature ranged between 19^0C to 29^0C (refer Fig4.6). As the temperature crossed 30^0C, the proportion of 'BL'-use descends gently reaching to its lowest limit, i.e. 20% at 36^0C. Blinds are observed to be used under a wider range of temperature and have shown more variation in the usage pattern as compare to 'W' and 'BD'. The minimum use of 'BL'-drawn around 'neutral' votes confirms the adaptive behavior of the subjects as a response to only extreme outdoor conditions.

The correlation coefficient of TSV with clothing insulation was significantly negative in winter and summer period (-0.5 & -0.6) & moderately correlated (-0.2) in monsoon period (refer Table4.4b). The variability in 'clo' level increased as subjects voted for discomfort on a TSV scale (i.e. -3,-2, 2&3). As shown in Fig4.10d, 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, similar observations are drawn by

Schiavon and Lee [112]. This implies that subjects use clothing as an adaptive measure in response to the uncomfortable environmental conditions.

The results have clearly shown the significance of seasonal variability of various physical and contextual parameters on the adaptive behavior of the subjects. In a country like India, this has far more implications on the overall energy demand of naturally ventilated buildings, considering the comfort tolerance of the natives to a wider range of temperatures. And, thus, it is not only essential but inevitable to efficiently design the building controls (i.e. '*in-built controls*') in order to minimize the dependence on '*seasonal*' or '*energy intensive'* controls.

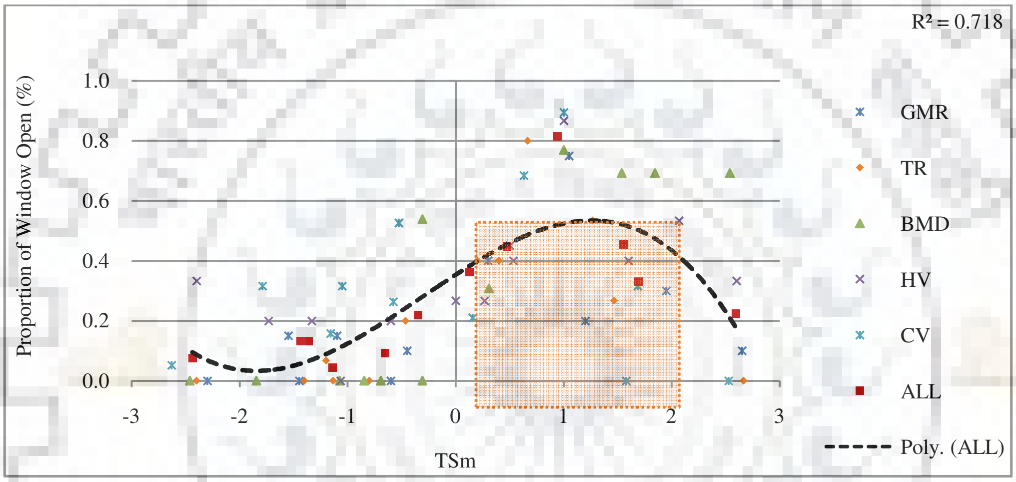


Fig4.10a. Proportion of Window-use as a function of TSm

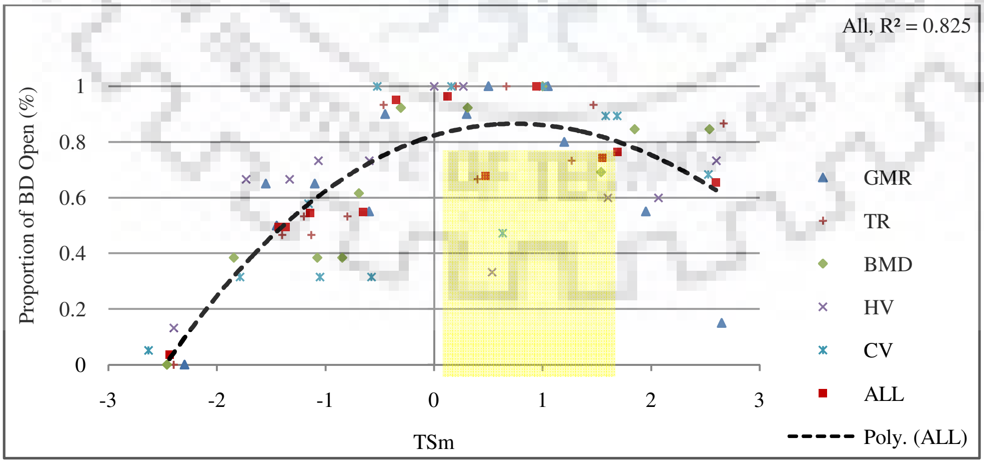


Fig4.10b. Proportional use of BD as a function of TSm

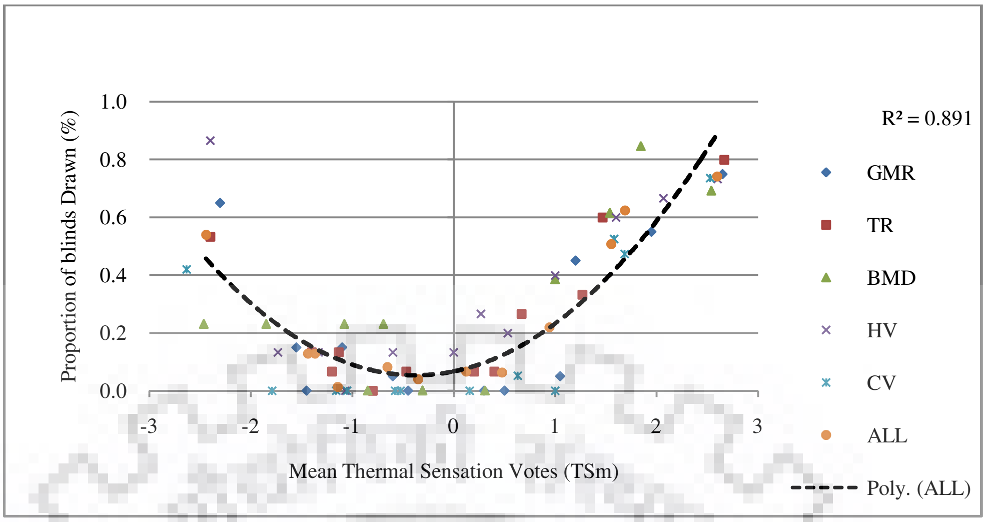


Fig4.10c. Proportion of BL use as a function of TSm

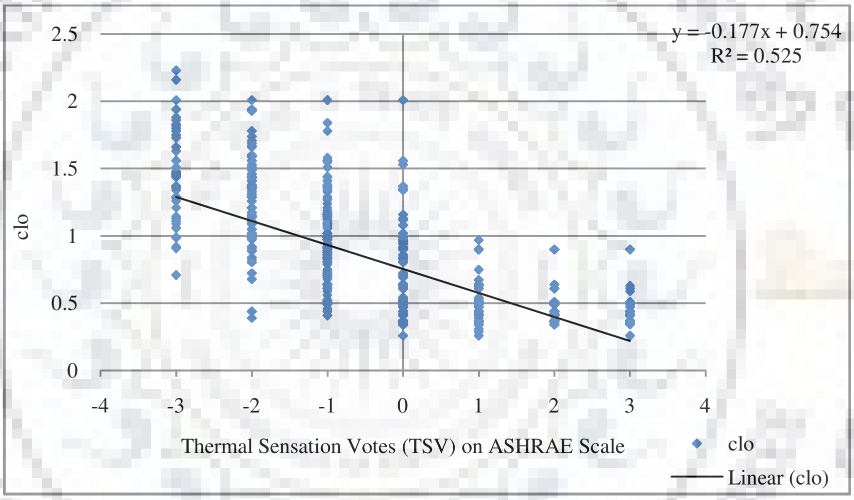


Fig4.10d Linear Regression of ‘clo’ with TSV

4.4 Distribution of Usage Pattern of Controls

Subjects are observed to be using ‘BD’ in a number of ways, so to generalize their responses, its usage pattern is further categorized, as illustrated in Fig. 4.11a. In winters, 60% of the subjects preferred to ‘mostly close’ their BD and 20% preferred to open BD ‘only during the daytime’. During winters, the outdoor temperature drops up to 7^0C & 5^0C (in Roorkee & Chandigarh, respectively) and indoors are preferred to be kept warm with the use of hot blowers/heaters and keeping doors and windows closed. In summer period, the distribution of BD use is moderately divided between ‘mostly close’ (i.e. 35%) & ‘open only in morning & evening’ (33%). It is important to note that at peak summer time, due to the harsh gush of hot wind or '*loo*', it is undesired to allow any cross ventilation in the daytime. In monsoon, the opening distribution slightly varied with the maximum responses in favour of 'half open & half close' (i.e. 55%).

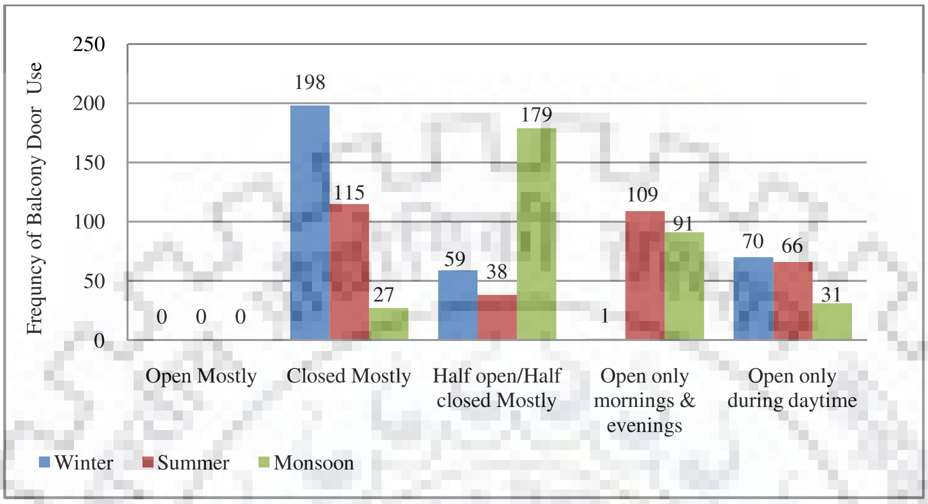


Fig4.11a Seasonal Use of Balcony Doors (BD)

The proportion of 'W'-use is predominantly below 20% in winter period with a strong regression coefficient ,r^2=0.77 (refer Fig4.4a). Out of this, approximately 10% preferred 'half open & half closed' and 90% of subjects preferred to 'mostly close' the windows (refer Fig4.11b). The usage pattern in summer is 'half open & half close' (26%) and 'mostly closed' (70%), as shown in Fig4.11b. The proportional use of 'W' reached to its maximum level in the monsoon period, with its usage pattern moderately distributed between 'mostly closed (57%) and 'half open & half close' (41%), refer Fig4.11b.

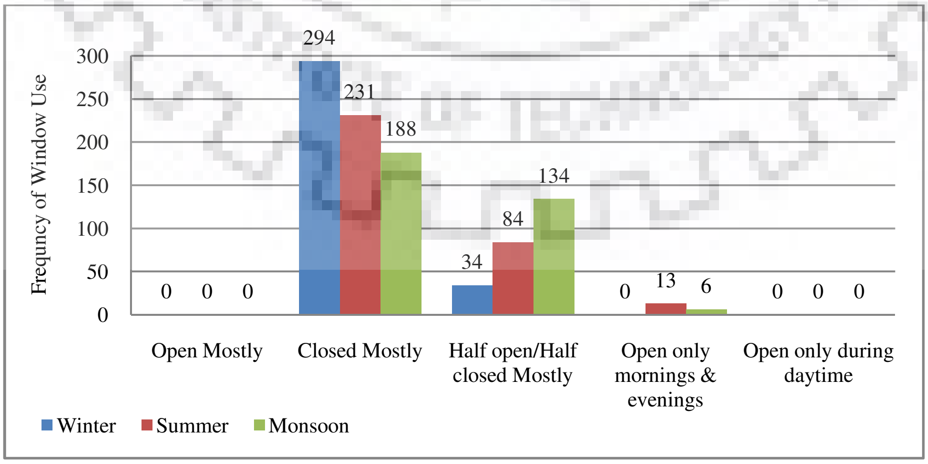


Fig4.11b. Seasonal Use of Windows

Blinds are observed to be used under a wider range of temperature and have shown more variation in the usage pattern as compare to 'W' and 'BD'. Almost 50% kept their blinds 'half open & half close' and 28% 'mostly open' in winter (refer Fig4.11c). The usage pattern of 'BL'-use is moderately distributed between 'open mostly' (24%), 'closed mostly' (34%) and 'half open & half close' (38%) in summer (refer Fig4.11c). Almost 70% kept their blinds 'half open & half close' in monsoon. The minimum use of 'BL'-drawn around 'neutral' votes confirms the adaptive behavior of the subjects as a response to only extreme outdoor conditions.

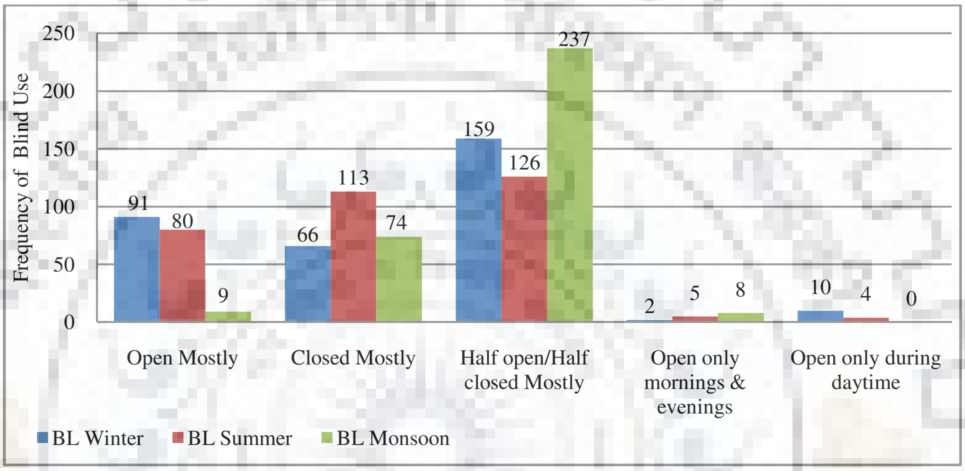


Fig4.11c. Seasonal Use of Blinds

4.5 Inferences

A field survey on thermal comfort has been conducted in apartment buildings with the prior focus to investigate the thermal perception of the occupants in multi-storied apartments in composite climate of north India.Following is the summary of the findings:

- A comfort temperature of 26.1 °C is estimated using linear regression analysis with a comfort band (22.5–30.6 °C). Thermal acceptance of subjects is observed to be significant even when the comfort votes are lower or subjects voted for discomfort (i.e. '3&2' in summer and monsoon and '-2& -3' in winters).
- TSI & TSV has shown a significant correlation of 0.86. with a comfort range of 22.0°C -29.8°C for 80% acceptability.The inconsistency in the results can be attributed to the difference in the time period for which the survey was conducted.
- Balcony doors or 'BD' have been widely used in the study in spite of the negligible use of balcony spaces. Subjects preferred to open it (in all seasons), not just for cross

ventilation but to get the feeling of ‘freshness’ and openness’. This has considerably played a significant role in the thermal sensation of subjects, making it a very important control in naturally ventilated buildings.

- Windows or ‘W’ are observed to be minimally opened during winters, moderately in summers and elaborately in monsoon period. It is also observed that window use, though, not used extensively as any other controls but has significantly affected the thermal perception of the occupants.
- Seasonal regression of the proportional use of blinds or ‘BL-use’ with Tg has exhibited a very strong relationship as compared to ‘W’ and ‘BD’ open. It is observed that the BL-use is very low at ‘neutral’ on TSV scale and it rises as the TSV shifted to either side of the neutrality.
- Clothing adjustments have shown a strong linear dependence on Tg in summer & winter period and weak correlation in the monsoon period. It is also inferred that ‘clo’ adjustment is an effective control measure in summer period when the air movement (forced or natural) is controlled by the subjects.
- Metabolic activity has shown no correlation with any of the physical variable or with the comfort votes of the subjects. But gender-wise analysis of ‘met’ rates has shown some clear differences for male and female subjects.
- The statistical summary of fan, A/c and heater has shown a strong dependence on Tg. Subjects have responded to the thermal discomfort by controlling the air flow (fans, evaporative coolers, door, windows etc.) But, it is observed that electrical expenditure, especially in summer period, has affected the A/c usage even at the peak discomfort hours. Subjects were observed to be deliberately pushing their comfort limits to the extent they can bear in order to control their electricity expenditures.
- Finally, it is inferred that the efficient design of the building controls (i.e. ‘in-built controls’) is essential in order to minimize the dependence on *‘seasonal’* or *‘energy intensive’* controls.

CHAPTER 5

ENERGY-USE ANALYSIS

5.INTRODUCTION

Energy efficiency in a building refers to '*its ability to operate and function with minimum energy consumption'* [6].To facilitate the identification of energy-predictors and the suitable measures to optimize the energy load, it is important to assess the energy-use profile of a building [113,114,115]. Residential sector, which accounts for 23% of the total energy consumption [2], is a major issue of concern in India, not only because of its demand but due the changing trends in living standards [4, 46]. 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 [8]. Other studies have highlighted, lighting (approx. 30%) as a major contributor to the electricity-use in residential sector; followed by refrigerators, fans, electric water heaters, and TVs [116].

The initial steps towards the identification of energy intensive predictors are 'energy behaviour characterisation' and its 'quantification'[117].The assessment of variables like occupancy, heat flow through building envelope, lighting system, heating/cooling systems etc. is also relevant, as they play an important part in the complex interactive system of a building [114]. One important aspect of energy utilization in building is the thermal behavior of the building envelope. Previously, studies have highlighted its contribution to the energy losses and the opportunities it provides for energy performance [72,118]. In case of naturally ventilated building, the heat conduction through the building fabric is directly affected by the outdoor conditions. This makes the indoor environmental conditions dynamic (unlike controlled conditioned spaces) and, consequently, affects the overall energy consumption. With the dearth of proper energy standards for naturally residential buildings, the case becomes more appalling. This chapter highlighted the findings of energy-use analysis using a '*whole building calibrated simulation approach'* [84]. Design Builder's software is employed to analyze the energy use pattern of a typical naturally ventilated multi-storied apartment in north India. The highlights of this chapter are:

- Identified the predictors for energy load in naturally ventilated building
- Analyzed the thermal performance of the building envelope.
- Evaluated the retrofitted measures and identified best alternatives for the surveyed buildings.

5.1 As-Designed Baseline Model

The construction strategy for naturally ventilated multi storied apartments is, more or less, analogous in north India. The only difference is the type of finishing which mostly depends on the preference of the owners. Fig1.1 a, b, c, d & e of Appendix-1 shows the geometrical representation of the baseline models.

The external walls of all the surveyed buildings are composed of brick (230mm thick) with an inner and outer layer of plaster (12mm thick each).The indoor partition walls are composed of three layers, a sandwich of two cement plaster layer with a 150mm brick layer in between. The floor is composed of 115mm concrete slab with a finishing of stone chipping/marble/ceramic porcelain tiles and a layer of cement mortar underneath. The exposed roof is in RCC (115mm thick) with an outer layer of bitumen felt sheet (in BMD,GMR & TR) or MW Glass Wool (HV & CV) overlaid with cement mortar. The windows are single glazed units, consisting of 6 mm thick glass in a painted wooden frame. Fig 1.2a-i in Appendix-1 gives the detailed illustration of the construction details employed to establish the baseline models of the surveyed buildings. Natural ventilation is predominant in all the buildings but during extreme summer and winter period, cooling and heating appliances are employed. Table 1.12 in Appendix-1 gives the detailed summary of the baseline models of HV, CV, GMR, BMD and TR.

5.1.1 Annual loads: Simulated baseline models

Table 5.1 gives the summary of the annual energy loads, CO_2 emissions and internal loads (through heat gain and loss) of GMR, TR, BMD, HV and CV. As the baseline models have already been validated using percentage error, CV (RMSE) and MBE (refer Chapter 3); it is assumed that the simulated models represents the existing thermal environment of the surveyed buildings.

Cooling load, conceivably, is observed to be predominant in baseline models of all the surveyed buildings (refer Fig1.3a-e of Appendix-1). As the heat conduction occurs, primarily, due to the building's interaction with the environment; the identification of the share of latent heat through each of the building component becomes important. The effect of heat conduction on the overall energy load is categorized into following categories:

(i) Fabric & ventilation (i.e. heat transfer from wall, roof etc. to the room air)

(ii) Internal gain (convective loads through lighting, occupancy, equipments etc.)

(iii) Fuel-Breakdown

(iv) Total Energy-Load & CO_2 emissions

Table 1.13-1.17 and Fig1.4 -1.6 in Appendix-1 gives the detailed summary of monthly simulation outputs of baseline models of the surveyed buildings (all five). The graphical representation of the percentage-wise distribution of heat gains and losses of the baseline models of all the buildings are is presented in Fig.5.1, 5.2 &5.3.

Table 5.1 Annual Energy Load and Heat Gain/ Loss of Baseline Models (All Buildings)

	GMR	TR	BMD	HV	CV
Annual Energy Load(MWh)	146.7	203.0	69.8	126.2	66.3
Annual CO_2 Emission (kgx103)	100.5	139.1	47.8	86.4	45.4
			Annual Heat Gain / Loss (MWh)		
Solar Gain (Ext. Windows)	524.0	341.2	188.6	211.5	215.4
Walls	-128.6	-66.1	-57.6	-80.0	-27.0
Roof	-3.17	-6.8	-3.4	-2.6	1.1
Glazing	-165.6	-141.8	-69.9	-89.3	-55.1
General Lighting	46.9	58.9	22.9	39.3	21.9

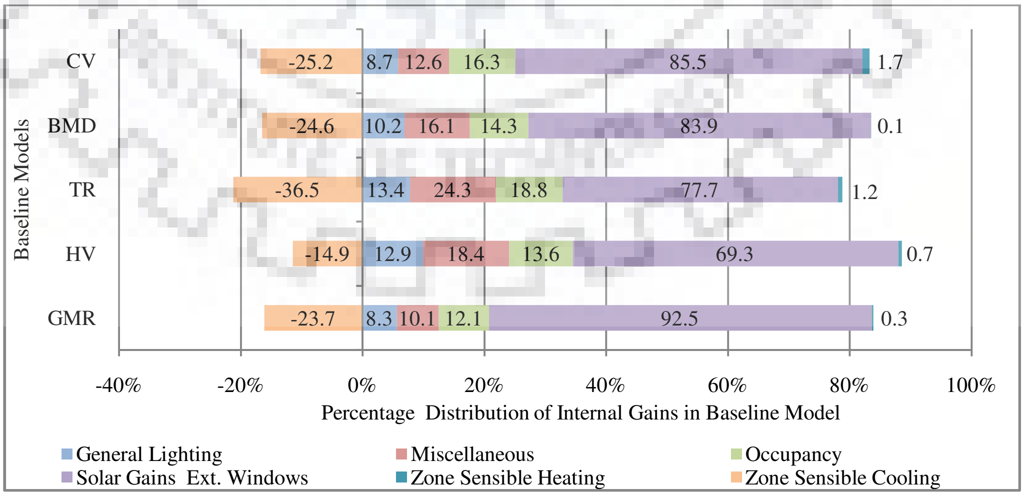


Fig5.1 Percentage Distribution of internal gains in the baseline models

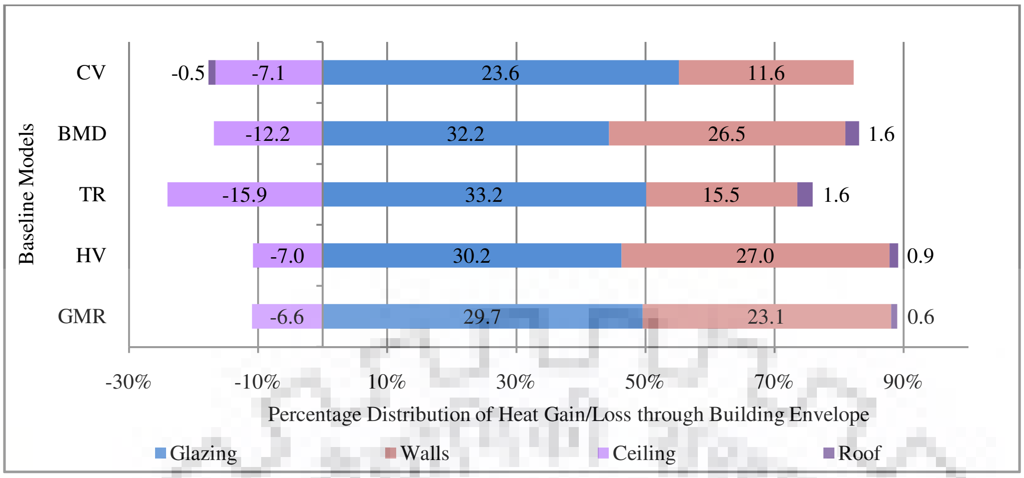


Fig5.2 Distribution of heat gain/ loss through builing envelope in the baseline models (in%)

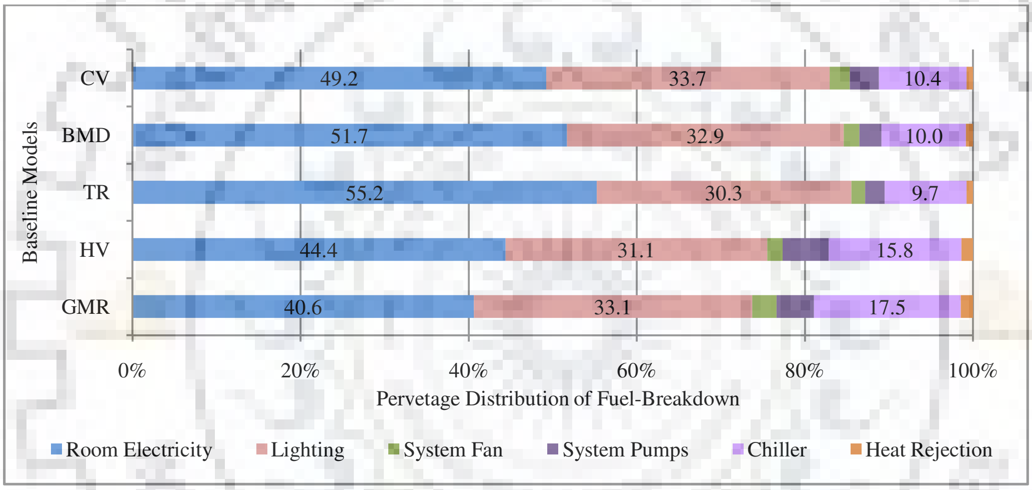


Fig5.3 Percentage Distribution of Fuel Breakdown in the baseline models

5.1.2 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 temperatures within the comfort range. In composite climate, cooling load is maximum and 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's or evaporative coolers). 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. Internal gains through *'solar gains through exterior windows'* and *'zone sensible cooling'* is observed to be maximum in the baseline models, whereas heat flows through the building envelope is maximum through ‘*glazing*’, ‘*walls*’ and ‘*air infiltration*’. Fig 5.1&5.2 shows the distribution of the internal gains and the heat conduction gains of the baseline models.

5.2 Retrofitted Measures: Identified Energy-Intensive Predictors

In order to identify the energy intensive predictors the retrofit suggestions are employed, one by one, keeping all other variables same as in the baseline model. Energy Conservation Building Code, 2007 (ECBC) is referred, for the resistance (R-value) and conductance values (U-value) of wall & roof and SHGC value of glazing unit, to compare its effect. Table 5.2 shows that the conductance and resistance values of the roof & wall assembly of a typical building in north India (here, the construction details of HV,CV, GMR, TR and BMD are assumed to be representing the case) is much varied from the one recommended by the ECBC standards. This clearly suggests the possibilities that one can achieve, to improve the energy performance of the buildings in India by just using suitable construction assemblies.

Table 5.2 Comparison of U-factor & R-value of wall and roof assembly of Baseline model with ECBC recommended values

	Maximum U-factor of the overall assembly (W/m^2 °C)	Minimum R-value of insulation alone (m^2 °C/W)	Baseline Value
Roof	U-0.261	R-3.5	R= .42 to .48
Wall	U-0.440	R-2.10	R = 0.6

The following section is focused on analyzing the effect of each retrofit measure on the overall energy consumption in the surveyed buildings. It is observed that any change in the retrofit measure has consequently affected the overall heat conduction processes through the other structural elements. This suggests that a thorough understanding of the dynamics of these interactive processes needs to be evaluated. Following retrofit measures that are assigned to the assemblies or systems for simulation evaluation:

a) *Glazing*

- Single glaze with low-e clear 6mm
- Double glaze with clear 6mm glass
- Double glaze with Low Emissivity (Low-e) 6mm clear glass

- Triple glaze with clear 3mm glass/6mm Air

b) Wall

- XPS Extruded Polystyrene(XPS) insulated layer wall assembly
- Concrete Block (internal and external layer) with an air gap
- Concrete Block (external layer), brick (internal layer) with an air gap
- Brick (internal and external layers) with an air gap
- Aerated Concrete Block assembly(AAC)

c) Roof

- XPS insulated layer
- External layer of Ceramic Porcelain

d) Lighting

- T5
- T12
- T5 with control

e) Surface Absorptance

- White Color
- Light Color
- Dark Color

Fig 1.7 a, b, c, d , e,f &g in Appendix-1 presents the illustration of the wall & roof assembly, respectively, adopted for the analysis as retrofit measures.

5.2.1 Glazing retrofit

Window glazing is the major source of heat gain through the direct and indirect solar radiations. ECBC recommends glazing with lower SHGC (solar heat gain coefficient) in composite climate. Table5.3 gives the descriptive summary of the baseline model (Single Clr 6mm) and the retrofit models with lower SHGC value. Fig5.4 shows that Double glazed unit with 6mm low-e clear glass has significantly reduced the solar gains through exterior windows (SHG) and heat conduction loss through glazing (HC) in all the baseline models. The reductions ranged between 22 to 44% for SHG and from 42% to 83% for HC, (refer Fig5.4). The reductions in energy consumption were also marked in Double glazed 6 mm low e clear glasses as compared to other glazing assemblies, (refer Fig 5.5).But, it is important to note that the impact of each retrofit differed for all the buildings. For example, in GMR the reductions were as high as 83%, whereas, in case of BMD it reached a moderate value of 43%. The difference can be explained by the building parameters like window to wall ratio (WWR), building form, orientation etc. Chapter 6 elaborates the effect of building design on internal gains and heat flow processes in detail. It is also observed that heat flow through other building components (like walls, ceilings etc.) and the zone sensible heating & cooling decreased markedly in case of Double glazed 6 mm low e clear glass, in all the buildings, (refer Fig 5.6 a-d). From the above analysis, it is deduced that the double glazed low-e glazing unit, minimizing the ultra-violet rays (UV) and infra-red rays(IF) without compromising the visible light, is suitable for buildings with similar characteristics as observed in the surveyed multi-storied apartments.

Due to high density zones with large floor area i.e. 1430.2m^2, the retrofit changes in glazing units, in case of TR, have complicated the simulations. For most of the cases, the simulation process didn't even finish or were time lagged. The results obtained through the simulations were not showing any changes and it is assumed that the extended simulation process has produced biased results for TR. Therefore, TR simulations are excluded in the glazing analysis.

Table 5.3 Descriptive Summary of Glazing Used for Simulation

	Glaze Retrofit	SHGC	Direct Solar Transmission	Light Transmission	U-value (ISO 10292/EN 673	U-value (W/m2-K)
Baseline Model	Single Clr 6mm	0.82	0.78	0.88	5.7	5.8
Retrofit Models	Single LoE; Clr 6mm	0.72	0.68	0.81	3.8	3.8
	Double Clr 6mm/6mm air	0.70	0.60	0.78	3.2	3.1
	Double LoE Clr 6mm/6mm Air	0.57	0.47	0.75	2.5	2.4
	Triple Clr 3mm/6mm Air	0.68	0.59	0.7	2.3	2.2

SHGC (Solar heat gain coefficient) is the ratio of solar gain that passes through fenestration to the total incident solar radiation that falls on fenestration. ; LoE : Low Emissivity ; Clr : Clear

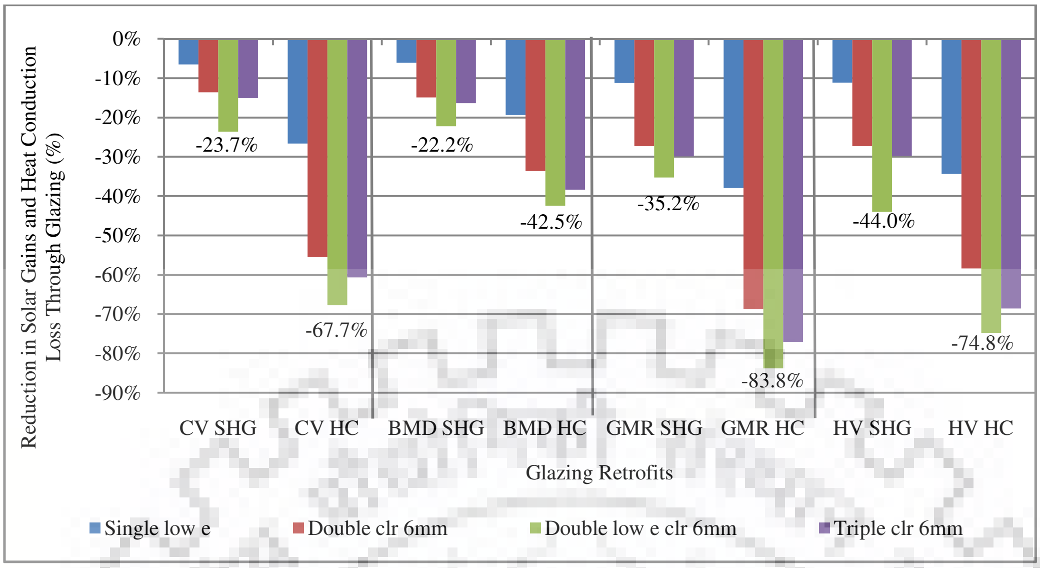


Fig 5.4 Percentage reductions in solar gains (SHG) and Heat conduction loss (HC) through glazing

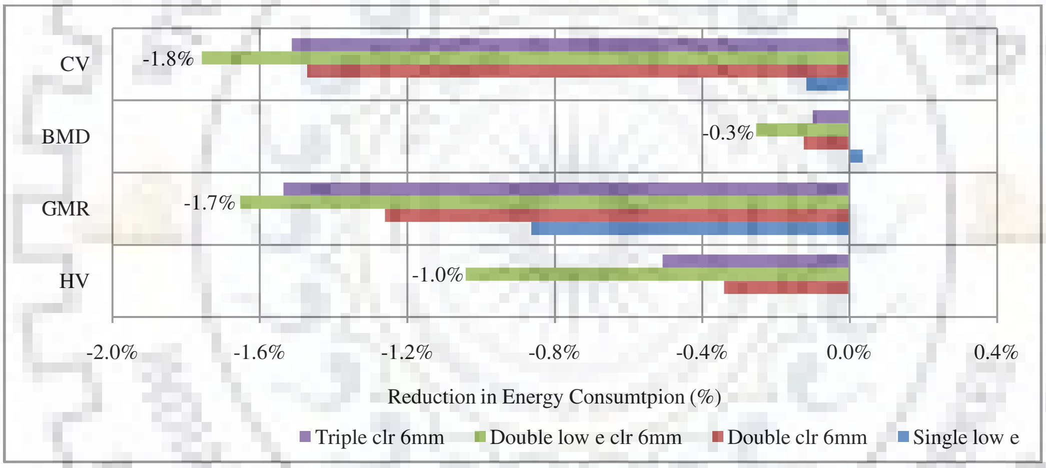


Fig 5.5 Percentage reductions in energy-use for glaze retrofits

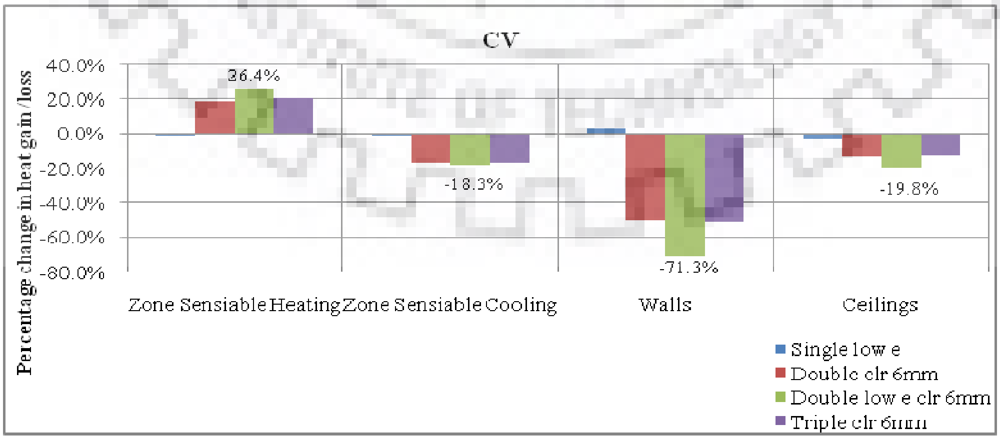


Fig 5.6a Percentage reductions in heat flow through other building component : Glaze Retrofit (CV)

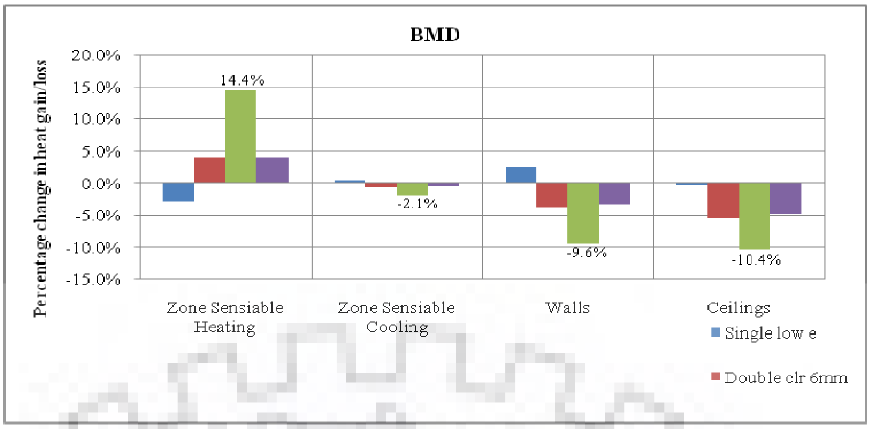


Fig 5.6b Percentage reductions in heat flow through other building component : Glaze Retrofit (BMD)

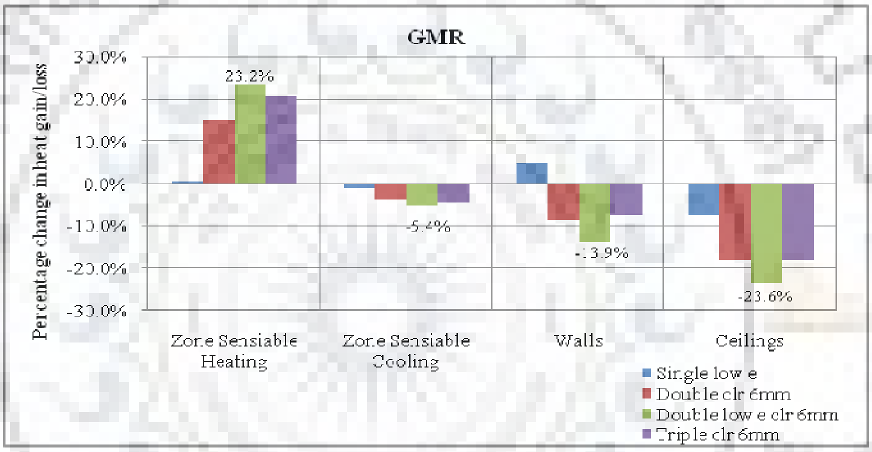


Fig 5.6c Percentage reductions in heat flow through other building component : Glaze Retrofit (GMR)

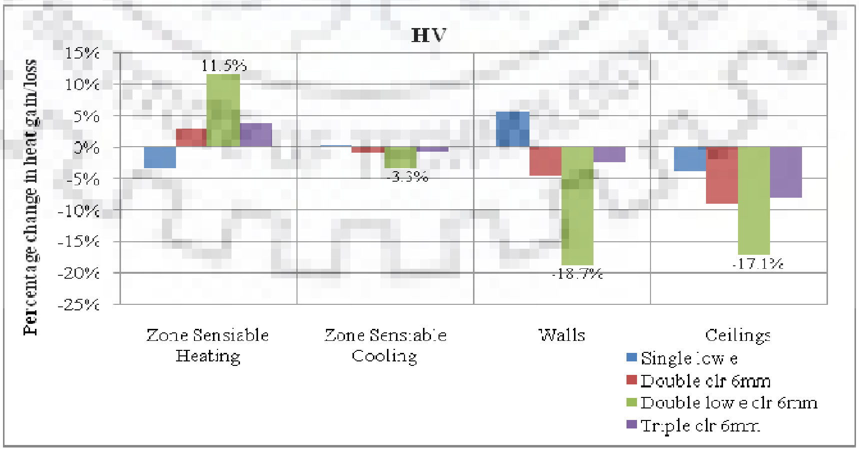


Fig 5.6d Percentage reductions in heat flow through other building component : Glaze Retrofit (HV)

5.2.2 Wall retrofit

As discussed in the previous section, the thermal properties of the wall have not complied with the ECBC standards in all the surveyed buildings. Therefore, wall alternatives within ECBC standards are retrofitted and simulated to analyze the effective reductions in the energy consumption and, subsequently, its effect on heat gain/loss through the building envelope. It should be noted that no other changes are employed and only wall assemblies are retrofitted in order to evaluate the overall heat conduction flows and its effect on the energy-use and thermal environment of the buildings. Table 5.4 gives the descriptive summary of the wall assembly used for retrofitting.

Table 5.4 Descriptive Summary of Wall Assembly Used for Simulation

Wall Retrofit	U-value	R-value
Concrete air gap Brick	0.97	1.03
Brick air gap Brick	1.24	0.81
AAC Wall	0.58	1.73
Concrete air gap Concrete	0.78	1.27
XPS wall	0.35	2.8

Fig5.7 illustrates the percentage reductions (heat gain/loss) observed in the retrofitted model as compare to the existing wall assembly in the baseline model. The wall assembly with XPS insulated layer has shown the maximum reductions (i.e. 30% to 63%) in heat loss through wall. But the relative reduction in the total energy consumption has not been much pronounced and effective for the same (refer Fig5.8). It is observed that for the retrofit models, the reductions in wall heat gain are accompanied with a subsequent increase in the heat conductivity through glazing and ceilings, shown in Fig 1.8a,b,c,d &e in Appendix-1. From the above observations, it is inferred that each building (owing to its orientation, WWR, building form etc) creates distinct indoor environmental conditions with respect to the outdoor conditions it experiences. Therefore, retrofit measures are case specific and, thus, will differ from building to building.

It is suggested that wall retrofit should be selected only after evaluating the effect of each retrofit on the overall performance of each building system. Also, parameters like orientation, WWR, building form etc. should be kept in mind as it significantly controls the thermal behavior of the building, discussed in Chapter 6. For the studied buildings, the retrofit measures were decided on the basis of reductions in the energy consumption.

Concrete air gap concrete is recommended for CV, Concrete air gap Brick for BMD, AAC wall for TR and XPS wall for HV and GMR.

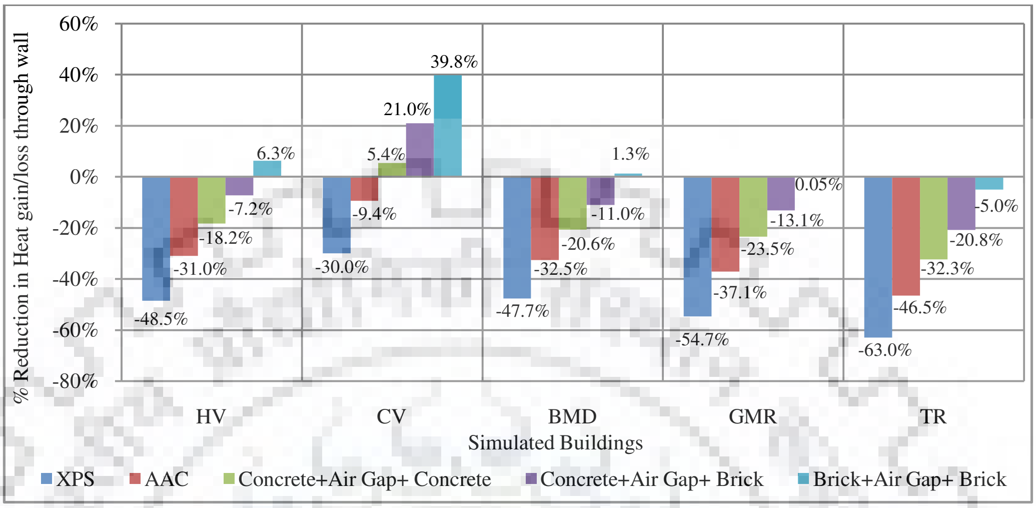


Fig5.7 Percentage reductions in Heat gain/loss through wall

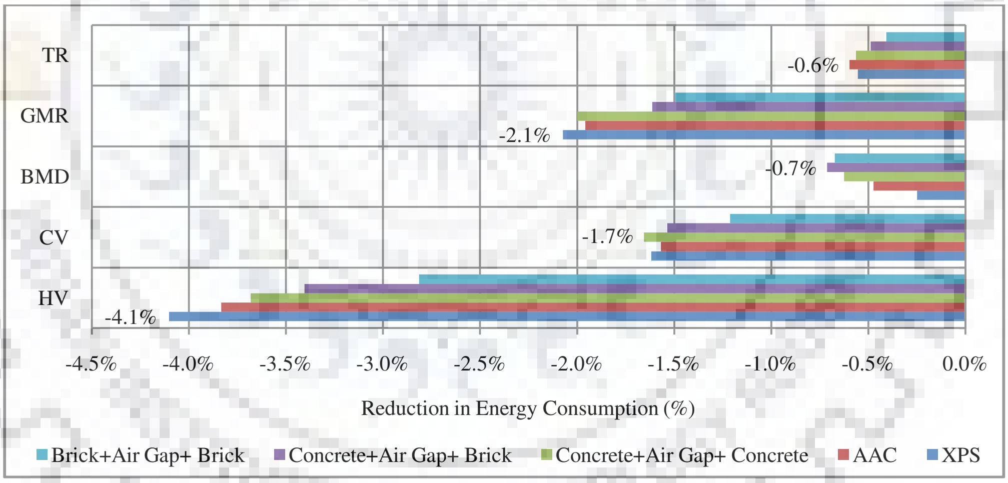


Fig5.8 Percentage reductions in energy-use for wall retrofits

5.2.3 Roof retrofit

Solar radiation through roof is the main source of internal gains in the roof exposed floors. On the basis of the analysis, roof assembly with high emissivity and reflectivity is compared with the insulated roof assembly to analyze the effective change in the energy consumption and the heat conduction flows through the roof. Table 5.5 gives the description of the roof retrofit employed for the analysis. Results show that by increasing the emissivity of the exposed surface, in this case by using ceramic Porcelain tiles, has significantly reduced the heat gain through roof (refer Fig 5.9), wheras the reductions in the energy consumption is moderate for the retrofit models with insulated layers (i.e. insulated layer of XPS Extruded Polystyrene), refer Fig5.10. As discussed in the previous chapter, the thermal environment of the top exposed floors is much harsh and is prone to energy intensive activities. Therefore it is recommended to choose the roof retrofit measures on the basis of the reductions in the heat gain/loss through roof only.

Table 5.5 Descriptive Summary of Roof Assembly Used for Simulation

Roof Retrofit	U-value	R-value
Ceramic Porcelain	2.1	.48
XPS Extruded Polystyrene insulation	.29	3.4

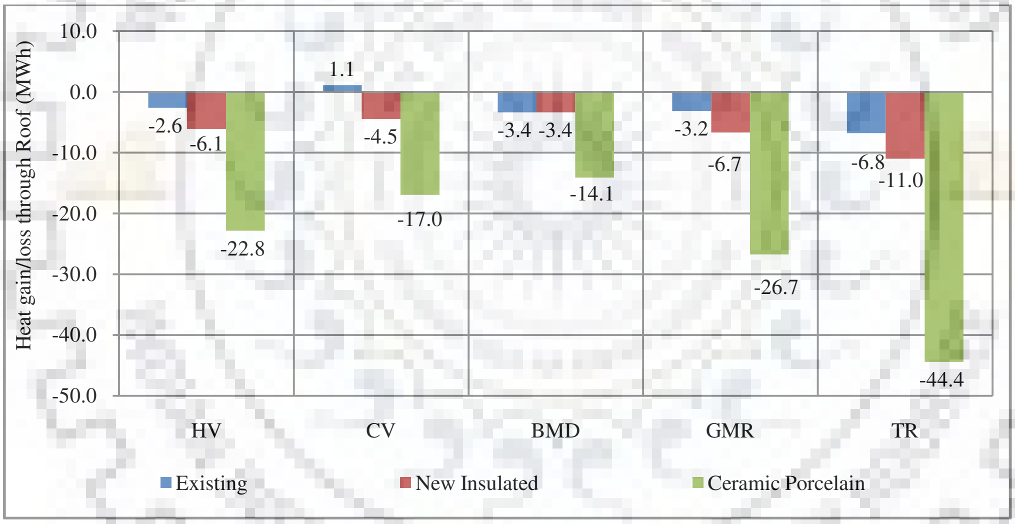


Fig 5.9 Percentage reductions in Heat gain/loss through roof

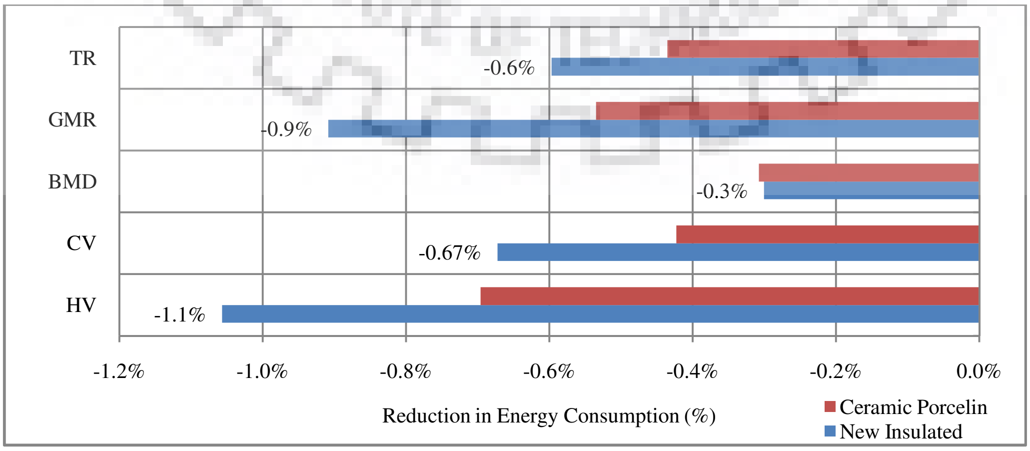


Fig5.10 Percentage reductions in energy-use for roof retrofits

5.2.4 Lighting measures

Survey has shown that occupants were aware of the significance of the energy rated fixtures/appliances and are observed to be using energy efficient lighting fixtures and lamps (CFL's). Therefore, simulations for the lighting retrofits with 'T5 type', 'T12 type' lighting has not brought any changes in the lighting load or energy consumptions. On the other hand, when 'T5type' lighting is used with an automated control, significant reductions of 20-25% is observed in the internal loads (refer Fig5.11). Analysis has also revealed that lighting load has directly affected the zone heating and cooling load. Fig5.11 shows that the zone sensible heating has moderately increased whereas mild reductions are observed in zone sensible cooling when automated lighting is employed. For the studied buildings, automated 'T5' lighting has shown the major reductions in the energy consumption, ranging from 5%-9% (refer Fig5.12). It is important to note that use of automated or occupancy sensors based lighting has tremendously been explored in the commercial setup but not in the domestic households. It is strongly recommended to explore the same for different zones of the building.

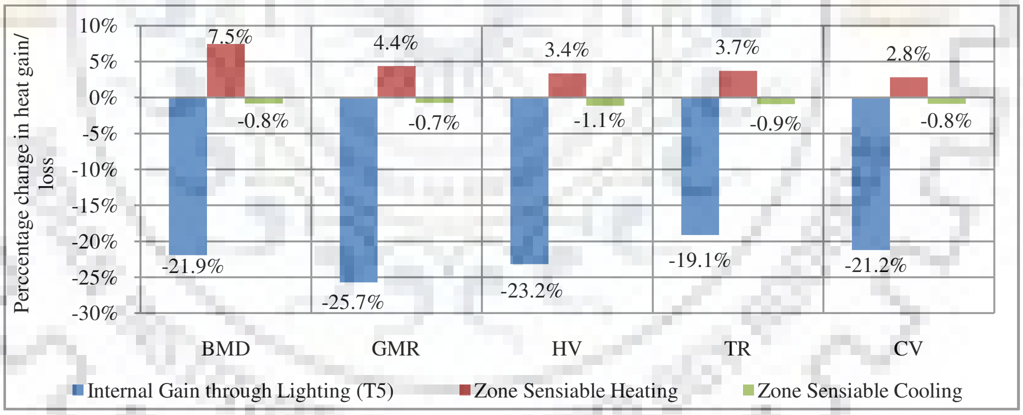


Fig5.11 Percentage reductions in Heat gain/loss for automated lighting retrofit (T5)

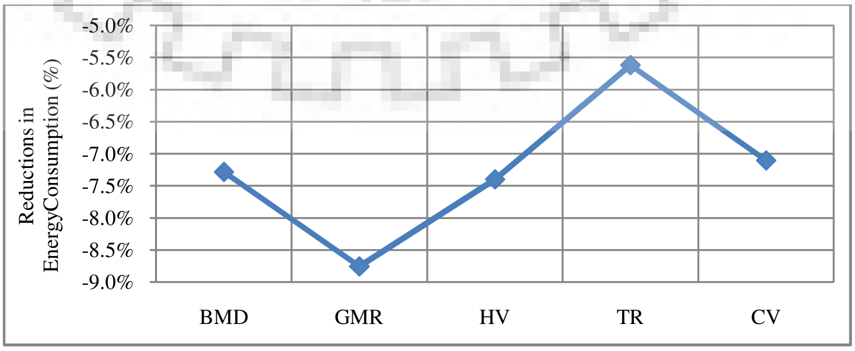


Fig5.12 Percentage reductions in energy-use for automated lighting retrofit(T5)

5.2.5 Surface absorptance of external walls

The surface treatment of the external wall has a huge implication on the heat flows through the wall. In order to analyze the same, simulations are run for three different cases i.e. with different surface absorptance value:

- *0.25 (White Color)- A1*
- *0.45(Light Colors)- A2*
- *0.75 (Dark Colors)- A3*

Conceivably, light colored surface with low surface absorptance and high emissivity value has shown significant reductions as compared to dark colored surface. Fig5.13 illustrates that the heat loss through wall is as high as 88% for the light colored surfaces whereas it has moderately increased the same for dark colored surface. Energy consumption has also considerably decreased for light colored surfaces, i.e. ranging from 1% to 5% (refer Fig5.14).

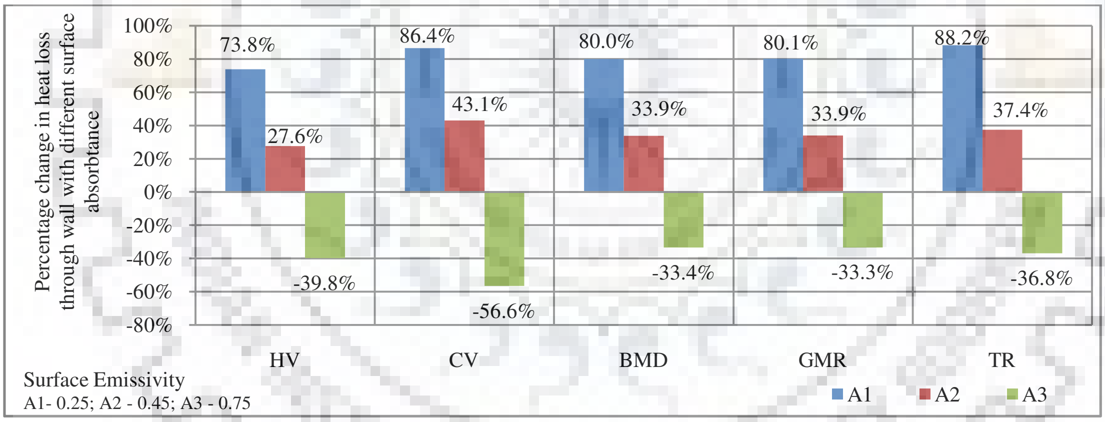


Fig5.13 Percentage change in heat loss for surface treatment

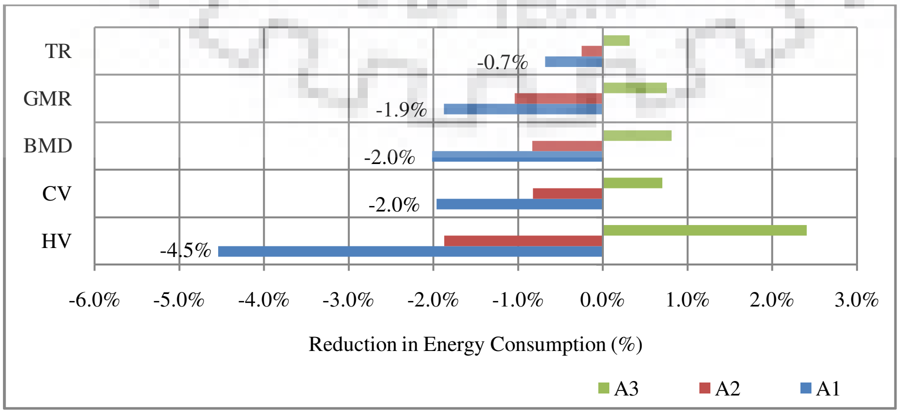


Fig5.14 Percentage reductions in energy-use for surface treatment

5.3 Identified Energy Intensive Predictors

Based on the above analysis, **glazing, wall and lighting** has clearly shown the maximum effect on the internal loads through the heat conduction processes and the resultant energy load. As the surface exposure to the outdoor environmental condition is more in multi-storied buildings, it becomes necessary to make wise decisions, in terms of material selection, orientation, window opening etc., at the early stages of the design. The decisions made in the designing of such buildings (i.e. multi-storied and naturally ventilated buildings) have huge implications on the perceived comfort levels of the occupants and also on the dependence on energy-intensive appliance to achieve the comfort conditions. The understanding of the thermal behavior of the building envelope (especially, glazing and wall) can help in optimizing the energy loads. The use of well furnished technology, like the use of automated lighting fixtures, needs to be explored and advertised; and finally well documented for the practical use.

Simulations can simplify the decision making process for designing an energy efficient and thermally comfortable building; as the thermal performance of the buildings can be evaluated for ‘n’ number of options. It gives the choice to explore different alternatives for improving the building performance at early stages. However, it has its limitations as the ‘independent variable’; like weather, occupancy behavior can bring ‘uncertainties’ or ‘errors’ in the predicted energy load. Especially when assessing the naturally ventilated domestic setup, the likeliness of these uncertainties increases and, thus, it is strongly suggested to inculcate the findings of the adaptive field studies to the simulation tools to ascertain the performance of the buildings.

5.4 Comfort Performance of Baseline Models

As the study is focused on thermal comfort and energy efficiency of multi-storied apartments, the thermal performance of the buildings in terms of comfort is further explored using Discomfort Degree Hours (i.e., no. of hours for which the humidity ratio and operative temperature is beyond the comfort range, as specified in ASHRAE 55-2004).

The overall percentage of discomfort hours (as shown in Table 5.6) for the baseline models of all surveyed buildings is ranged within 26 to 35. The analysis is further extended by comparing the simulation output of baseline model with the retrofitted models (wall retrofits, in this case), refer Table 1.18 in Appendix-1. The percentage change in the discomfort hours is observed to have decreased slightly for all the buildings except for ‘GMR’.

It is important to mention that the mathematical model, on which the simulation calculation for the comfort analysis is established, is based on the heat balance model. It predicts the thermal sensation of the simulated environment using following models:

- P.O. Fanger (the Fanger Comfort Model), the
- J. B. Pierce Foundation (the Pierce Two-Node Model)
- Kansas State University (the KSU Two-Node Model)

As mentioned in the previous chapter, adaptive model of thermal comfort is more suitable for naturally ventilated buildings. Therefore, the simulation outputs for comfort performance needs to be ascertain further.

Table 5.6 Percentage Discomfort Hours of Baseline Models

	Discomfort Hours (Annual)	Percentage discomfort hours (Annual)
GMR	3098.7	35.4
HV	2275.6	26.0
TR	2763.3	31.5
BMD	2622.3	29.9
CV	2941.6	33.6

Assuming that the simulated environment is representing the physical environmental variables of the surveyed building (referring to the statistical tolerances of the calibrated baseline models, as explained in Chapter 3), the comfort analysis output of the simulations is compared with the actual TSV (from the field survey). The comparison has shown a marked difference between the two. Simulations have underestimated the thermal sensation in winter months whereas overestimated the same in summer months, when compared with the actual TSV. Table 1.19 in Appendix-1 shows the difference (absolute deviation) between the actual and simulated comfort outputs. As mentioned earlier, the comfort analysis of the Design Builder’s is based on the heat balance model and, thus, can predict fairly good for the conditioned buildings. But, its applicability on naturally ventilated buildings on the basis of simulation outputs, in this study, needs to be justified. Analysis has shown that adaptive model of thermal comfort predicts better for the naturally ventilated buildings and, thus, suggested to be explored in simulation programs to derive comfort outputs.

5.5 Inferences

- Glazing, wall and lighting are identified as the energy intensive predictors on the basis of the results obtained through simulations.
- Solar gains through exterior windows and zone sensible cooling have shown the maximum internal gains in the baseline models, whereas heat flows through the building envelope in the baseline was maximum through glazing, walls and air infiltration.
- Double glazed unit with 6mm low-e clear glass is identified as the best retrofit measure for glazing. It has not only reduced the solar gains through exterior windows (SHG) and heat conduction loss through glazing (HC) but also reduced the heat flow through other building components (walls, ceilings) and zone sensible heating and cooling. The reductions ranged between 22to 44% for SHG and from 42% to 83% for HC. The reductions in energy consumption were also marked in case of Double glazed 6 mm low e clear glasses.
- Reductions in wall heat gain are observed to be accompanied with a subsequent increase in the heat conductivity through glazing and ceilings for wall retrofit measures. From the above observations, it is inferred that each building (owing to its orientation, WWR, building form etc.) creates distinct indoor environmental conditions with respect to the outdoor conditions and its design. Retrofit measures are suggested to be case specific and, thus, will differ from building to building.
- Roof with high emmissivity & reflectivity (Porcelain tiles) have significantly reduced the heat gains as compared to the insulated roof assembly (XPS Extruded Polystyrene). As the thermal environment of the top exposed floors is much harsh and is prone to energy intensive activities, it is recommended to choose this roof retrofit measures.
- Automated lighting control is proved to be an affective retrofit measure significantly bringing down the internal loads (up to 20-25%) & energy consumption (up to 5%-

9%). It is strongly recommended to explore, advertise and document the use of automated/ occupancy based lighting fixtures.

- Surface treatment, in terms of solar absorptance, has proved to be a significant parameter while considering the heat flow through the wall assembly. Heat loss through wall is up to 80% whereas energy reductions ranged between 1-5% for the light colored surfaces as compared too dark colored surfaces.
- It is inferred from the simulation results, that mere complying with the ECBC standards will not help in optimizing the energy-use and a thorough understanding of the interactive processes due to retrofit measures needs to be evaluated. It is also observed that each retrofit measure has consequently affected the overall heat conduction processes through other structural elements.
- It is suggested that wall retrofit should be selected only after evaluating the effect of suggested retrofit on the overall performance of each building system. Also, parameters like orientation, WWR, building form etc. should be kept in mind as they significantly controls the thermal behavior of the building.
- Typical construction strategy in north India for naturally ventilated multi-storied apartments observed to be not complying with the ECBC standards (mainly wall & roof assembly).The possibilities one can achieve to improve the energy performance of the buildings is tremendous and it is strongly recommended to explore different construction strategies (using locally available material, climatic responsive designs) for each climatic zone of India.
- Simulations have underestimated the thermal sensation in winter months whereas overestimated the same in summer months, when compared with the actual TSV. As the simulation calculation of the Design Builder's for the comfort analysis is based on the heat balance model, which explains the discrepancies between the two. It is, therefore, strongly suggested to inculcate the findings of the adaptive field studies to the simulation tools to improve the energy assessment of the buildings.

CHAPTER 6

DISCUSSION & RESULTS

6. INTRODUCTION

Previous chapters (i.e. Chapter 4& 5) evaluated the thermal perception of the occupants, in terms of comfort, and the thermal performance of the buildings, in terms of heat conduction flows. This chapter, basically, gives an insight to the questions like- *what* affects the thermal perception of the occupants? *Why* are the heat conduction flows so high in some buildings whereas moderately low in others? *How* building-design affects the thermal behavior of the surveyed buildings? And so forth.

Thermal evaluation of the occupants in warm climate has always been debated by the propagators of the thermal comfort models (i.e. Fanger's Model & Adaptive model). As the focus of this study is naturally ventilated buildings in composite climate (with extreme warm & cold conditions) and has already employed the adaptive approach (in Chapter4). It is important to explore the other model also, i.e. PMV model, for the current dataset. As suggested in the previous studies, PMV model overestimates the thermal sensation of the subjects in warm climate [14,15,103,104,119] and, thus, a deliberate attempt is made to find if the same applies to this study also. The derived adaptive model of thermal comfort is compared with the Fanger's PMV model. The discrepancies between the two is further extended by analyzing the demographic (age & gender) and contextual (seasonal variation & exposure to roof) variables. This basically establishes the, already accepted, concept that there are factors beyond the physical variables that affects the thermal perception of the occupants.

It is notable that as the discomfort level surpasses the endurable thresholds of the human body certain measures are necessary at the building level. Controlling the microclimate to reduce the effect of the outdoor temperature, reducing the direct or diffused solar gains and other heat gain/loss and allow cross ventilation, among all, are few of the significant ones [100]. In the later part of the chapter, therefore, parameters pertaining to the energy-use & thermal behavior of the surveyed buildings are evaluated with respect to its design. Passive measures for each building are identified on the basis of derived comfort range and the mean outdoor temperatures.

6.1 Thermal Evaluation of Occupants

Thermal sensation, thermal preference and thermal acceptable votes have shown some interesting voting patterns. In summer and monsoon period, majority of the subjects voted for 'neutral' or '0' on TSV scale but still 40%-50% preferred for 'slightly cool' on TP scale. Thermal acceptability was also observed to be high even when the subjects voted for discomfort (i.e. 'hot' or 'warm' in summer & monsoon and 'cool' or 'cold' in winters).

In India, the operational comfort model is based on ASHARE-55 (1992) guidelines (i.e. Fanger's Model) and follows a narrow comfort range. PMV model assumes that the thermal response of the subject is relative to four environmental parameters (Ta, RH, Tg & Av), clothing& activity of the occupants. Although it has yielded satisfactory results in conditioned buildings but overestimated the subjective thermal sensation in naturally ventilated buildings [60]. The following section compares the subjective thermal sensation of the surveyed occupants with the predicted mean vote (PMV).

6.1.1 Comparison of PMV & TSV

Fanger's predicted mean vote (PMV) is estimated using CBE's comfort calculator [120] to compare the results with the subjective thermal responses (TSV). For the dataset of 984, PMV was mostly higher for the warmer period and lower for the cooler period than the actual thermal sensation (or TSV). (refer Table 1.20 of Appendix-2 for details). 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 Table 6.1). 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 ,as shown in Table 6.1 (refer Fig 1.9a,b &c of APPENDIX-1 for detailed illustrations). The reliability of the difference can be argued with the inherent errors involved in 'clo' and 'met' estimations, as mentioned in the studies before [20, 61]. 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 a wider range of temperature as oppose to what is predicted by the PMV. This has subsequently affected the distribution of the comfort votes when accounting the annual data.

A scatter plot diagram between TSV and PMV has shown that the predicted thermal sensation for summer and monsoon period is +0.13 & + 0.26, respectively, when the actual thermal sensation vote is ‘neutral’ or ‘0’ on TSV scale (refer Fig 6.1& Table 6.2). But the *‘PMV residual’* is observed to be marked for the winter period with a value of -1.3. The results, thus, support the argument that the traditional PMV model overestimates the thermal sensation, similar to the findings of previous studies [14, 15,121,122].The higher discrepancy in the winter period can be attributed to the lower thermal sensitivity. The regression slope of Tg against TSV is observed to be lower for the winter period (0.148/°C) as compared to the summer (0.23/°C) and monsoon (0.31/°C), refer Fig 1.10 of APPENDIX-1. The adaptive control of the indoor environment in winters; i.e. closed doors (60%) and windows (90%) along with the heater usage, has considerably affected the thermal responses and, thus, resulted in lower thermal sensitivity. Humphreys [104] has also mentioned that the lower values of the slope from field studies suggests the adaptive control of the thermal environment by the occupants. 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 [112].

Table 6.1 TSV-PMV Seasonal Evaluation

	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

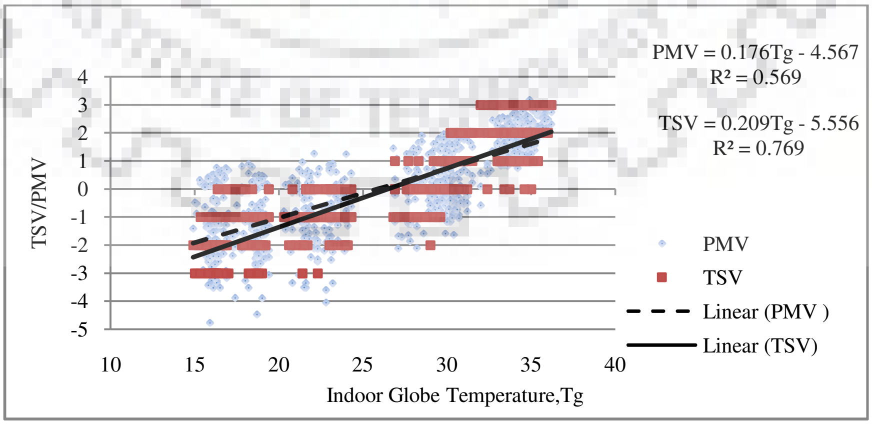


Figure 6.1 Variations of TSV and PMV with Tg

Table 6.2 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

6.2 Thermal Comfort: Gender, Age, Seasonal Variability & Roof Exposure

As explained in the previous section, there are factors beyond the physical environmental conditions that, directly or indirectly, affect the thermal perception and expectations of the occupants. The adaptive approach to analyze comfort temperatures and thermal perception of the subjects is incomplete if the physiological and contextual factors are not included. So far, not many studies have detailed out the relevance of age, gender, seasonal dependency and roof exposure on thermal comfort. This section deliberately makes an attempt to elucidate the same.

6.2.1 Gender differences

Many studies have shown different thermal responses, dissatisfaction level and comfort band when the data set is analyzed for the two genders separately. In the current study, male subjects are found to be more tolerant to temperature variation as oppose to the female subjects. The comfort band of male subjects (21.3°C to 31.7°C) is broader than the female subjects (21.9°C to31.0°C), with a significant difference of 1.3°C (refer Fig.6.2). Not only this, the percentage of unacceptable votes are found to be slightly higher for female subjects (refer Fig. 6.3 & 6.4), although no difference was found in the comfort temperatures. The greater sensitivity to temperature variations and higher dissatisfaction of female subjects has been mentioned in similar studies before [123,124,125]. It is important to note that most of the female subjects in the study were housewives & thus were spending more time indoors than the males. This, with the ease of use of controls and familiarity with the available adaptive opportunities, has greatly influenced their thermal expectations. These differences in thermal perception of the two genders are often explained in terms of morphological differences that eventually affects the thermo-regulatory mechanism of the subjects. Personal variables i.e. ‘clo’ and ‘met’ level are also analyzed to further ascertain these biases in thermal sensation. Clothing ensembles of men and women often have different clo values, with women showing more inter & intra seasonal variation [16]. Similar results are observed in this study with the female subjects having a slightly broader clo range (i.e. 0.3 to 2.2) as oppose to the male subjects (.3 to 1.9). The negative correlation of clo with TSV & Tg is found to be marginally stronger for males as compared to females. Met, as such, showed no strong correlation with Tg & TSV but have shown a marked difference when compared gender-wise. Almost 80% of the male subjects were observed to be involved in light sedentary activities as oppose to female subjects (approx. 56%). Most of the heavy household activities (i.e. cooking, washing clothes, etc.) were done by females. This difference in the ‘met’ level and ‘clo’ level, further, contributes to the variations observed in the thermal comfort perception of the two genders.

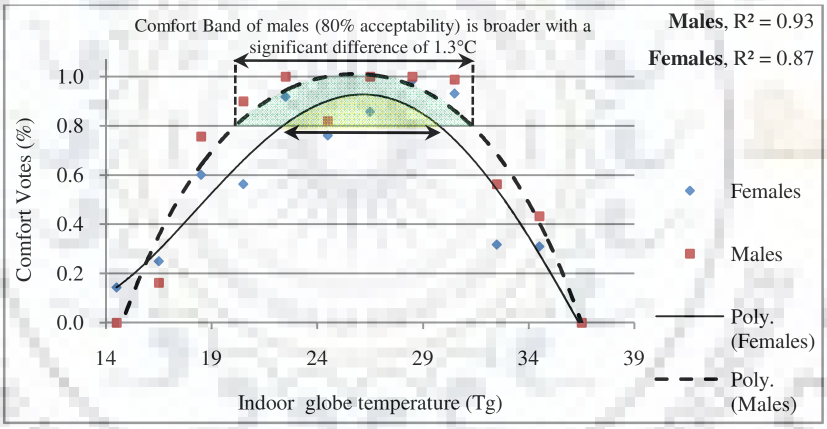
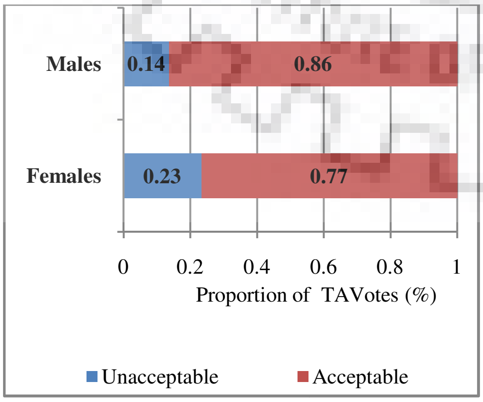


Fig.6.2 Proportion of TS votes within a comfort band (male & female subjects)



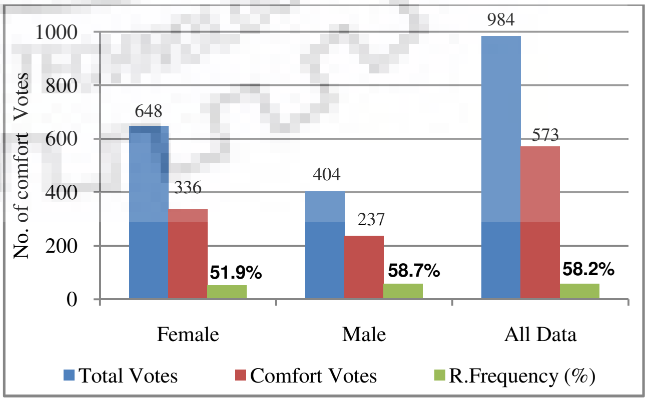


Fig.6.3 Gender-wise distribution of TA vote

Fig.6.4 Gender-wise distribution of Comfort Votes

6.2.2 Age differences

Age-wise distribution of comfort votes is plotted against Tg to analyze the variation in thermo-regulatory capacity [60] of the subjects. The difference in the comfort temperatures for the three age groups (26.6°C, young; 26.6°C, middle aged & 26.4°C, elderly) was not conclusive, which is in agreement with the previous field studies [16, 126]. In general, elderly seems to perceive thermal comfort differently from the other age groups due to physical ageing and behavioral differences. In the present study, the percentage of elderly subjects voting comfortable (i.e. -1,0 or 1) on TSV scale is found to be less as compared to other two age groups (refer Fig.6.5). It should be noted that the comfort range for 80% acceptability is observed to be narrower for elderly subjects (refer Fig.6.6), as mentioned by Auliciems [57]**.** Studies have revealed that the ability to regulate body heat tends to decrease with age [127]. This explains the increased thermal sensitivity of elderly subjects and the resultant narrow comfort range. Low Basal Metabolic Rate (BMR) of older subjects could be another explanation as the heat loss and heat gain is influenced by it most of the times. Another notable observation was that the curve for comfort votes plotted against Tg is skewed towards the lower side of the temperature range for elderly people, Fig.6.6. This shows that subjects under this age group feel comfortable at a lower temperature than the young and middle age groups. Collins has also mentioned similar results [128]. On further analysis, it is found that clo level of elderly subjects is higher (min. = 0.31 and max. =2.23) as oppose to middle age group (min. =0.26 & max. =2.01) and young subjects (min=0.26 & max=1.78) which could be the possible explanation for the difference in thermal perception.

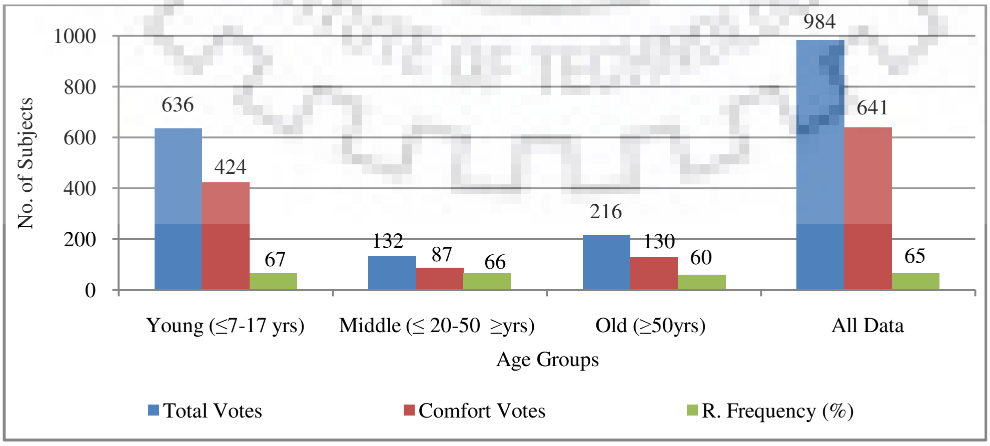


Fig.6.5 Age-wise distribution of comfort votes

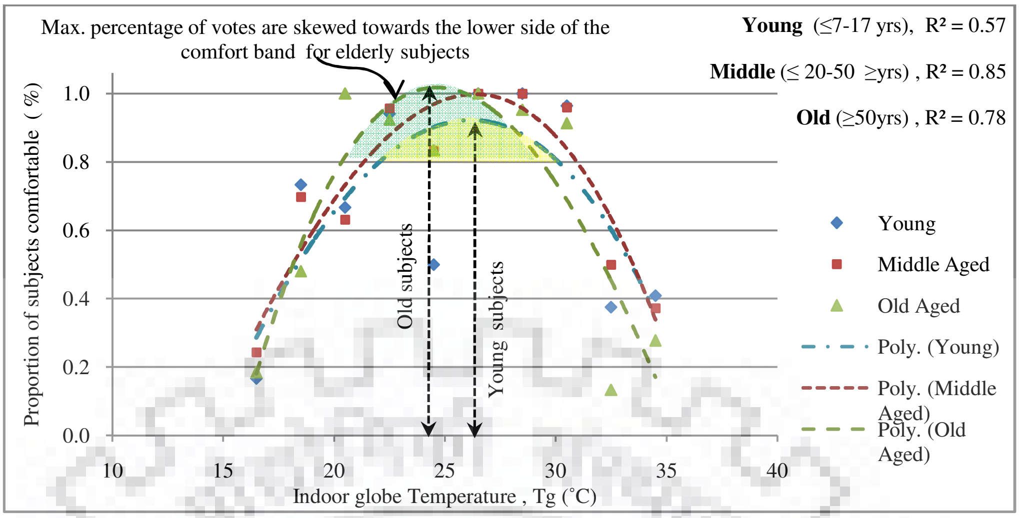


Fig.6.6 Proportion of comfort votes as function of Tg

6.2.3 Seasonal variation

Many studies have been performed to elucidate the differences in thermal sensation of the subjects for cold and warm seasons [15, 20,101, 103, 126]. This study has also revealed some striking seasonal variations. For winters, the correlation between Tg and TSV is observed to be poor (0.44) as compared to summer and monsoon period with a significant correlation of 0.85 and 0.77 respectively. The slope is observed to be slightly higher in summer (0.23/^{o}C) and monsoon (0.31/^{o}C) and lower for the winter period (0.148/^{o}C), refer Fig 6.7. It clearly indicates that the occupants were least sensitive to Tg during the winter period as compared to other seasons. On an average, mean thermal sensation changed one unit for every 6.7˚C of Tg in the cold season, 4.4^{o}C in summer and 3.2^{o}C in the monsoon period. This poor correlation and least sensitivity in winter period can be explained by the closed doors (60%) and windows (90%) along with the heater usage.

In summer, majority of the votes were equally distributed between feeling 'neutral' or '0' and feeling ‘slightly warm’ or '1' on TSV scale (refer Fig 6.8). Interestingly, around 40% of the subjects still preferred for 'slightly cool' or '-1' on the TP scale (refer Fig 6.9). Monsoon period has reflected the increased discomfort level, with almost 33% of the subjects feeling 'warm' and around 50% preferred for 'slightly cool' on TP scale. This increased discomfort and the consequent increase for thermal preference on cooler side can be explained by the excessive humidity and moderately high temperatures (which make conditions quite stuffy). In winters, almost 40% of the subjects voted for '-2' or ' very cool' on TSV scale and around 54% preferred for 'slightly warm or '1' on preference scale. Majority of the subjects found the existing environmental conditions acceptable in all the seasons and the TA votes ranged between 77-84% for all the seasons.

The variations observed in the thermal sensation can be attributed to the outdoor temperature (which has strongly correlated with the indoor globe temperature, r = 0.96). Another explanation is the behavioral adjustments (i.e. door, window, fan etc.) in response to the changes in the outdoor and indoor conditions. Clothing has also shown a strong linear dependence on outdoor temperature [129] and comfort temperature [60] earlier. In the current study, similar results are drawn with a strong correlation of clo with Tg in summer (-0.7) and winter (-0.7) as oppose to monsoon (-0.3).

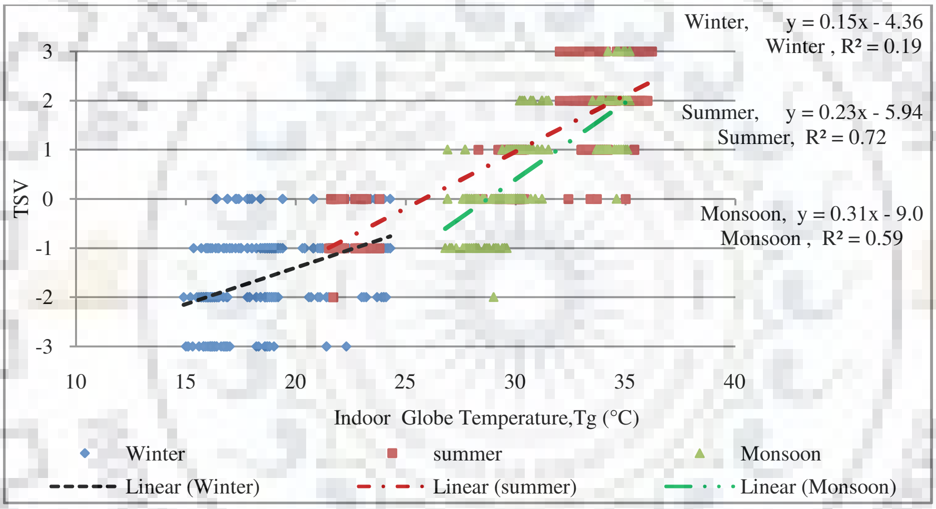


Fig.6.7 Seasonal Regression of TSV with Tg

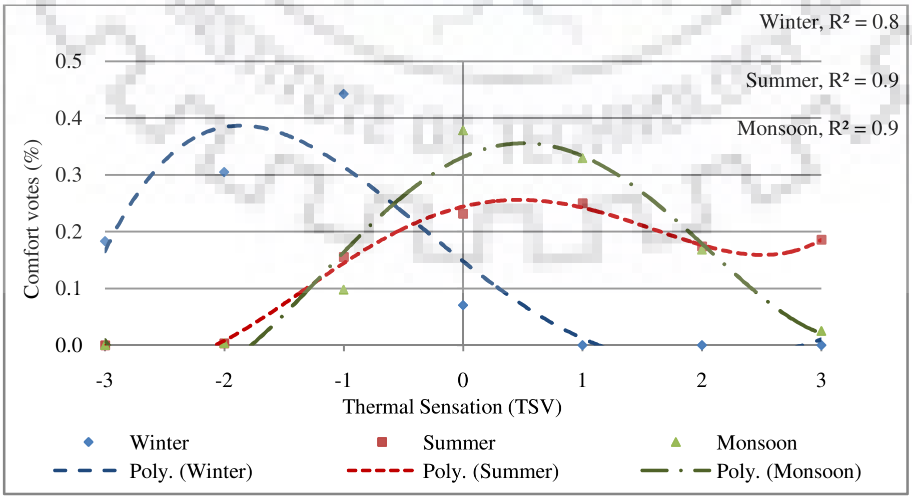


Fig.6.8 Seasonal distribution of comfort votes

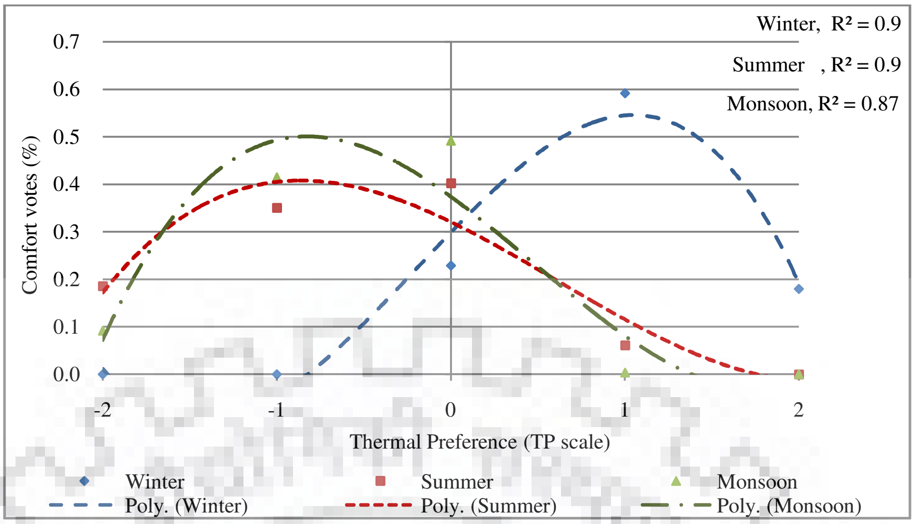


Fig.6.9 Seasonal Distribution of preference votes

6.2.4 Roof exposure variation

Top floors have different level of exposure to sun and wind which can affect the thermal experience of the inhabitants. Owing to direct exposure to extreme environmental conditions through the roof, Tg has varied in top exposed floors (TF) & lower floors (LF). This consequently has affected the TSV of the subjects. The comfort temperature for the respective floor levels has also varied such that 'TF' has higher values than the 'LF' (refer Table 6.3). Indraganti [10], in her study, has also reported that 'roof solar exposure' results in higher discomfort in top floors & affects the thermal sensation votes of the subjects. In winters, TSm was towards the lower side of TSV scale for both 'LF' and 'TF' (approx. 41-45% voted '-1') but maximum discomfort was reported in the top floors (23% in TF voted '-3' as oppose to 17% in LF). In summer, a similar discomfort pattern is observed with a moderately high number of subjects voting discomfort on the upper side of TSV scale (23% in TF voted '3' as oppose to 15% in LF). In monsoon, majority of the votes were around neutrality or '0' on TSV scale. However, more subjects voted 'warm' or '2' on the TSV scale in 'TF' (approx. 26% in TF as oppose to 12% in LF). Thermal acceptance of the subjects in 'TF' is also observed to be lower than 'LF' for all the three seasons (refer Fig 6.10). During summer higher proportion voted for "unacceptable" in TF (approx. 30%) as oppose 20% in LF. This difference can be explained by the roof exposure which leads to the increased heat gain (in summers) and heat loss (in winter). It is observed that subjects when experienced extreme environmental conditions has automatically opted for energy intensive controls, like A/c's & fans (in summers) & heater /blowers (in winters) as oppose to doors ,windows ,blinds etc. This suggests that the inefficacy of the available adaptive opportunities to control the harsh environment in top floors can result in the increase of energy load.

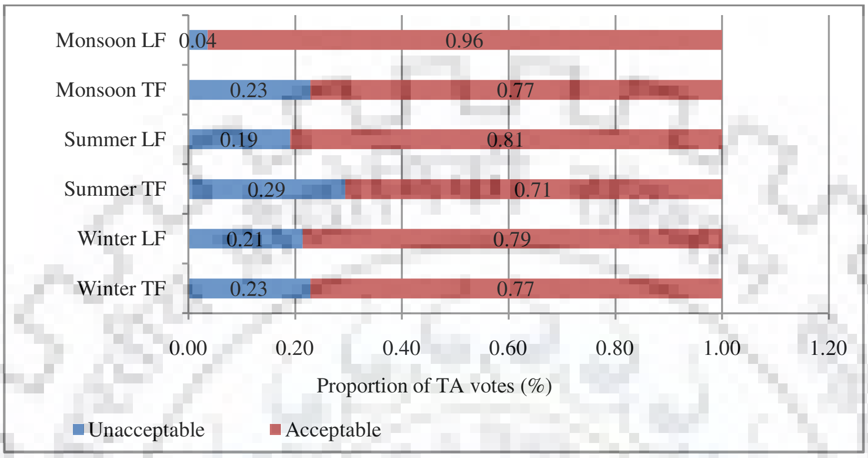


Fig.6.10 Distribution of TA votes for TF & LF (all seasons)

Table 6.3 Neutral Temperature of TF and LF (all seasons)

	Winter			Summer			Monsoon		
	Tn	**Tgm**	**TnG2**	**Tn**	**Tgm**	**TnG2**	**Tn**	**Tgm**	**TnG2**
GMR TF	24.3	18.8	25.5	26.8	30.7	27.0	28.8	31.4	27.1
BMD TF	27.2	19.3	25.3	27.3	30.9	26.9	27.6	30.9	26.6
HV TF	30.2	18.8	25.9	25.2	29.3	25.1	23.7	30.6	26.8
CV TF	33.4	19.1	26.3	26.5	31.2	26.8	28.6	30.8	27.9
TR TF	22.5	18.1	24.4	25.5	30.5	25.7	68.7	31.4	28.4
GMR LF	11.6	18.1	25.1	25.9	29.8	26.3	28.9	30.6	29.1
BMD LF	25.0	18.5	24.0	25.2	30.1	26.3	29.2	30.6	29.1
HV LF	33.3	17.9	23.5	25.1	29.1	24.8	27.8	30.1	27.7
CV LF	23.1	18.9	25.4	25.1	29.9	26.1	29.4	30.3	29.3
TR LF	18.3	17.9	24.9	26.9	29.9	26.9	29.8	30.8	29.4

TnG2: Neutral Temperature using regression coefficient (r =.25) is estimated to alter the unreliable values obtained using simple regression (explained in earlier section)

6.3 Building Design : Effect on Heat Gain/Loss

The thermal performance of the building helps in evaluating the heat flow processes with the outdoor environment. Windows, wall & roof are identified (Chapter 5) to be affecting the internal gains through the building envelope the most. But the design parameters that have regulated these heat gain and loss processes and the resultant energy load needs to be analyzed. Some of the climatic responsive variables for an energy efficient design are summarized as: site-specific conditions (landforms, water-bodies etc.), geometrical shape of the building, material properties (thermal conductivity, solar heat gain capacity etc.), buffer spaces (balconies, courtyards, verandahs etc).

The following section explains the thermal behavior of the baseline models in terms of each of its design.

6.3.1 Orientation and building form

Orientation is an important consideration while evaluating the solar gains through the building envelope, as the heat conduction flows through each façade is unequal owing to the different level of exposure to the solar radiation [130].The analysis has shown that the building orientation and the window to wall ratio (WWR) for the corresponding directions 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 6.4). The solar gains through ext. windows in HV are, thus, allowed only when required (i.e. in the winter period) and restricted in the warmer period (refer Fig 6.11), an ideal case for composite climate.

Table 6.4 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 6.12a shows the key plan of GMR; it is 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 6.12 b & c). 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 also observed to be 1°C higher than the block on E-W axis, i.e. Bb, for both the floor levels (refer Table 6.5). The zones facing the prevalent north westerly winds are observed to be cooler in blocks ‘Ba’ and ‘Bb’.

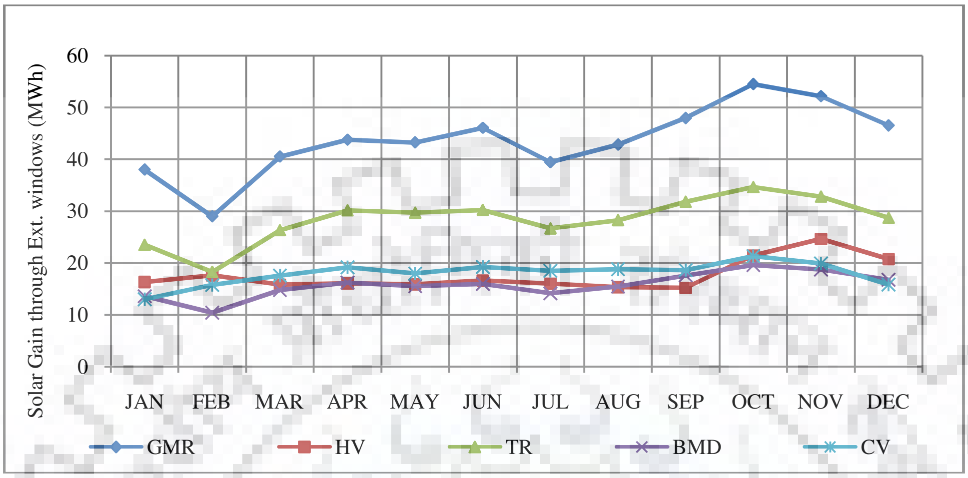


Fig 6.11 Solar Gain through Exterior Windows

Table 6.5 Zone temperatures of all blocks (TF and LF) of BMD

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

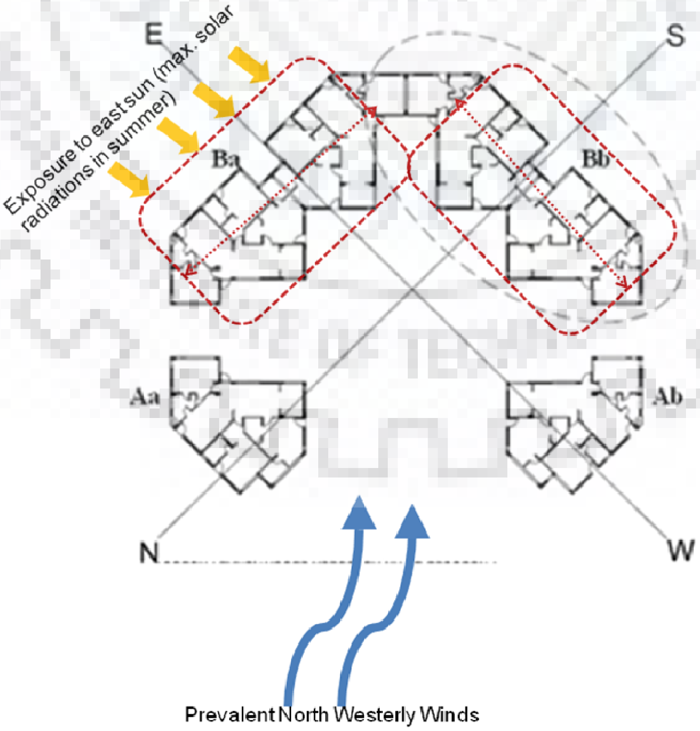


Fig6.12a Key Plan of GMR

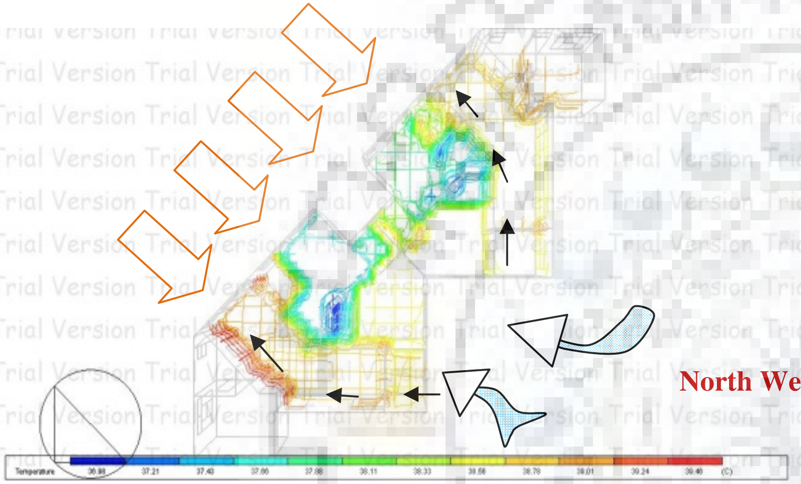


Fig 6.12b GMR ‘Ba’ Block (TF)

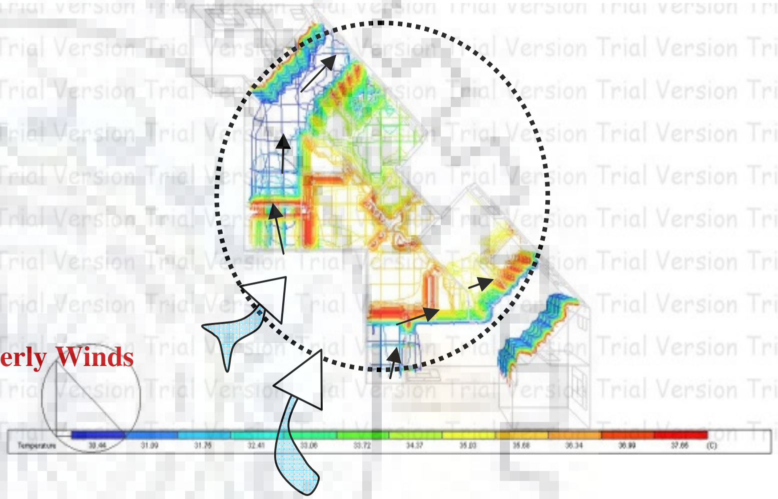


Fig 6.12c GMR ‘Bb’ Block (TF)

- Higher heat conduction gains in TF as compared to LF
- 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.
- Zones facing the prevalent north westerly winds are observed to be cooler in blocks both the block.
- East facing façade has resulted in higher heat gains through wall.

6.3.2 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 [130].Therefore, WWR for the façades with maximum solar radiations, have been summarized in the Table 6.6. 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 5.1 & 5.2 in Chapter 5) 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 5.2 in Chapter 5) 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 higher as compared other buildings (refer Table 6.6 and Fig 6.13). 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.

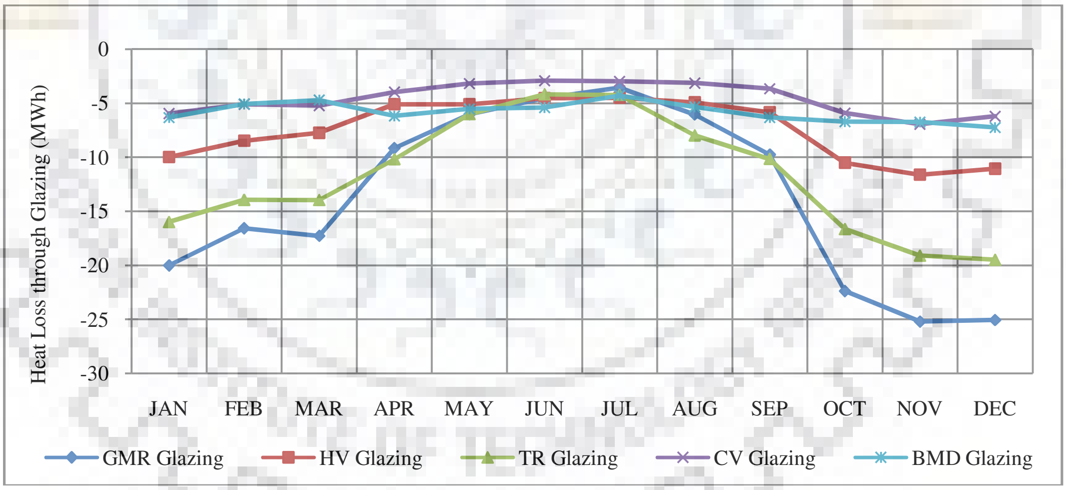


Fig 6.13 Heat Flow through Glazing

Table 6.6 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

6.3.3 Roof exposure

The diurnal range or difference between the night and daytime ambient temperatures of the studied areas is high during the summer and winter period. This has considerably affected the heat flow through the roof and, apparently, the indoor thermal environment of the top exposed floors (TF), as explained in the previous section. The simulation outputs for the baseline model has clearly shown that the heat flow through the roof is adding to the discomfort in the peak summer and winter months. Fig 6.14 illustrates that the heat flow through the roof in summer has resulted in the heat gain whereas in the winter period heat loss is prominent. It should be noted that TR, in particular, has shown the maximum heat gain and loss as compared to other buildings and the observed difference can be attributed to the larger roof area (i.e. 1430.2 m^2) of TR.

The roof composition of all the buildings is ,more or less, similar in terms of thermal properties (refer Table 6.7). In order to explore the heat gain pattern through the building envelope, simulations for typical summer period i.e. 12th June to 18th June is done. It is observed that the nightime heat flow is , though, lower than the daytime heat gains but not efficient enough to stimulate the night time cooling. Fig 6.15. shows the graphical output of the baseline model for TR. It can be seen that lower/downside contours of the roof gain are hardly crossing the ‘0’ level. It shows that for the daytime heat gain through roof, wall or glazing; roof is not efficiently contributing to the nightime time cooling in top exposed floors & adding to the thermal discofort in summertime. It can be explained by the low resistance value of the roof assembly used in the building as compared to the recommeded ECBC standards (refer Table 6.7).

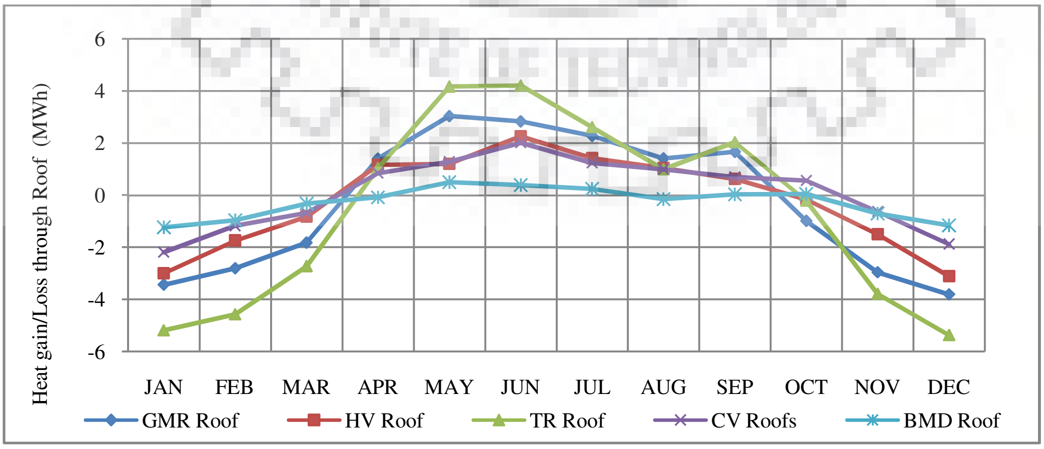


Fig 6.14 Heat Flow through Roof

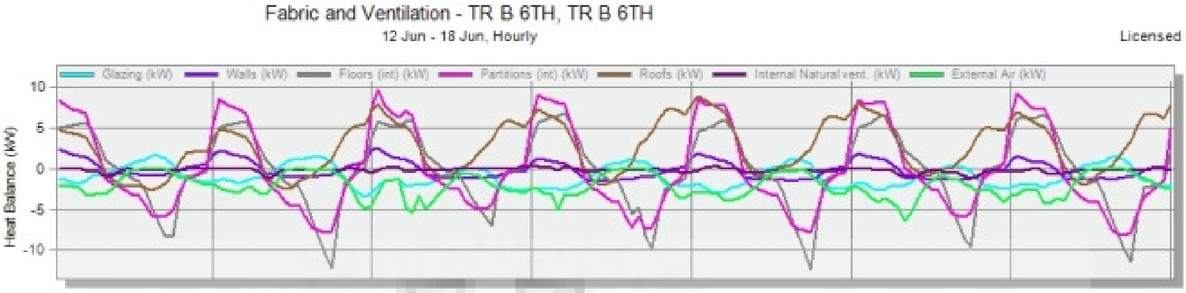


Fig 6.15 Heat flow through building envelope for typical summer week (TR)

Table 6.7 ECBC recommended R-value (m2 °C/W)

	ECBC Minimum R-value	Baseline value
Roof	R-3.5	R= .42 to .48
Wall	R-2.10	R = 0.6

6.3.4 Walls

In multi-storied buildings, walls and glazing account for most of the heat gain [32] and contribute to about 80% of the annual cooling load in such buildings [6]. The thermal resistivity of the wall composition for all the buildings is observed to be lower than the recommended ECBC value (refer Table 6.7). This has considerably affected the heat flow through the walls. Heat gain in summertime and heat loss in winter time is observed to be much pronounced in case of wall assembly (refer Fig 6.16).

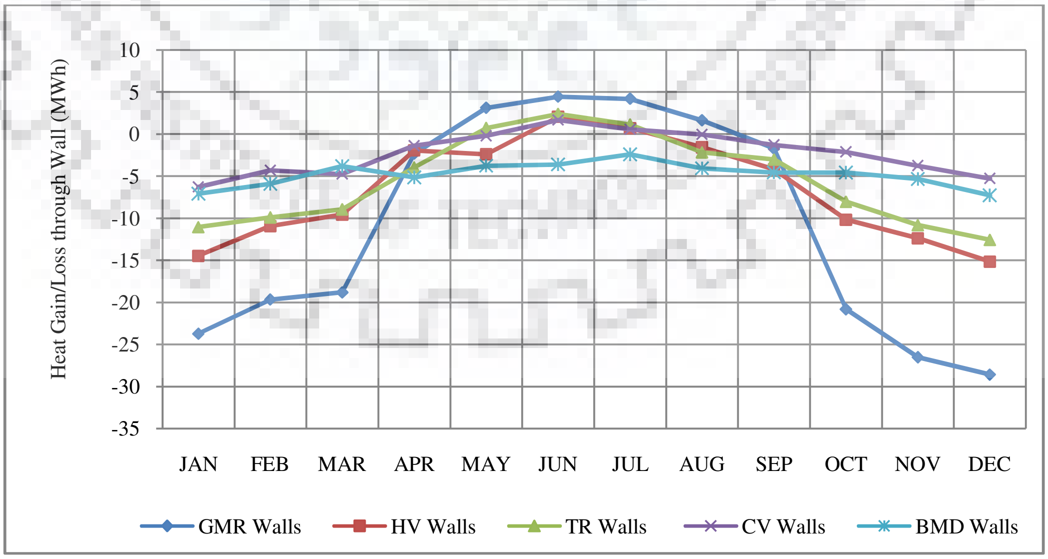


Fig 6.16 Heat Flow through Wall

6.4 Monthly Heat Gain/Loss Through Buildings Envelope

It is important to note that the building design has a considerable effect on the way the energy predictors behave to the exposed thermal environment. Therefore, mere changing the glazing type or wall assembly won't optimize the energy-use and indoor comfort conditions. In case of wall, the monthly heat flows through wall, for example, has been observed to be adding to the internal gains in the peak summer months whereas in winter heat loss is more evident. The internal gains are also observed to be more evident in the peak summer months whereas in winter period the heat loss through wall is occurring. It should be noted that the alternative with least heat gains in the summer months and minimum heat loss in the winter period would make an ideal selection. The following section elaborates the affect of seasonal change on the energy consumption, indoor air temperature and comfort temperature. The analysis is further explored for the passive measures to be effective in the studied buildings.

6.4.1 Evaluation of passive measures from comfort temperatures and mean outdoor temperature

Comfort temperature or 'Tn' is observed to be slightly above the mean globe temperature and falls outside the outdoor temperature range in January (in GMR & BMD).It suggests that the heating controls employed to maintain the indoor temperatures are not sufficient. This thermal discomfort of the subjects has consequently resulted in the higher consumption units in winter months. Fig.6.17a, b, c, d & e illustrates the higher energy consumption in the winter period i.e. in the months of Jan, Feb, Nov and Dec. As the temperature starts ascending after peak winter (after Feb) or descending after peak summer (after Aug), the curve for mean globe temperature & mean neutral temperature has overlapped and lies within the outdoor temperature range. This time of the year (i.e. in Mar, Apr, Sept and Oct) offers pleasant thermal environment with reduced energy loads to maintain comfort level. The thermal sensation of the subjects, as mentioned in the earlier section, has significantly driven with indoor/outdoor temperature and this has directly affected the energy use of the surveyed building. In summer months, comfort temperature is lower than the mean globe temperatures which explains the increased in energy consumption in these months (i.e. May, June, July and Aug.) to restore the indoor comfort level. In July the mean neutral temperature is slightly below the mean outdoor temperature and has shown the peak energy load as compared to other summer months.

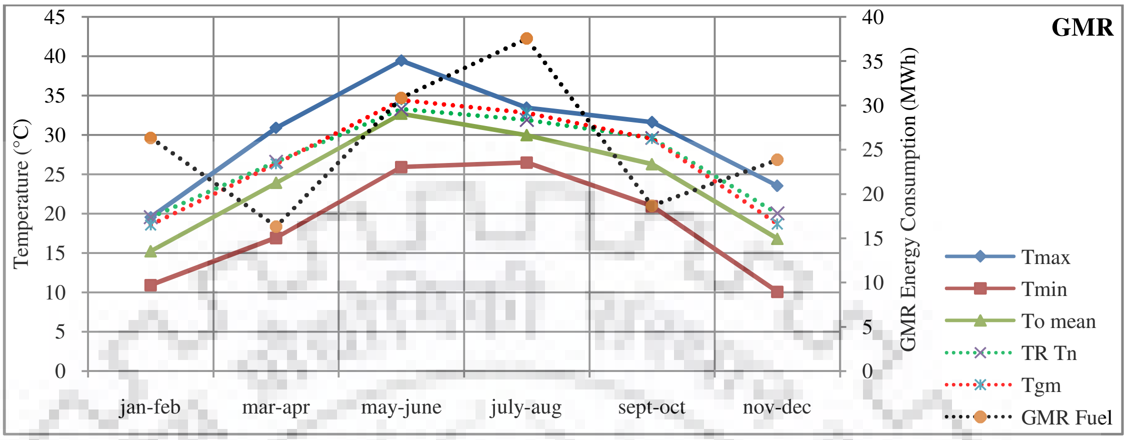


Fig 6.17a Mean Monthly temperature (outdoor & indoor) and comfort temperature(GMR)

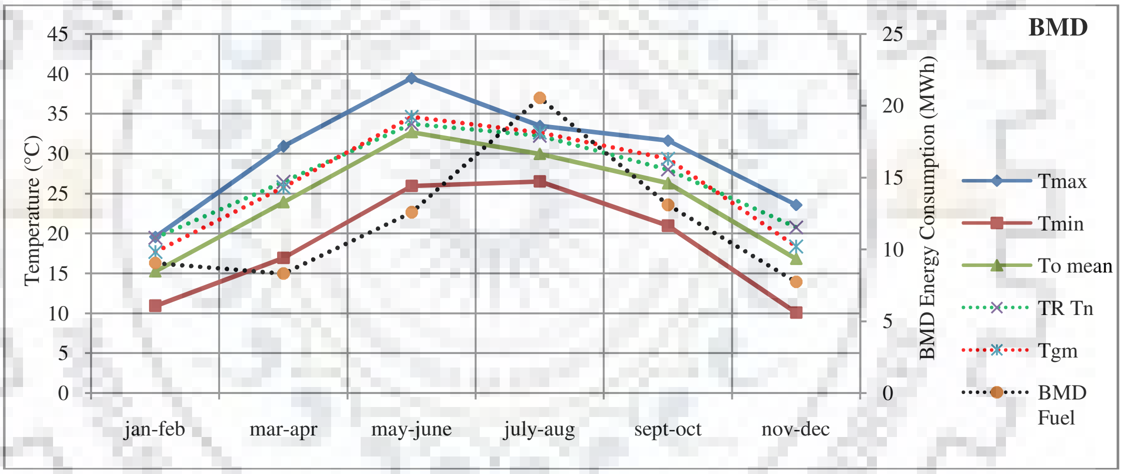


Fig 6.17b Mean Monthly temperature (outdoor & indoor) and comfort temperature

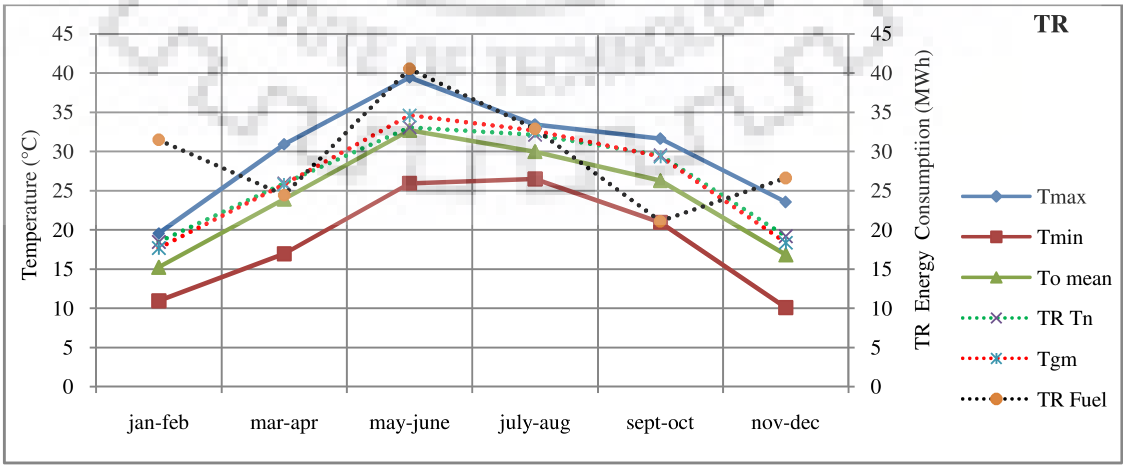


Fig 6.17c Mean Monthly temperature (outdoor & indoor) and comfort temperature

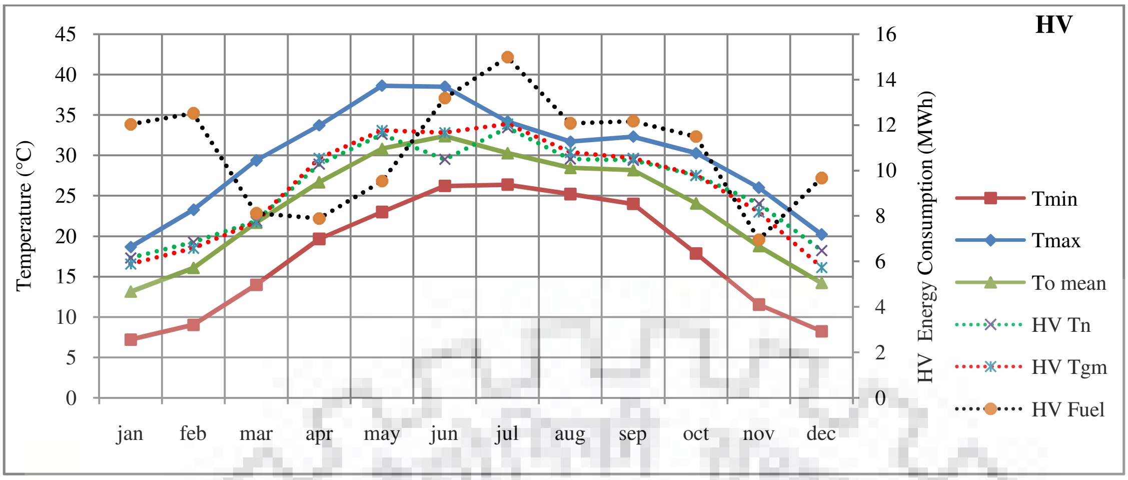


Fig 6.17d Mean Monthly temperature (outdoor & indoor) and comfort temperature

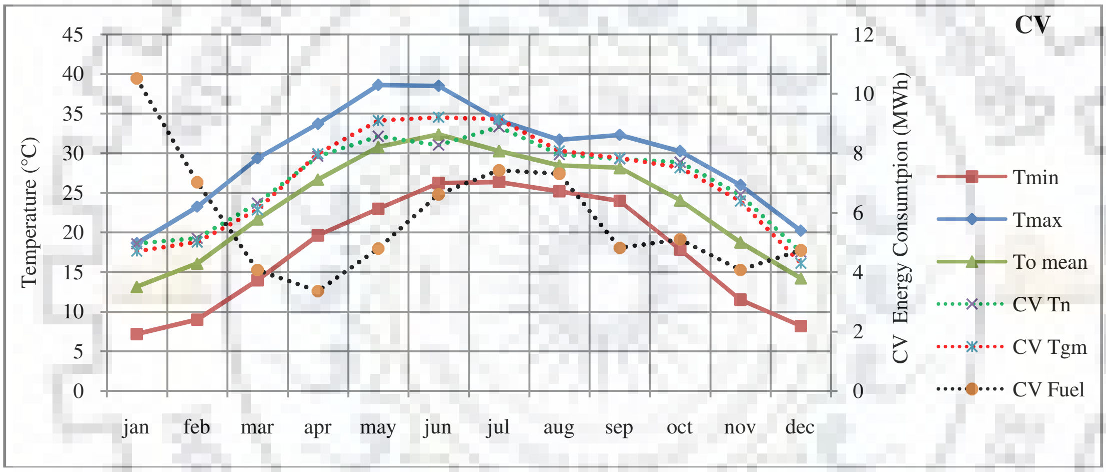


Fig 6.17e Mean Monthly temperature (outdoor & indoor) and comfort temperature

6.5 Inferences

- Tg and TSV have also shown a poor correlation coefficient (.44) in winter as compared to summer (.85) and monsoon (.77). The thermal sensitivity of subjects is also observed to be higher in summer & monsoon period as compared to the winter period.
- The regression slope/thermal sensitivity is observed to be higher in summer (0.23/^{o}C) and monsoon (0.31/^{o}C) and lower for the winter period (0.148/^{o}C). Along with outdoor temperature, the behavioral adjustments (i.e. door, window, fan etc.) of the occupants have played an important role in this seasonal variation.
- 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.

- Gender based analysis have shown that females have greater sensitivity to temperature variation and that they have a narrow comfort range than males with a temperature difference of 1.3°C.
- The comfort range of elderly subjects is observed to be narrow as compared to other age groups. Also the curve for comfort votes plotted against Tg is skewed towards the lower side of the temperature range for elderly people which can be explained by their higher clo level.
- Top exposed floors (TF) and lower floors (LF) have differed considerably in the comfort temperature. Thermal acceptance of the subjects in TF is also observed to be lower than the LF for all the three seasons. This difference can be explained by the direct exposure to the harsh weather conditions causing increased heat gain (in summers) and heat loss (in winter).
- Building orientation, WWR and 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. 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 which explains the minimum solar gains and heat conduction gains in buildings with E-W orientation.
- Building form has 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’ block of GMR (along N-S axis) is observed to be 1°C higher than the block on E-W axis, i.e. Bb.
- Window to wall ratio has not only affected 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.
- It is observed that the roof assembly is not efficiently contributing to the nightime time cooling in top exposed floors(TF) rather adding to the thermal discomfort in summertime. It can be explained by the low resistance value of the roof assembly used in the building as compared to the recommeded ECBC standards.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7. CONCLUSIONS

A Class II field survey is conducted in five naturally ventilated multi-storied apartments in the composite climatic zone of north India. A total of 984 data-sets were collected for the whole year, involving over 82 subjects and 55 apartment units from the surveyed buildings. The adaptive behaviour and thermal expectations of the occupant is observed to be very well adapted to their thermal environment. A comfort temperature of 26.1 °C is estimated using linear regression analysis with a comfort band (22.5–30.6 °C). PMV is observed to be overestimating the thermal sensation as oppose to the actual thermal sensation votes. The difference between the observed and predicted neutral temperatures was significant for the winter data, i.e. 5.2°C , as compare to the annual data, i.e. 0.6°C.

Thermal acceptance of subjects is observed to be significant even when the comfort votes are lower or subjects voted for discomfort (i.e. '3&2' in summer and monsoon and '-2& -3' in winters). The thermal sensitivity of subjects is also observed to be higher in summer & monsoon period as compared to the winter period. In the study, one unit change is observed in the mean thermal sensation for every 6.7˚C of globe temperature in the winters, 4.4°C in summer and 3.2°C in monsoon period. Along with outdoor temperature, the behavioral adjustments (i.e. door, window, fan etc.) of the occupants have played an important role in this seasonal variation in the thermal sensitivity. Indoor & outdoor temperatures were found to have strong relation with the control usage when plotted against globe temperature.

Windows have shown the highest and blind the weakest regression coefficient with Tg. Balcony doors are observed to be used in a wider range of temperatures & more uniformly as compared to any other control. Clothing adjustments have shown a strong linear dependence on Tg in summer & winter period and weak correlation in monsoon. Metabolic activity has shown no correlation with any of the physical variable or with the comfort votes of subjects.

- Balcony doors have been widely used in the study in spite of the negligible use of balcony spaces. Subjects preferred to open it (in all seasons), not just for cross ventilation but to get the feeling of 'freshness' and openness'. This has considerably played a significant role in the thermal sensation of subjects, making it a very important control in naturally ventilated buildings.

- ‘W’ is observed to be minimally opened during winters, moderately in summers and elaborately in monsoon period. It is also observed that window use, though, not used extensively as any other controls but has significantly affected the thermal perception of the occupants.
- Seasonal regression of the proportion of BL-use with Tg has exhibited a very strong relationship as compared to ‘W’ and ‘BD’ open. It is observed that the BL-use is increased as the TSV shifted to either side of the neutrality.
- Clothing adjustments have shown a strong linear dependence on Tg in summer & winter period and weak correlation in the monsoon period. Clothing level is also observed to be decreasing with increase in warmer sensation, till it reaches a minimal acceptable limit. Socio-cultural constraint has, thus, considerably affected the adaptive use of clothing in the study. It is also inferred that clo adjustment is an effective control measure in summer period when the air movement (forced or natural) is controlled by the subjects
- Metabolic activity has shown no correlation with any of the physical variable or with the comfort votes of the subjects. But, gender-wise analysis of ‘met’ rates has shown some clear differences for male and female subjects.
- The statistical summary of fan, A/c and heater has shown a strong dependence on Tg. Subjects have responded to the thermal discomfort by controlling the air flow (fans, evaporative coolers, door, windows etc.) But, it is observed that electrical expenditure, especially in summer period, has affected the A/c usage even at the peak discomfort hours. Subjects were observed to be deliberately pushing their comfort limits to the extent they can bear in order to control their electricity expenditures.

Adaptive use of control is just a response to the discomfort caused by the changes in the physical environment. But, it doesn’t explain the unexpected thermal response received during the field study, for e.g. some subjects voted for neutral at extreme summer/ winter conditions as oppose to their counter mates (those who are exposed to the same thermal environment or sharing the same apartments). This inexplicable thermal behavior is further explained by analyzing the demographic and contextual parameters.

- Gender based analysis have shown that females have greater sensitivity to temperature variation and that they have a narrow comfort range than males with a temperature difference of 1.3°C.
- The comfort range of elderly subjects is observed to be narrow as compared to other age groups. Also the curve for comfort votes plotted against Tg is skewed towards the lower side of the temperature range for elderly people which can be explained by their higher clo level.
- Top exposed floors (TF) and lower floors (LF) have differed considerably in the comfort temperature. Thermal acceptance of the subjects in TF is also observed to be lower than the LF for all the three seasons. This difference can be explained by the direct exposure to the harsh weather conditions causing increased heat gain (in summers) and heat loss (in winter) in the top exposed floors.

Building Design is very important for optimizing energy load and controlling thermal discomfort and, thus, evaluated using simulations (Design Builder's software). A wide range of information was collected, i.e. architectural drawings, monthly utility bills, operational hours of the appliances, occupancy details, tenancy details etc. The simulation arrangement used to construct the baseline models are also supported with the necessary statistical indices for validation. The estimated percentage error between the simulated energy consumption and measured data are within the acceptable tolerance of ±15% for annual data and ±25% for monthly data. The Coefficient of Variation of Root Mean Squared Error, CV(RMSE) and Mean Bias Error (MBE) for the monthly electricity consumption is obtained within the acceptable tolerances of ±15% and ±5% respectively, as defined in the ASHRAE Guideline 14-2002. Main simulation findings are as follows:

- Solar gains through exterior windows and zone sensible cooling have shown the maximum internal gains in the baseline models, whereas heat flows through the building envelope in the baseline was maximum through glazing, walls and air infiltration.

- Double glazed unit with 6mm low-e clear glass is identified as the best retrofit measure for glazing as it has not only reduced the solar gains through exterior windows (SHG) and heat conduction loss through glazing (HC) but also reduced the heat flow through other building components (walls, ceilings) and zone sensible heating and cooling.

- Reductions in wall heat gain are observed to be accompanied with a subsequent increase in the heat conductivity through glazing and ceilings for wall retrofit measures. From the above observations, it is inferred that each building (owing to its orientation, WWR, building form etc) creates distinct indoor environmental conditions with respect to the outdoor conditions and its design and, thus, retrofit measures will differ from building to building.
- Porcelain tiles have significantly reduced the heat gain through roof as oppose to the retrofit measure of insulated layer of XPS Extruded Polystyrene (although it has shown moderately high reductions in overall energy-use). As the thermal environment of the top exposed floors is much harsh and is prone to energy intensive activities, it is recommended to choose the roof retrofit measures on the basis of the reductions in the heat gain/loss through roof only.
- Automated lighting control is proved to be an affective retrofit measure significantly bringing down the internal loads (up to 20-25%) & energy consumption (up to 5%-9%). It is important to note that use of automated or occupancy sensors based lighting has been tremendously explored in commercial setups but not the domestic households. It is strongly recommended to explore the same for different zones of the building.
- Surface treatment, in terms of solar absorptance, has proved to be a significant parameter while considering the heat flow through the wall assembly. Heat loss through wall is up to 80% whereas energy reductions ranged between 1-5% for the light colored surfaces as compared to dark colored surfaces.
- The comfort analysis of the Design Builder's is based on the heat balance model and, thus, can predict fairly well for conditioned buildings. But, its applicability on naturally ventilated buildings, on the basis of simulation outputs in this study, needs to be justified. Analysis has shown that adaptive model of thermal comfort predicts better for naturally ventilated buildings and, thus, suggested to be explored in simulation programs to derive comfort outputs.

Building design, especially, the orientation and WWR is observed to be significantly affecting the thermal behavior of the building envelope, and are suggested to be the prime focus while designing naturally ventilated buildings in this climatic zone.

- Building orientation, WWR and building form have 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. 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 which explains the minimum solar gains and heat conduction gains in buildings with E-W orientation.
- Building form has also considerably effected the orientation of the building; which has further 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.
- Window to wall ratio or ‘WWR’ has not only affected 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 as compared to counter buildings.
- It is observed that the roof assembly is not efficiently contributing to the nightime cooling in top exposed floors, but rather adding to the thermal discomfort in summertime. It can be explained by the low resistance value of the roof assembly used in the building as compared to the recommeded ECBC standards.

7.1 RECOMMENDATIONS FOR FUTURE STUDIES

The current approach of thermal comfort standards in India needs to be thoroughly evaluated, especially considering the climatic diversity of the country. The results presented in this study are merely a snapshot of *‘how’* and *‘what’* affects the thermal perception of the occupants along with the thermal behavior of the building.

Vernacular construction strategies vary all across the country and needs to be explored in order to evolve new strategies. Passive strategies, to optimize the energy efficiency, are very much a part of the local construction techniques in rural India. Due to change in the living standards and urbanization, people are less inclined towards these construction techniques. It is strongly believed that research on the use of locally available materials and the construction techniques can help in improving comfort conditions and the energy-load of the buildings. The study can be further extended covering all the climatic zones of India. CFD (computation fluid dynamics) is strongly recommended to be used in order to assess the thermal performance of the alternate building materials.

The present study has only focused on the composite climatic zone of India and, thus, the adaptive model of thermal comfort is applicable to multi-storied apartment (with similar construction strategies) in this climatic zone only. A thorough field study in other climatic zones is recommended so that the current thermal comfort standards can be amended.As the thermal evaluation in the current study is done on a monthly basis, the relative impact of physical variables like humidity produced generic results. It is strongly believed that hourly thermal evaluation of the occupants for peak summer and winter can refine the results. When assessing the naturally ventilated domestic setup, the likeliness of 'uncertainties' or 'errors' in the simulation models increases and, thus, it is strongly suggested to inculcate the findings of the adaptive field studies to the simulation tools to ascertain the thermal performance of the buildings.

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APPENDIX I

APPENDIX-1

Table 1.1 Distribution of Surveyed Apartments on Different Floor Levels

	LF	MF	TF
GMR	6	2	5
TR	6	2	4
BMD	4	3	4
HV	3	1	4
CV	5	2	4
Total	**24**	**10**	**21**

LF+MF+TF=55

Floor Level :
LF - Lower Floors ; MF- Mid Floors; TF- Top Floors;

Table 1.2a, Clothing Insulation Values for Typical Ensembles (ASHRAE-55)

Summer Garment	clo	Winter Garment	clo
Undergarments	**0.04**	**Undergarments**	**0.04**
Upholstery	**0.15**	**Upholstery**	**0.15**
Cotton Sari + petticoat blouse	**0.69**	**Cotton Sari + petticoat blouse**	**0.69**
Sari (polyester) + petticoat+ blouse	**0.76**	**Sari (polyester) + petticoat blouse**	**0.76**
Cotton Salwar Suit =	**0.28**	**Cotton Salwar Suit**	**0.28**
Trouser (thin)	**0.15**	**Woolen Salwar Suit**	**0.47**
Walking Shorts	**0.08**	**Jacket**	**0.35**
Long sleeves shirt	**0.25**	**Thin Sweater**	**0.2**
Short sleeves shirt	**0.15**	**Thick Sweater**	**0.28**
Sleeveless/scoop neck top	**0.13**	**Trouser (thin)**	**0.15**
Skirt (thin)	**0.15**	**Trouser (thick)**	**0.25**
Light Dress, short sleeves	**0.2**	**Long sleeves shirt**	**0.25**
Short sleeves pajamas (thin)	**0.42**	**Short sleeves shirt**	**0.15**
T-shirt	**0.08**	**Sweatshirt (long sleeves)**	**0.34**
Shoes	**0.02**	**Sweatpants**	**0.28**
Sandals	**0.02**	**Shawl**	**0.45**
Socks (calf length)	**0.03**	**Warmer**	**0.57**
		Shoes	**0.02**
		Sandals	**0.02**
		Socks (calf length)	**0.03**
		Long sleeve long gown(thick)	**0.46**
		Long sleeve long wrap robe(thick)	**0.69**

Table 1.2b, Metabolic Rates for Typical Tasks (ASHRAE-55)

Activity	Met units	Metabolic Rate (W/m²)
Sleeping	**0.7**	**40**
Sitting (Passive Work)	**0.8**	**45**
Sitting (Active work)	**1**	**60**
Standing Relaxed	**1.2**	**70**
Seated, reading or writing	**1**	**60**
Walking about	**1.7**	**100**
Standing Working -		
a. Cooking	**1.6-2.0**	**95-115**
b. House Cleaning	**2.0-3.4**	**115-200**

Table 1.3a, Annual summary of Measured Indoor Environmental Variables (Air Temperature , Relative Humidity , Air Velocity & Globe Temperature) of all Subjects

		January				February				March				April				May				June				July				August				September				October				November				December			
S.No.	Subject	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)	Ta (°C)	RH (%)	Av (m/s)	Tg (°C)
1	Neer Jhamra	18	46	0	18	18	56	0	19	23	35	0	23	30	34	0	30	34	29	0.7	34	35	53	0.7	36	34	53	0.7	35	30	80	1.2	31	29	60	0.6	30	29	48	0.9	29	21	44	0	22	15.3	66	0	16
2	Shilpi Sharma	16	61	0	16	18	58	0	19	21	50	0	22	30	37	0	30	32	31	0.4	32	34	52	0.7	34	33	54	0.9	34	29	78	1.2	30	29	62	0.7	29	27	57	0	28	19	50	0	21	14.6	65	0	15
3	Surinder Nath	18	47	0.7	19	19	50	0.3	19	23	38	0	23	30	31	0.1	30	34	24	0.6	34	35	56	0.6	35	35	52	1.2	35	31	76	1.2	31	30	60	0.5	30	28	50	0.6	29	21	44	0.1	21	15.7	65	0	16
4	Malabika Roy	17	50	0.1	19	19	55	0	19	22	37	0	22	30	35	0.7	30	33	29	0.3	34	35	54	0.6	35	34	53	0.8	35	30	79	1.5	31	30	59	0.6	30	29	52	0	29	20	46	0	21	15.2	63	0	16
5	Debaratta Roy	17	50	0.1	19	19	55	0	19	22	37	0	22	30	35	0.7	30	33	29	0.3	34	35	54	0.6	35	34	53	0.8	35	30	79	1.5	31	30	59	0.6	30	29	52	0	29	20	46	0	21	15.2	63	0	16
6	Meenakshi Mudgal	17	50	0	18	18	53	0	19	21	45	0	22	30	40	0.1	30	33	32	0.6	33	34	57	0.5	35	34	55	1	34	30	81	0.7	31	29	60	0.4	30	29	48	1.3	30	21	48	0	21	15	61	0	16
7	Aashi Goyal	16	55	0	17	19	58	0	19	21	46	0	22	30	35	0.3	29	33	29	0.4	33	34	53	0.9	35	34	55	1.2	34	29	78	1.5	30	29	58	0.4	30	29	50	0.6	29	21	49	0	21	14.9	63	0	16
8	Jayaprakash Dhull	17	52	0	17	19	56	0	19	21	48	0	22	30	38	0.3	30	33	29	0.6	34	35	55	0.7	35	34	56	0.7	34	30	79	2.5	30	29	60	0.5	29	29	49	0	29	21	44	0.1	21	15.2	63	0	16
9	Archana Sethia	16	57	0	16	18	58	0	19	21	48	0	22	30	40	0.2	30	33	29	0.3	33	35	53	0.6	35	34	56	1.2	35	30	79	0.9	31	29	60	0.5	29	27	56	0	28	21	44	0	21	14.8	65	0	16
10	Rajnish Dhanda	18	47	0	18	19	55	0	19	22	35	0	23	29	35	0.1	30	33	29	0.6	34	34	55	0.6	35	33	60	1.2	35	30	78	1.1	30	30	57	0.6	30	28	56	0	28	21	45	0	22	15.4	63	0	16
11	Rashi Gupta	18	45	0	19	19	56	0	19	23	35	0	23	30	34	0.1	30	34	28	0.6	34	35	54	0.7	35	34	58	0.9	35	31	77	0.7	31	30	57	0.7	30	29	49	1.2	30	22	44	0.1	22	15.6	62	0	16
12	R.K. Gupta	18	45	0	19	19	56	0	19	23	35	0	23	30	34	0.1	30	34	28	0.6	34	35	54	0.7	35	34	58	0.9	35	31	77	0.7	31	30	57	0.7	30	29	49	1.2	30	22	44	0.1	22	15.6	62	0	16
13	Minakshi	18	42	0	18	18	57	0	19	23	34	0	23	30	36	0.2	30	34	28	0.4	34	34	54	0.7	35	34	59	1	35	30	77	0.9	31	30	58	0.4	30	29	49	1.3	29	21	49	0	21	15.4	64	0	16
14	Rajeev Kumar	18	42	0	18	18	57	0	19	23	34	0	23	30	36	0.2	30	34	28	0.4	34	34	54	0.7	35	34	59	1	35	30	77	0.9	31	30	58	0.4	30	29	49	1.3	29	21	49	0	21	15.4	64	0	16
15	Mridul Gupta	18	45	0	19	19	56	0	19	23	35	0	23	30	34	0.1	30	34	28	0.6	34	35	54	0.7	35	34	58	0.9	35	31	77	0.7	31	30	57	0.7	30	29	49	1.2	30	22	44	0.1	22	15.6	62	0	16
16	Rohit Bhatia	18	51	0	19	19	56	0.4	19	23	39	0.3	23	30	34	0.8	30	34	24	0.8	34	35	55	0.8	36	35	54	1.2	35	31	77	1.6	32	30	59	0.7	30	29	51	1.2	30	21	46	0.3	22	15.7	65	0	16
17	Naina Bhatia	18	51	0	19	19	56	0.4	19	23	39	0.3	23	30	34	0.8	30	34	24	0.8	34	35	55	0.8	36	35	54	1.2	35	31	77	1.6	32	30	59	0.7	30	29	51	1.2	30	21	46	0.3	22	15.7	65	0	16
18	Ritul Bhatia	18	51	0	19	19	56	0.4	19	23	39	0.3	23	30	34	0.8	30	34	24	0.8	34	35	55	0.8	36	35	54	1.2	35	31	77	1.6	32	30	59	0.7	30	29	51	1.2	30	21	46	0.3	22	15.7	65	0	16
19	Vivek Sharma	18	57	0	18	19	58	0.2	19	22	39	0.2	23	30	32	0.4	30	34	25	0.8	34	35	58	0.8	35	34	55	1.1	35	31	80	1.3	31	30	62	0.7	30	29	53	0.5	29	21	46	0	21	15.4	65	0	16
20	Shaily Sharma	18	57	0	18	19	58	0.2	19	22	39	0.2	23	30	32	0.4	30	34	25	0.8	34	35	58	0.8	35	34	55	1.1	35	31	80	1.3	31	30	62	0.7	30	29	53	0.5	29	21	46	0	21	15.4	65	0	16
21	Bharat Bhushan	18	50	0	18	18	57	0	19	23	38	0.1	23	29	36	0	30	34	28	0.6	34	35	50	0.9	36	35	60	0.9	35	30	80	0.8	30	29	58	0.4	30	27	56	0.6	28	20	60	0	21	15.6	64	0	16
22	Rekha Bora	16	71	0	17	18	58	0	19	22	40	0	22	30	40	0.1	30	33	29	0.6	33	35	50	1	36	34	56	1	35	30	80	0.9	30	29	59	0.6	29	27	60	1.2	29	20	64	0	21	15	65	0	16
23	Shabnam Thakur	16	67	0	17	19	57	0	19	22	37	0	22	30	35	0.4	30	33	30	0.4	33	35	51	0.9	36	34	55	1.2	35	30	80	1.3	31	30	60	0.6	30	28	50	0.8	29	21	49	0	22	15.3	63	0	16
24	Orana Das	17	64	0	17	18	58	0	19	22	35	0	22	30	34	0.2	30	33	29	0.6	33	36	50	1.2	36	35	60	1	35	31	80	1.2	31	30	57	0.7	30	30	52	0	30	20	54	0	21	15.5	65	0	16
25	Geeta Sharma	16	61	0	16	19	59	0.3	19	21	43	0	22	30	40	0	30	34	26	0.6	35	36	44	0.6	36	34	55	1.3	35	31	79	1.3	31	30	58	0.6	30	29	50	0.4	30	20	50	0	21	15.2	63	0	16
26	Surinder Gupta	15	60	0	16	19	57	0	19	21	45	0	22	30	36	0.3	30	34	27	0.6	34	36	52	0.7	36	35	57	1	35	30	81	0.8	31	30	59	0.8	30	29	49	0.2	30	20	50	0	20	14.5	65	0	16
27	Aashima	16	56	0	16	18	55	0	19	22	36	0	22	30	37	0.2	30	34	29	0.6	34	35	50	0.9	36	34	58	1.2	35	30	80	1.3	31	30	58	0.4	30	29	48	0.8	29	20	56	0	20	15.4	64	0	16
28	Monica	15	63	0	16	19	58	0	19	22	45	0	22	29	42	0.3	30	33	29	0.6	33	36	47	1.1	36	34	56	1	35	30	85	1.2	31	29	60	0.4	30	27	55	0.4	28	20	65	0	20	15	65	0	16
29	Ritu	16	57	0	16	18	58	0	19	21	47	0	22	29	42	0.3	29	33	30	0.6	33	35	48	1.2	36	34	57	1.2	35	30	81	0.7	30	29	57	0.6	30	28	54	0.4	28	20	61	0	21	15.2	64	0	16
30	Poonam Sharma	16	57	0	16	18	59	0	19	21	46	0	22	29	49	0.1	30	33	30	0.4	33	35	50	0.7	36	34	60	0.9	35	30	80	1.4	30	30	59	0.6	30	29	54	0.3	29	20	52	0	21	15.3	63	0	16
31	Lalit Katoch	16	57	0	16	18	57	0	19	21	48	0	22	29	44	0.4	29	33	29	0.3	33	35	48	0.6	35	34	59	1	35	30	78	1.2	30	29	57	0.9	30	28	57	0.4	28	20	60	0	20	15.2	64	0	16
32	Preet Katoch	16	57	0	16	18	57	0	19	21	48	0	22	29	44	0.4	29	33	29	0.3	33	35	48	0.6	35	34	59	1	35	30	78	1.2	30	29	57	0.9	30	28	57	0.4	28	20	60	0	20	15.2	64	0	16
33	Rimjhim Bhatt	16	58	0	16	18	58	0	19	21	46	0	22	29	50	0.5	29	33	26	0.7	33	35	49	1	36	34	60	0.9	35	30	77	1.2	30	29	60	0.6	30	29	54	0.5	29	20	51	0	21	15.4	65	0	16
34	Anmol Bhatt	16	58	0	16	18	58	0	19	21	46	0	22	29	50	0.5	29	33	26	0.7	33	35	49	1	36	34	60	0.9	35	30	77	1.2	30	29	60	0.6	30	29	54	0.5	29	20	51	0	21	15.4	65	0	16
35	Vipul Bhatt	16	58	0	16	18	58	0	19	21	46	0	22	29	50	0.5	29	33	26	0.7	33	35	49	1	36	34	60	0.9	35	30	77	1.2	30	29	60	0.6	30	29	54	0.5	29	20	51	0	21	15.4	65	0	16
36	Tej Kumar	16	50	0	17	18	56	0	19	21	49	0	22	29	34	0	30	33	31	0.6	33	35	46	0.6	35	35	55	0.8	35	30	80	1.2	30	29	58	0.4	30	27	60	0.8	28	22	63	0	22	15.3	63	0	16
37	Deepshikha	17	46	0	17	18	58	0	19	22	39	0	22	30	33	0	30	33	30	0.6	33	35	46	0.4	36	34	57	1	35	30	79	0.9	30	29	58	0.4	30	27	56	0.6	28	23	62	0	23	15.7	63	0	16
38	Sunita	18	44	0.1	19	19	56	0	19	23	35	0	23	30	35	0.4	30	34	29	0.6	34	36	44	0.4	36	35	59	1.2	35	30	80	0.6	30	30	57	0.6	30	28	53	0.4	28	23	61	0	24	15.8	64	0	16
39	Shalu Luthra	15	51	0	17	19	58	0	19	21	40	0	22	29	35	0.4	30	33	30	0.6	33	36	45	0.6	36	34	56	0.9	35	30	80	1.3	30	30	58	0.4	30	27	55	0.6	27	23	62	0	23	15.3	63	0	16
40	Kavita Aggarwal	16	44	0.1	17	19	55	0	19	22	37	0	22	29	37	0.6	30	33	29	0.6	33	35	45	0.6	36	34	58	1	35	30	77	1.3	31	29	58	0.5	30	27	55	0.6	28	23	62	0	23	15.5	64	0	16
41	Anju Sharma	14	51	0	15	18	58	0	19	21	48	0	22	29	40	0.4	30	33	30	0.6	33	35	45	0.7	36	34	58	0.9	35	30	80	0.8	30	29	59	0.6	29	27	56	0.4	27	23	61	0	24	14.2	64	0	15
42	Renu Vashisht	15	55	0	15	19	58	0	19	21	48	0	22	29	42	0.6	30	33	30	0.4	33	35	45	0.8	36	34	55	0.7	35	30	79	0.9	30	29	58	0.4	30	28	55	0.8	28	23	62	0	23	14.5	65	0	15
43	Ritu Vyas	16	56	0	17	19	56	0	19	21	49	0	22	29	34	0.6	30	33	30	0.6	33	36	51	0.9	36	35	54	1.2	35	30	79	0.6	30	29	57	0.6	30	26	56	0.3	27	22	67	0	22	15.3	63	0	16
44	Jagandeep Kohli	18	43	0	19	19	57	0.2	19	23	35	0	23	30	35	0.1	30	34	28	0.4	34	36	44	0.8	36	35	57	1.4	35	30	80	1	30	30	56	0.4	30	27	55	0.3	28	23	62	0	23	15.5	65	0	16
45	Navneet Kohli	18	43	0	19	19	57	0.2	19	23	35	0	23	30	35	0.1	30	34	28	0.4	34	36	44	0.8	36	35	57	1.4	35	30	80	1	30	30	56	0.4	30	27	55	0.3	28	23	62	0	23	15.5	65	0	16
46	Reema Mahajan	16	54	0	17	19	57	0	19	22	39	0	22	30	33	0.4	30	33	29	0.6	34	35	48	0.9	36	34	57	1.6	35	30	79	1.2	31	30	58	0.6	30	27	55	0.4	28	23	62	0	23	15.2	64	0	16
47	Joy Mahajan	16	54	0	17	19	57	0	19	22	39	0	22	30	33	0.4	30	33	29	0.6	34	35	48	0.9	36	34	57	1.6	35	30	79	1.2	31	30	58	0.6	30	27	55	0.4	28	23	62	0	23	15.2	64	0	16
48	Manohar Kashyap	15	53	0	16	19	58	0	19	21	37	0	22	29	38	0.4	30	33	29	0.8	33	36	46	1	36	34	54	0.8	35	30	80	0.8	30	29	58	0.6	30	27	53	0.5	28	23	62	0	24	15	65	0	16

49	Shashi Pandey	15	61	0	15	18	58	0.2	18	21	49	0	22	28	42	0.3	29	32	32	0.2	33	33	44	0.7	33	33	53	1	34	30	80	1.2	30	29	57	0.3	29	26	59	0	27	22	68	0	22	14.1	62	0	15
50	Anuradha	15	51	0	16	18	55	0	18	21	51	0	22	28	41	0.6	28	33	29	0.4	33	33	41	1	33	33	56	0.7	34	30	80	1.3	30	29	58	0.6	30	26	56	0.4	27	22	66	0	22	14.8	60	0	16
51	Y K Gupta	15	51	0	16	18	55	0	18	21	51	0	22	28	41	0.6	28	33	29	0.4	33	33	41	1	33	33	56	0.7	34	30	80	1.3	30	29	58	0.6	30	26	56	0.4	27	22	66	0	22	14.8	60	0	16
52	Premlata Thakur	16	51	0	16	18	56	0	19	21	50	0	22	29	36	0.4	30	32	31	0.6	33	33	43	0.6	33	33	55	0.9	34	29	82	1.8	30	29	57	0.7	29	27	57	0	27	23	63	0	23	15.5	61	0	16
53	Rekha Singh	17	45	0	17	18	54	0	19	22	48	0	22	30	33	0.4	30	32	33	0.4	33	32	52	1	32	34	57	0.7	34	30	79	1.4	31	30	57	0.8	30	28	54	0.6	28	23	64	0	23	15.9	62	0	16
54	Sandeep Singh	17	45	0	17	18	54	0	19	22	48	0	22	30	33	0.4	30	32	33	0.4	33	32	52	1	32	34	57	0.7	34	30	79	1.4	31	30	57	0.8	30	28	54	0.6	28	23	64	0	23	15.9	62	0	16
55	Saurabh Singh	17	45	0	17	18	54	0	19	22	48	0	22	30	33	0.4	30	32	33	0.4	33	32	52	1	32	34	57	0.7	34	30	79	1.4	31	30	57	0.8	30	28	54	0.6	28	23	64	0	23	15.9	62	0	16
56	Balram	17	49	0	17	18	53	0	19	21	46	0	22	30	34	0.2	30	33	31	0.6	33	32	40	0.6	33	33	53	0.5	34	30	80	1.7	31	29	58	0.6	30	27	54	0.8	28	23	64	0	23	15.6	62	0	16
57	Kalyani Singh	17	49	0	17	18	53	0	19	21	46	0	22	30	34	0.2	30	33	31	0.6	33	32	40	0.6	33	33	53	0.5	34	30	80	1.7	31	29	58	0.6	30	27	54	0.8	28	23	64	0	23	15.6	62	0	16
58	Vir Singh	17	44	0	17	18	56	0	19	21	48	0	22	30	34	0.1	30	32	31	0.4	33	32	48	0.9	32	33	56	0.8	34	30	81	0.9	31	30	57	0.8	30	27	53	0.4	28	23	64	0	23	15.7	62	0	16
59	Nitu Singh	17	44	0	17	18	56	0	19	21	48	0	22	30	34	0.1	30	32	31	0.4	33	32	48	0.9	32	33	56	0.8	34	30	81	0.9	31	30	57	0.8	30	27	53	0.4	28	23	64	0	23	15.7	62	0	16
60	Pallavi	16	50	0	16	18	55	0	18	21	48	0	22	30	34	0.3	30	32	32	0.3	33	32	47	0.6	33	34	56	1	34	29	82	1.8	30	29	58	0.6	29	27	55	1.2	28	23	62	0	24	15.3	64	0	16
61	Shivangi	16	50	0	16	18	55	0	18	21	48	0	22	30	34	0.3	30	32	32	0.3	33	32	47	0.6	33	34	56	1	34	29	82	1.8	30	29	58	0.6	29	27	55	1.2	28	23	62	0	24	15.3	64	0	16
62	Kiran Bala Wason	16	51	0	16	18	56	0	19	21	50	0	22	29	36	0.4	30	32	31	0.6	33	33	43	0.6	33	33	55	0.9	34	30	81	1.7	30	29	57	0.7	29	27	57	0	27	23	63	0	23	15.5	61	0	17
63	Hardeep Kaur	16	51	0	17	18	53	0	18	22	47	0	22	30	34	0.2	30	33	30	1	34	34	39	0.9	34	34	54	0.9	34	30	77	1.3	30	29	58	0.6	30	28	56	1.2	28	23	64	0	23	15.3	62	0	16
64	Mahima Aggarwal	17	61	0	17	18	57	0	19	22	39	0	22	29	34	0.2	30	33	30	0	34	34	38	0.6	34	34	57	1	34	29	82	0.8	30	29	57	0.5	29	27	56	0.3	27	24	61	0	24	15.4	63	0	16
65	Vibhu Aggarwal	17	61	0	17	18	57	0	19	22	39	0	22	29	34	0.2	30	33	30	0	34	34	38	0.6	34	34	57	1	34	29	82	0.8	30	29	57	0.5	29	27	56	0.3	27	24	61	0	24	15.4	63	0	16
66	Surinder Arora	17	60	0	18	18	58	0	19	22	34	0	23	29	34	0.2	30	33	29	0.3	34	34	36	0.4	35	34	57	0.9	34	29	81	0.4	30	28	59	0.6	29	27	57	0	28	24	61	0	24	15.7	63	0	16
67	Navneet Arora	17	60	0	18	18	58	0	19	22	34	0	23	29	34	0.2	30	33	29	0.3	34	34	36	0.4	35	34	57	0.9	34	29	81	0.4	30	28	59	0.6	29	27	57	0	28	24	61	0	24	15.7	63	0	16
68	Swapnaja Hote	17	64	0.1	17	18	59	0	19	22	37	0	22	30	33	0.4	30	33	32	0.4	33	34	36	0.6	34	34	57	1.2	34	30	81	0.7	30	29	57	0.7	29	28	53	0	29	23	59	0	24	15.6	66	0	16
69	Mudita Pandey	18	55	0	18	18	56	0	19	23	35	0	23	30	33	0.4	30	34	28	0.4	34	34	36	0.4	34	34	58	1.2	34	30	80	1.2	30	29	59	0.6	29	28	52	0	28	24	59	0	24	15.6	60	0	16
70	Sunanda Pandey	18	55	0	18	18	56	0	19	23	35	0	23	30	33	0.4	30	34	28	0.4	34	34	36	0.4	34	34	58	1.2	34	30	80	1.2	30	29	59	0.6	29	28	52	0	28	24	59	0	24	15.6	60	0	16
71	Supriya Kaushal	18	56	0	18	18	58	0	19	23	35	0	23	30	35	0.4	30	33	29	0	34	34	36	0.4	34	34	57	0.9	34	30	80	1.3	30	29	59	0.3	29	28	53	0	28	24	61	0	24	15.4	63	0	17
72	Raj Sharma	17	61	0	18	18	57	0	19	23	32	0	23	30	32	0.3	30	35	23	0.6	35	35	35	0.6	35	34	55	1.2	35	30	78	1.2	31	29	56	0.6	30	27	54	0.6	28	23	62	0	24	15.5	65	0	16
73	Akriti Sharma	17	61	0	18	18	57	0	19	23	32	0	23	30	32	0.3	30	35	23	0.6	35	35	35	0.6	35	34	55	1.2	35	30	78	1.2	31	29	56	0.6	30	27	54	0.6	28	23	62	0	24	15.5	65	0	16
74	Arshi Rastogi	17	59	0	18	18	57	0	19	22	40	0	23	30	34	0.4	30	33	30	0.3	34	34	38	0.6	34	34	57	0.9	34	30	81	0.9	30	29	59	0.6	29	27	53	0.4	28	23	63	0	23	15.7	60	0	16
75	Sakshi	17	59	0	18	18	57	0	19	22	40	0	23	30	34	0.4	30	33	30	0.3	34	34	38	0.6	34	34	57	0.9	34	30	81	1	30	29	59	0.6	29	27	53	0.4	28	23	63	0	23	15.7	60	0	16
76	Anil Kumar	17	61	0	17	18	58	0	19	22	39	0	22	29	34	0.3	30	33	30	0.3	34	33	37	0.9	34	34	56	1	34	30	80	0.8	30	29	56	0.6	29	28	49	0	29	24	61	0	24	15.2	64	0	16
77	Rashmi Maheshwari	17	62	0	18	18	58	0.1	19	23	38	0	23	30	35	0.2	30	33	35	0.4	33	33	41	0.6	34	34	56	1.2	34	30	80	1	30	29	58	0.4	29	30	47	0	30	24	58	0	24	15.5	63	0	16
78	Garima	17	61	0	17	18	57	0	19	23	32	0	24	30	34	0.3	30	33	32	0.6	33	34	37	1	34	34	54	1	34	30	79	1.2	30	29	58	0.6	30	28	53	0	28	24	63	0	24	15.8	60	0	16
79	Tripti Chatterji	17	60	0	18	18	59	0	19	23	35	0	24	30	32	0.6	30	35	23	0.6	35	36	34	0.6	36	35	54	1.2	35	30	77	1.2	31	29	57	0.8	30	28	52	0	29	24	60	0	24	15.5	63	0	16
80	Partha Kaushal	18	56	0	18	18	58	0	19	23	35	0	23	30	35	0.4	30	33	29	0	34	34	36	0.4	34	34	57	0.9	34	30	80	1.3	30	29	59	0.3	29	28	53	0	28	24	61	0	24	15.4	63	0	17
81	Rajdeep Chatterji	17	60	0	18	18	59	0	19	23	35	0	24	30	32	0.6	30	35	23	0.6	35	36	34	0.6	36	35	54	1.2	35	30	77	1.2	31	29	57	0.8	30	28	52	0	29	24	60	0	24	15.5	63	0	16
82	Roma Bannerji	17	60	0	18	18	59	0	19	23	35	0	24	30	32	0.6	30	35	23	0.6	35	36	34	0.6	36	35	54	1.2	35	30	77	1.2	31	29	57	0.8	30	28	52	0	29	24	60	0	24	15.5	63	0	16

Table 1.3b Detailed monthly summary of the 'clo' & Met' values of all the surveyed subjects

		January			February			March			April			May			June			July			August			September			October			November			December		
S.No.	Subject		Met level			Met level			Met level			Met level			Met level			Met level			Met level			Met level			Met level			Met level			Met level			Met level	
		clo	met	W/m²	clo	met	W/m²	clo	met	W/m²	clo	met	W/m²	clo	met	W/m²	clo	met	W/m²	clo	met	W/m²	clo	met	W/m²	clo	met	W/m²	clo	met	W/m²	clo	met	W/m²	clo	met	W/m²
1	Neer Jhamra	1.6	2.0	115.0	0.9	2.0	115.0	0.9	0.8	45.0	1.0	0.8	45.0	1.0	1.6	95.0	0.5	1.6	95.0	0.4	1.0	60.0	0.5	1.6	95.0	0.9	0.8	45.0	0.5	0.8	45.0	1.0	1.6	95.0	1.4	1	60
2	Shilpi Sharma	1.8	1.6	95.0	1.3	0.8	45.0	0.9	1.0	60.0	0.5	0.8	45.0	0.5	0.8	45.0	0.4	2.0	115.0	0.5	1.6	95.0	0.4	0.8	45.0	0.5	1.6	95.0	0.4	0.8	45.0	0.9	1.6	95.0	2.0	1	60
3	Surinder Nath	1.8	0.8	45.0	1.1	1.0	60.0	0.8	0.7	40.0	0.5	0.7	40.0	0.4	1.0	60.0	0.4	0.7	40.0	0.5	1.0	60.0	0.6	1.0	60.0	0.5	1.0	60.0	0.6	1.0	60.0	1.3	1.6	95.0	1.6	0.8	45
4	Malabika Roy	2.2	0.8	45.0	1.1	1.6	95.0	1.6	2.0	115.0	0.9	0.8	45.0	0.9	0.8	45.0	0.4	0.8	45.0	0.9	1.0	60.0	0.4	2.0	115.0	0.4	1.6	95.0	0.4	0.7	40.0	1.4	1.0	60.0	1.8	1.6	95
5	Debaratta Roy	0.9	1.0	60.0	1.3	1.0	60.0	0.8	0.8	45.0	0.6	1.2	70.0	0.6	0.7	40.0	0.4	1.0	60.0	0.4	0.8	45.0	0.4	1.0	60.0	0.6	1.2	70.0	0.6	1.0	60.0	0.8	1.0	60.0	1.6	0.8	45
6	Meenakshi Mudgal	1.0	1.6	95.0	1.2	0.8	45.0	0.5	1.6	95.0	0.3	2.0	115.0	0.5	0.8	45.0	0.3	2.0	115.0	0.4	2.0	115.0	0.3	1.6	95.0	0.4	1.6	95.0	0.5	2.0	115.0	0.5	1.6	95.0	1.44	1.2	70
7	Aashi Goyal	1.0	1.0	60.0	1.1	1.0	60.0	0.8	1.0	60.0	0.4	0.8	45.0	0.4	0.8	45.0	0.4	1.0	60.0	0.4	0.8	45.0	0.3	1.2	70.0	0.5	1.7	100.0	0.4	1.0	60.0	0.7	1.0	60.0	1.4	1	60
8	Jayaprakash Dhull	1.4	0.8	45.0	1.1	1.2	70.0	0.9	0.8	45.0	0.4	1.0	60.0	0.4	1.0	60.0	0.6	0.8	45.0	0.4	1.0	60.0	0.4	0.8	45.0	0.5	1.0	60.0	0.5	1.6	95.0	1.1	2.0	115.0	1.4	1	60
9	Archana Sethia	1.4	1.6	95.0	1.0	1.6	95.0	1.1	1.0	60.0	0.5	1.6	95.0	0.5	0.8	45.0	0.5	1.6	95.0	0.4	1.6	95.0	0.5	1.6	95.0	0.5	1.0	60.0	0.5	1.6	95.0	1.1	0.8	45.0	1.6	1.6	95
10	Rajnish Dhanda	0.9	0.8	45.0	1.1	0.8	45.0	1.0	0.8	45.0	0.3	0.8	45.0	0.4	1.6	95.0	0.4	0.8	45.0	0.4	0.8	45.0	0.6	0.8	45.0	0.6	0.8	45.0	0.6	0.8	45.0	0.8	0.8	45.0	1.4	0.8	45
11	Rashi Gupta	1.4	1.0	60.0	0.9	2.0	115.0	1.2	1.6	95.0	0.5	1.0	60.0	0.5	0.8	45.0	0.4	0.7	40.0	0.5	1.6	95.0	0.4	1.6	95.0	0.5	1.0	60.0	0.5	1.6	95.0	0.9	1.6	95.0	1.9	1	60
12	R.K. Gupta	1.0	0.8	45.0	0.9	0.7	40.0	0.8	0.8	45.0	0.4	0.8	45.0	0.4	2.0	115.0	0.4	0.8	45.0	0.4	0.8	45.0	0.4	0.8	45.0	0.6	0.8	45.0	0.5	1.0	60.0	0.6	0.8	45.0	1.37	0.8	45
13	Minakshi	1.4	0.8	45.0	1.1	1.0	60.0	0.8	1.0	60.0	0.4	1.6	95.0	0.6	0.8	45.0	0.4	1.2	70.0	0.5	0.8	45.0	0.4	1.2	70.0	0.4	2.0	115.0	0.5	1.2	70.0	0.4	2.0	115.0	1.7	1.6	95
14	Rajeev Kumar	1.0	1.0	60.0	0.8	1.0	60.0	0.8	0.8	45.0	0.5	0.7	40.0	0.4	1.0	60.0	0.6	0.8	45.0	0.5	1.0	60.0	0.4	0.8	45.0	0.6	0.8	45.0	0.6	1.0	60.0	0.6	1.6	95.0	1.51	0.8	45
15	Mridul Gupta	1.0	1.0	60.0	1.0	1.7	100.0	0.8	0.8	45.0	0.6	1.2	70.0	0.4	1.0	60.0	0.4	0.7	40.0	0.4	1.0	60.0	0.4	1.2	70.0	0.4	0.8	45.0	0.6	1.0	60.0	0.8	0.8	45.0	1.78	1	60
16	Rohit Bhatia	1.0	0.8	45.0	1.0	1.0	60.0	0.9	1.0	60.0	0.6	1.0	60.0	0.6	1.0	60.0	0.4	0.8	45.0	0.4	0.7	40.0	0.5	1.0	60.0	0.6	1.0	60.0	0.6	0.8	45.0	0.9	1.0	60.0	1.46	0.8	45
17	Naina Bhatia	1.4	1.6	95.0	1.1	0.8	45.0	0.9	0.8	45.0	0.5	1.0	60.0	0.5	2.0	115.0	0.5	0.7	40.0	0.4	0.8	45.0	0.5	1.6	95.0	0.5	0.8	45.0	0.5	1.0	60.0	0.9	0.7	40.0	1.44	1.6	95
18	Ritul Bhatia	1.3	1.0	60.0	0.9	0.8	45.0	0.8	0.8	45.0	0.6	1.2	70.0	0.4	1.0	60.0	0.4	0.8	45.0	0.4	1.0	60.0	0.4	1.2	70.0	0.4	1.0	60.0	0.5	0.8	45.0	0.7	1.0	60.0	1.66	0.8	45
19	Vivek Sharma	1.1	1.0	60.0	0.9	1.0	60.0	0.8	0.8	45.0	0.6	1.0	60.0	0.5	1.0	60.0	0.4	0.7	40.0	0.4	0.7	40.0	0.4	0.8	45.0	0.6	1.2	70.0	0.6	0.8	45.0	0.8	1.0	60.0	1.49	0.8	45
20	Shaily Sharma	1.3	1.0	60.0	1.2	0.8	45.0	0.9	1.0	60.0	0.5	0.8	45.0	0.4	1.0	60.0	0.4	1.6	95.0	0.5	0.8	45.0	0.4	1.0	60.0	0.6	0.8	45.0	0.4	1.6	95.0	0.6	0.8	45.0	1.88	1.6	95
21	Bharat Bhushan	1.1	1.2	70.0	0.8	1.0	60.0	0.8	1.0	60.0	0.6	1.0	60.0	0.5	1.6	95.0	0.6	1.0	60.0	0.7	1.0	60.0	0.6	0.8	45.0	0.6	0.8	45.0	0.6	1.0	60.0	0.8	1.0	60.0	1.9	1	60
22	Rekha Bora	1.6	1.6	95.0	1.1	1.6	95.0	1.4	1.0	60.0	0.5	0.8	45.0	0.3	2.0	115.0	0.5	1.0	60.0	0.5	1.6	95.0	0.5	1.6	95.0	0.5	1.0	60.0	0.5	0.8	45.0	0.7	2.0	115.0	1.7	1.6	95
23	Shabnam Thakur	0.6	1.0	60.0	1.1	1.0	60.0	0.9	1.2	70.0	0.6	1.0	60.0	0.4	1.0	60.0	0.4	1.6	95.0	0.4	0.8	45.0	0.5	1.6	95.0	0.4	1.6	95.0	0.5	1.2	70.0	0.4	1.6	95.0	1.7	0.8	45
24	Orana Das	0.8	0.8	45.0	1.1	0.8	45.0	0.9	1.6	95.0	0.9	1.6	95.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	1.0	60.0	0.5	1.6	95.0	0.4	1.0	60.0	0.5	1.6	95.0	0.7	1.6	95.0	1.4	0.8	45
25	Geeta Sharma	1.6	0.8	45.0	0.9	2.0	115.0	1.1	1.0	60.0	0.3	2.0	115.0	0.5	0.8	45.0	0.3	1.6	95.0	0.4	2.0	115.0	0.5	0.8	45.0	0.5	1.6	95.0	0.5	2.0	115.0	0.7	1.2	70.0	1.5	1.6	95
26	Surinder Gupta	1.3	0.8	45.0	0.9	1.0	60.0	0.8	1.0	60.0	0.4	2.0	115.0	0.4	1.0	60.0	0.6	0.8	45.0	0.5	0.8	45.0	0.4	1.0	60.0	0.6	0.8	45.0	0.5	0.8	45.0	0.9	1.0	60.0	1.5	0.8	45
27	Aashima	1.0	0.8	45.0	1.0	0.8	45.0	0.9	0.8	45.0	0.5	0.8	45.0	0.5	0.8	45.0	0.4	1.6	95.0	0.5	0.7	40.0	0.4	2.0	115.0	0.5	1.6	95.0	0.6	0.8	45.0	1.0	1.0	60.0	1.7	1.6	95
28	Monica	1.0	2.0	115.0	1.1	1.0	60.0	1.0	0.8	45.0	0.4	1.0	60.0	0.4	1.0	60.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	1.6	95.0	0.4	0.7	40.0	0.5	1.6	95.0	0.7	1.0	60.0	1.4	1.6	95
29	Ritu	1.3	0.8	45.0	1.2	1.6	95.0	1.2	1.2	70.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	1.6	95.0	0.5	1.6	95.0	0.5	0.8	45.0	1.2	0.7	40.0	1.5	0.8	45
30	Poonam Sharma	1.3	0.8	45.0	1.0	1.0	60.0	0.8	1.0	60.0	0.3	2.0	115.0	0.3	2.0	115.0	0.4	0.7	40.0	0.4	0.8	45.0	0.4	1.0	60.0	0.4	0.8	45.0	0.4	0.8	45.0	0.8	1.6	95.0	1.5	1.2	70
31	Lalit Katoch	1.1	0.8	45.0	1.0	0.8	45.0	0.9	1.2	70.0	0.5	1.0	60.0	0.4	0.8	45.0	0.5	1.0	60.0	0.4	0.8	45.0	0.4	0.8	45.0	0.5	1.0	60.0	0.6	1.0	60.0	0.7	1.0	60.0	1.37	0.8	45
32	Preet Katoch	1.4	1.6	95.0	1.2	1.0	60.0	0.9	1.0	60.0	0.5	0.8	45.0	0.5	1.0	60.0	0.4	0.8	45.0	0.4	1.0	60.0	0.5	1.6	95.0	0.5	0.8	45.0	0.5	1.6	95.0	0.8	1.6	95.0	1.41	1	60
33	Rimjhim Bhatt	1.4	1.0	60.0	1.2	1.0	60.0	0.9	0.8	45.0	0.5	1.6	95.0	0.5	0.8	45.0	0.4	1.2	70.0	0.4	2.0	115.0	0.5	1.0	60.0	0.5	1.0	60.0	0.6	0.8	45.0	0.9	1.2	70.0	1.51	0.8	45
34	Anmol Bhatt	1.0	0.8	45.0	0.9	1.2	70.0	0.8	1.0	60.0	0.5	1.2	70.0	0.4	0.8	45.0	0.4	1.0	60.0	0.4	1.0	60.0	0.4	0.8	45.0	0.4	1.0	60.0	0.6	1.0	60.0	0.6	0.8	45.0	1.59	1	60
35	Vipul Bhatt	1.2	0.8	45.0	1.2	1.0	60.0	0.9	0.8	45.0	0.5	1.0	60.0	0.5	1.0	60.0	0.4	0.8	45.0	0.4	1.2	70.0	0.5	1.0	60.0	0.5	1.0	60.0	0.6	0.8	45.0	0.7	1.0	60.0	1.41	1	60
36	Tej Kumar	1.0	1.2	70.0	0.9	1.0	60.0	0.8	1.0	60.0	0.4	1.0	60.0	0.4	1.2	70.0	0.5	1.6	95.0	0.4	0.8	45.0	0.4	0.8	45.0	0.6	0.8	45.0	0.6	0.8	45.0	0.8	0.8	45.0	1.3	0.8	45
37	Deepshikha	1.9	1.7	100.0	1.1	1.6	95.0	1.0	1.6	95.0	0.3	1.6	95.0	0.5	1.0	60.0	0.5	1.0	60.0	0.5	1.7	100.0	0.4	1.6	95.0	0.6	1.6	95.0	0.6	1.7	100.0	1.0	0.8	45.0	1.4	1	60
38	Sunita	1.6	0.8	45.0	1.2	0.8	45.0	1.4	0.8	45.0	0.9	0.8	45.0	0.3	1.6	95.0	0.5	0.8	45.0	0.4	1.2	70.0	0.5	1.0	60.0	0.5	1.0	60.0	0.5	1.2	70.0	0.7	1.0	60.0	2.0	0.8	45
39	Shalu Luthra	1.6	2.0	115.0	0.7	1.0	60.0	0.9	0.8	45.0	0.5	0.8	45.0	0.5	1.6	95.0	0.4	0.8	45.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	1.0	60.0	0.5	0.8	45.0	1.0	1.0	60.0	1.9	1.6	95
40	Kavita Aggarwal	0.9	1.0	60.0	0.9	1.0	60.0	0.9	0.8	45.0	0.4	1.2	70.0	0.4	1.0	60.0	0.4	0.7	40.0	0.4	1.6	95.0	0.5	1.0	60.0	0.4	1.6	95.0	0.6	1.6	95.0	0.8	1.6	95.0	1.9	1	60
41	Anju Sharma	1.6	1.2	70.0	1.1	0.8	45.0	1.4	0.8	45.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	2.0	115.0	0.4	0.8	45.0	0.4	0.8	45.0	0.5	0.8	45.0	0.5	1.6	95.0	1.2	0.8	45.0	1.8	1.6	95
42	Renu Vashisht	1.3	1.2	70.0	1.2	0.8	45.0	0.7	0.8	45.0	0.5	2.0	115.0	0.5	2.0	115.0	0.5	0.8	45.0	0.5	1.0	60.0	0.5	0.8	45.0	0.4	1.0	60.0	0.4	1.2	70.0	0.7	1.6	95.0	1.7	0.8	45
43	Ritu Vyas	1.4	1.0	60.0	1.1	0.8	45.0	1.0	0.8	45.0	0.5	1.0	60.0	0.9	1.0	60.0	0.5	1.0	60.0	0.5	1.0	60.0	0.5	1.0	60.0	0.5	1.0	60.0	0.6	2.0	115.0	1.0	1.6	95.0	1.4	1	60
44	Jagandeep Kohli	1.1	0.8	45.0	1.0	1.0	60.0	0.9	1.0	60.0	0.6	1.0	60.0	0.5	0.8	45.0	0.4	0.8	45.0	0.4	1.0	60.0	0.4	0.7	40.0	0.6	1.0	60.0	0.5	1.2	70.0	0.6	1.0	60.0	1.86	0.8	45
45	Navneet Kohli	1.4	0.8	45.0	1.1	0.8	45.0	0.9	1.2	70.0	0.6	0.8	45.0	0.5	1.6	95.0	0.4	2.0	115.0	0.5	0.8	45.0	0.5	0.7	40.0	0.4	0.8	45.0	0.6	1.0	60.0	0.6	0.8	45.0	1.82	1.6	95
46	Reema Mahajan	1.4	0.7	40.0	1.0	0.8	45.0	0.9	0.8	45.0	0.5	1.0	60.0	0.4	0.7	40.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	0.7	40.0	0.5	0.8	45.0	0.5	0.8	45.0	1.0	1.0	60.0	1.93	0.8	45

47	Joy Mahajan	1.1	0.8	45.0	0.8	1.0	60.0	0.8	0.8	45.0	0.6	1.2	70.0	0.4	0.8	45.0	0.4	1.0	60.0	0.4	0.8	45.0	0.4	1.0	60.0	0.4	0.8	45.0	0.6	1.0	60.0	0.6	0.8	45.0	1.63	1	60
48	Manohar Kashyap	1.3	0.8	45.0	0.9	1.0	60.0	0.8	1.0	60.0	0.6	1.0	60.0	0.4	0.8	45.0	0.4	0.8	45.0	0.4	1.0	60.0	0.5	0.8	45.0	0.5	1.0	60.0	0.6	0.8	45.0	0.7	1.2	70.0	1.78	0.8	45
49	Shashi Pandey	1.6	1.6	95.0	1.4	1.0	60.0	0.7	1.6	95.0	0.5	1.0	60.0	0.4	1.6	95.0	0.4	1.6	95.0	0.4	1.2	70.0	0.3	1.2	70.0	0.5	0.8	45.0	0.5	1.6	95.0	0.9	0.8	45.0	1.4	1	60
50	Anuradha	2.0	0.8	45.0	1.0	1.6	95.0	0.9	1.0	60.0	0.4	1.6	95.0	0.5	0.8	45.0	0.5	1.0	60.0	0.5	0.8	45.0	0.5	0.8	45.0	1.0	0.8	45.0	0.5	1.6	95.0	0.7	0.8	45.0	1.4	0.8	45
51	Y K Gupta	1.1	0.8	45.0	1.09	1	60	0.7	1.0	60.0	0.6	1.0	60.0	0.5	0.8	45.0	0.5	1.2	70.0	0.4	1.0	60.0	0.5	1.2	70.0	0.6	0.8	45.0	0.6	1.0	60.0	0.6	0.8	45.0	1.05	0.8	45
52	Premlata Thakur	1.4	0.8	45.0	1.0	1.0	60.0	0.7	0.7	40.0	0.5	0.8	45.0	0.5	2.0	115.0	0.5	1.0	60.0	0.5	1.6	95.0	0.5	1.6	95.0	0.5	0.8	45.0	0.5	0.7	40.0	0.5	0.7	40.0	1.4	0.8	45
53	Rekha Singh	1.6	2.0	115.0	1.0	0.8	45.0	0.5	2.0	115.0	0.5	2.0	115.0	0.3	1.6	95.0	0.3	0.7	40.0	0.5	1.6	95.0	0.3	1.2	70.0	0.4	1.6	95.0	0.5	1.2	70.0	0.5	0.7	40.0	1.4	0.7	40
54	Sandeep Singh	1.3	1.0	60.0	1.0	0.8	45.0	0.8	0.8	45.0	0.6	1.0	60.0	0.5	1.0	60.0	0.4	0.8	45.0	0.4	0.8	45.0	0.5	1.2	45.0	0.4	0.8	45.0	0.6	1.0	60.0	0.6	1.0	60.0	1.29	1.7	100
55	Saurabh Singh	1.2	0.8	45.0	1.1	1.2	70.0	0.8	1.0	60.0	0.4	1.0	60.0	0.4	0.8	45.0	0.4	1.0	60.0	0.4	0.8	45.0	0.5	0.8	45.0	0.4	1.0	60.0	0.4	0.8	45.0	0.6	1.0	60.0	1.11	0.8	45
56	Balram	1.2	2.0	115.0	0.9	2.0	115.0	0.5	1.6	95.0	0.4	2.0	115.0	0.4	2.0	115.0	0.4	1.6	95.0	0.4	0.8	45.0	0.3	1.0	60.0	0.4	1.2	70.0	0.4	1.6	95.0	0.8	1.6	95.0	1.0	1.6	95
57	Kalyani Singh	2.2	1.2	70.0	1.1	0.8	45.0	1.4	0.8	45.0	0.5	0.8	45.0	0.9	0.8	45.0	0.4	0.8	45.0	0.4	0.8	45.0	0.9	0.8	45.0	0.5	1.0	60.0	0.9	0.8	45.0	0.9	0.8	45.0	1.4	1	60
58	Vir Singh	1.3	0.8	45.0	0.9	1.7	100.0	1.0	1.7	100.0	0.5	0.8	45.0	0.5	1.0	60.0	0.4	1.0	60.0	0.4	1.2	70.0	0.5	0.8	45.0	0.5	1.0	60.0	0.6	1.7	100.0	0.8	1.7	100.0	1.3	1	60
59	Nitu Singh	1.0	1.0	60.0	1.0	0.8	45.0	0.7	1.6	95.0	0.5	1.2	70.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	1.6	95.0	0.5	1.6	95.0	0.5	1.6	95.0	0.5	1.6	95.0	1.0	1.6	95.0	1.4	2	115
60	Pallavi	1.2	1.0	60.0	1.0	1.0	60.0	1.0	0.8	45.0	0.9	0.7	40.0	0.5	1.0	60.0	0.3	2.0	115.0	0.5	0.8	45.0	0.4	0.8	45.0	0.5	0.8	45.0	0.4	1.0	60.0	0.6	0.8	45.0	1.2	0.8	45
61	Shivangi	1.5	0.8	45.0	1.1	1.7	100.0	0.6	1.0	60.0	0.4	0.8	45.0	0.4	0.8	45.0	0.5	1.0	60.0	0.4	1.0	60.0	0.5	1.0	60.0	0.4	1.0	60.0	0.4	1.0	60.0	1.1	0.7	40.0	1.0	0.7	40
62	Kiran Bala Wason	1.3	1.0	60.0	1.2	0.8	45.0	0.5	0.8	45.0	0.5	1.0	60.0	0.5	0.8	45.0	0.5	2.0	115.0	0.5	2.0	115.0	0.3	1.2	70.0	0.5	0.8	45.0	0.5	1.0	60.0	0.7	1.0	60.0	1.0	1.6	95
63	Hardeep Kaur	1.4	1.6	95.0	1.0	1.6	95.0	0.5	1.6	95.0	0.5	1.6	95.0	0.5	2.0	115.0	0.5	1.6	95.0	0.4	1.6	95.0	0.5	2.0	115.0	0.5	1.0	60.0	0.5	1.6	95.0	0.9	1.6	95.0	1.0	2	115
64	Mahima Aggarwal	0.8	1.0	60.0	1.0	1.0	60.0	0.7	1.7	100.0	0.5	1.6	95.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	1.0	60.0	0.5	0.7	40.0	0.7	0.8	40.0	1.4	0.8	45
65	Vibhu Aggarwal	1.1	1.0	60.0	1.1	1.0	60.0	0.9	0.8	45.0	0.6	0.8	45.0	0.4	1.2	70.0	0.4	0.8	45.0	0.4	1.0	60.0	0.4	0.8	45.0	0.5	0.8	45.0	0.4	0.8	45.0	0.8	1.0	60.0	1.29	1	60
66	Surinder Arora	2.0	1.0	60.0	1.44	1.6	95	0.5	0.7	40.0	0.5	0.8	45.0	0.5	1.0	60.0	0.4	2.0	115.0	0.5	0.8	45.0	0.5	0.7	40.0	0.5	0.8	45.0	0.5	1.6	95.0	0.5	1.0	60.0	1.4	0.8	45
67	Navneet Arora	1.2	1.2	70.0	1.3	1.0	60.0	0.8	0.8	45.0	0.5	0.8	45.0	0.5	0.8	45.0	0.4	0.7	40.0	0.5	1.0	60.0	0.4	0.7	40.0	0.5	0.8	45.0	0.6	1.0	60.0	0.8	1.0	60.0	1.4	1	60
68	Swapnaja Hote	2.0	1.6	95.0	1.2	0.8	45.0	0.6	1.0	60.0	0.4	2.0	115.0	0.4	2.0	115.0	0.4	1.0	60.0	0.5	1.0	60.0	0.5	1.0	60.0	0.5	1.0	60.0	0.4	1.0	60.0	1.1	1.0	60.0	1.0	1	60
69	Mudita Pandey	1.8	1.7	100.0	1.2	1.0	60.0	0.7	1.0	60.0	0.9	0.8	45.0	0.4	2.0	115.0	0.5	0.7	40.0	0.4	0.7	40.0	0.4	0.8	45.0	0.6	0.8	45.0	1.0	1.6	95.0	1.1	0.8	45.0	1.5	1.6	95
70	Sunanda Pandey	1.7	0.8	45.0	1.2	0.8	45.0	1.0	1.6	95.0	0.9	1.0	60.0	0.9	0.8	45.0	0.9	0.8	45.0	0.9	0.8	45.0	0.9	1.0	60.0	0.9	1.0	60.0	0.9	0.8	45.0	1.1	0.8	45.0	1.66	0.8	45
71	Supriya Kaushal	1.6	1.6	95.0	1.0	1.6	95.0	0.9	0.8	45.0	0.5	1.0	60.0	0.5	0.8	45.0	0.5	1.6	95.0	0.5	1.6	95.0	0.5	0.8	45.0	0.4	1.6	95.0	0.5	1.2	70.0	0.7	1.0	60.0	1.7	1.7	100
72	Raj Sharma	1.6	0.8	45.0	0.8	0.7	40.0	0.5	2.0	115.0	0.5	0.7	40.0	0.5	1.6	95.0	0.5	0.7	40.0	0.5	0.7	40.0	0.5	0.8	45.0	0.5	0.8	45.0	0.5	0.7	40.0	0.5	0.8	45.0	1.4	0.7	40
73	Akriti Sharma	1.4	0.8	45.0	1.0	1.0	60.0	0.7	1.0	60.0	0.5	0.8	45.0	0.5	1.6	95.0	0.5	1.2	70.0	0.5	0.8	45.0	0.4	1.0	60.0	0.5	0.8	45.0	0.5	0.8	45.0	0.7	1.0	60.0	0.99	2	115
74	Arshi Rastogi	1.0	1.7	100.0	1.1	0.8	45.0	0.7	1.0	60.0	0.5	1.6	95.0	0.3	1.7	100.0	0.5	1.0	60.0	0.5	1.7	100.0	0.5	1.6	95.0	0.5	1.0	60.0	0.5	1.0	60.0	0.7	0.8	45.0	1.3	1	60
75	Sakshi	1.5	2.0	115.0	0.9	1.6	95.0	1.4	0.8	45.0	0.4	0.8	45.0	0.4	1.0	60.0	0.4	0.8	45.0	0.5	0.8	45.0	0.4	1.0	60.0	0.6	0.8	45.0	0.6	0.7	40.0	0.8	1.6	95.0	1.1	0.8	45
76	Anil Kumar	1.4	1.0	60.0	0.9	0.8	45.0	0.8	1.0	60.0	0.6	0.8	45.0	0.5	0.8	45.0	0.5	0.8	45.0	0.4	0.8	45.0	0.4	1.0	60.0	0.6	0.8	45.0	0.6	0.8	45.0	0.8	1.0	60.0	1.3	1	60
77	Rashmi Maheshwari	1.0	1.0	60.0	1.0	1.6	95.0	0.9	1.6	95.0	0.9	0.8	45.0	0.4	1.2	70.0	0.5	1.6	95.0	0.5	1.6	95.0	0.5	1.0	60.0	0.5	1.6	95.0	0.5	1.6	95.0	0.5	1.6	95.0	1.4	1.6	95
78	Garima	1.4	0.8	45.0	1.1	1.7	100.0	0.5	1.6	95.0	0.3	2.0	115.0	0.5	1.0	60.0	0.5	2.0	115.0	0.5	0.8	45.0	0.4	2.0	115.0	0.5	0.8	45.0	0.5	1.6	95.0	0.5	1.6	95.0	1.3	1	60
79	Tripti Chatterji	1.6	1.2	70.0	1.2	1.6	95.0	1.4	0.8	45.0	0.8	0.8	45.0	0.9	2.0	115.0	0.9	0.8	45.0	0.4	0.7	40.0	0.9	0.8	45.0	0.5	1.6	95.0	0.9	2.0	115.0	1.4	1.6	95.0	1.66	1.6	95
80	Partha Kaushal	1.1	0.7	40.0	1.0	1.2	70.0	1.0	1.0	60.0	0.6	0.8	45.0	0.4	1.0	60.0	0.4	0.8	45.0	0.4	0.8	45.0	0.4	0.8	45.0	0.5	1.6	95.0	0.5	0.8	45.0	0.8	1.0	60.0	1.02	0.8	45
81	Rajdeep Chatterji	1.3	0.8	45.0	1.0	1.0	60.0	0.9	1.0	60.0	0.8	1.2	70.0	0.6	0.8	45.0	0.5	1.0	60.0	0.4	1.2	70.0	0.5	0.8	45.0	0.5	1.0	60.0	0.6	1.0	60.0	0.8	0.8	45.0	1.29	1	60
82	Roma Bannerji	1.4	0.8	45.0	1.1	0.8	45.0	0.9	0.7	40.0	0.5	0.8	45.0	0.4	1.0	60.0	0.5	0.8	45.0	0.4	1.6	95.0	0.5	1.0	60.0	0.4	1.6	95.0	0.4	2.0	115.0	0.5	1.0	60.0	1.5	1	60

Table 1.3c Detailed Monthly Summary of Thermal Responses of the surveyed subjects: Thermal Sensation,Preference and Acceptance (TS,TP& TA)

S.No.	Subject	January			February			March			April			May			June			July			August			September			October			November			December		
		T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)	T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)	T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)	T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)	T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)	T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)	T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)	T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)	T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)	T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)	T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)	T S (-3 to +3)	TP (-2 to +2)	T A (1,no & 2,yes)
1	Neer Jhamra	-2	1	2	-1	1	2	-1	1	2	0	0	2	1	-1	2	3	-1	1	2	-2	1	1	-1	2	0	0	2	-1	0	2	-1	1	2	-2	1	2
2	Shilpi Sharma	-3	1	1	-2	1	1	-1	0	2	1	0	2	0	0	2	2	-1	2	1	-1	2	0	0	2	0	0	2	-1	0	2	-2	1	1	-3	2	1
3	Surinder Nath	-1	1	2	-2	1	2	0	0	2	1	-1	2	3	-1	1	3	-2	1	2	-2	1	2	-1	2	1	0	2	0	0	2	-1	0	2	-2	1	1
4	Malabika Roy	-3	1	2	-1	1	2	-1	0	2	1	-1	2	1	-1	2	3	-2	1	3	-2	1	1	-2	1	0	-1	2	-2	1	1	-1	0	2	-3	2	1
5	Debaratta Roy	-2	1	2	-2	1	2	-1	0	2	1	0	2	1	-1	2	3	-2	1	3	-2	1	1	-1	2	0	0	2	-1	0	2	-1	0	2	-2	1	1
6	Meenakshi Mudgal	0	0	2	-1	1	2	0	0	2	1	-1	2	1	-1	2	3	-2	1	2	-2	2	1	0	2	1	0	2	0	0	2	-1	0	2	-2	1	2
7	Aashi Goyal	0	0	2	-1	0	2	-1	0	2	0	0	2	2	-1	1	3	-1	1	2	-1	2	0	0	2	1	-1	2	0	-1	2	-3	1	2	-2	1	2
8	Jayaprakash Dhull	0	0	2	-1	0	2	0	0	2	0	0	2	1	0	2	3	-1	2	1	-2	2	0	-1	2	0	0	2	0	-1	2	-3	2	1	-2	1	2
9	Archana Sethia	-1	1	2	-1	1	2	-1	0	2	1	0	2	1	-1	2	3	-1	1	1	-1	2	1	0	2	0	0	2	0	0	2	-2	1	2	-2	2	1
10	Rajnish Dhanda	0	0	2	0	0	2	0	0	2	1	-1	2	2	0	2	0	0	2	0	-1	2	1	0	2	0	-1	2	-1	0	2	-1	0	2	-2	1	2
11	Rashi Gupta	-2	1	2	-1	1	2	0	0	2	1	0	2	1	-1	2	3	-2	1	2	-1	1	1	0	2	1	0	2	-1	0	2	-3	1	2	-3	2	1
12	R.K. Gupta	-1	1	2	-1	1	2	0	0	2	1	0	2	1	-1	2	2	-2	1	2	-1	1	1	-1	2	0	0	2	0	0	2	-1	0	2	-2	2	1
13	Minakshi	-1	1	2	-2	1	2	0	1	2	0	0	2	2	-2	1	3	-2	1	1	-2	2	1	-1	1	0	-1	2	0	0	2	-2	0	2	-2	2	1
14	Rajeev Kumar	-1	1	2	-1	1	2	-1	0	2	0	0	2	1	-1	2	3	-2	1	2	-2	2	1	-1	1	0	0	2	0	0	2	-1	0	2	-2	1	2
15	Mridul Gupta	-2	1	2	-1	0	2	-1	0	2	0	0	2	1	0	2	3	-2	1	2	-2	1	1	-1	1	0	-1	2	0	0	2	-1	0	2	-2	1	2
16	Rohit Bhatia	-2	1	2	-1	0	2	-1	0	2	1	0	2	1	-1	2	3	-1	1	3	-2	1	1	-1	2	1	0	2	0	0	2	-1	0	2	-3	2	1
17	Naina Bhatia	-3	1	2	0	1	2	-1	1	2	0	0	2	1	-1	2	3	-2	1	3	-2	1	2	-1	2	0	0	2	-1	0	2	-1	1	2	-2	2	2
18	Ritul Bhatia	-2	1	2	-1	1	2	0	1	2	0	0	2	1	0	2	2	-2	1	2	-2	2	2	-1	1	0	0	2	-1	0	2	-1	1	2	-3	2	1
19	Vivek Sharma	-3	1	1	-1	1	1	-1	1	2	0	0	2	1	0	2	2	-2	1	2	-2	2	1	-1	1	1	0	2	0	0	2	-1	1	2	-2	1	2
20	Shaily Sharma	-2	1	1	-1	1	2	-1	0	2	0	0	2	1	0	2	3	-2	1	3	-2	2	2	-1	1	0	0	2	0	0	2	-1	1	2	-3	2	2
21	Bharat Bhushan	0	0	2	-1	1	2	-1	0	2	1	-1	2	1	-1	2	2	-1	2	1	-1	2	0	-1	2	0	0	2	0	0	2	0	0	2	-2	1	2
22	Rekha Bora	-3	1	2	-1	1	2	-1	0	2	0	0	2	1	-1	2	3	-1	1	2	-1	1	0	-1	2	0	0	2	-1	0	2	-2	2	2	-3	2	1
23	Shabnam Thakur	0	0	2	-1	1	2	-1	0	2	1	-1	2	1	-1	1	3	-2	1	2	-2	1	1	0	1	1	0	2	0	0	2	-2	1	2	-2	1	2
24	Orana Das	0	0	2	-1	0	2	0	0	2	1	0	2	1	0	2	3	-2	1	1	-2	2	2	-1	1	1	-1	2	1	-1	2	-1	1	2	-2	2	2
25	Geeta Sharma	-3	1	1	-2	1	1	-1	0	2	0	-1	2	3	-1	2	3	-1	1	2	-2	1	0	-1	1	0	0	2	0	0	2	-2	1	2	-3	2	1
26	Surinder Gupta	-2	1	2	-1	1	2	-1	0	2	1	-1	2	2	-1	1	3	-1	1	2	-1	2	0	-1	2	0	0	2	-1	0	2	-1	0	2	-2	1	2
27	Aashima	0	0	2	-1	0	2	-1	0	2	0	0	2	1	-1	1	3	-2	1	1	-1	1	1	-1	2	0	0	2	-1	0	2	-1	0	2	-3	2	1
28	Monica	-1	1	1	-1	0	2	0	0	2	0	0	2	2	-1	2	2	-2	1	2	-1	2	1	-1	2	0	0	2	0	0	2	-1	1	2	-3	1	1
29	Ritu	-1	1	2	-1	1	2	-1	0	2	1	0	2	1	0	2	3	-1	1	1	-1	2	1	-1	1	0	-1	2	-1	0	2	-2	1	2	-2	2	1
30	Poonam Sharma	-3	1	1	-2	1	2	-1	0	2	0	0	2	1	-1	2	3	-1	1	2	-1	2	1	0	2	0	0	2	0	0	2	-1	1	2	-3	2	1
31	Lalit Katoch	-2	1	2	-1	1	2	-1	1	2	0	0	2	1	0	2	2	-2	1	2	-1	2	1	0	2	0	0	2	-1	0	2	-1	1	2	-2	1	1
32	Preet Katoch	-1	1	2	-1	1	2	-1	0	2	0	0	2	1	-1	2	3	-2	1	1	-1	2	0	-1	1	0	0	2	-1	0	2	-1	1	2	-2	2	1
33	Rimjhim Bhatt	-2	2	2	-1	1	2	-1	1	2	0	0	2	1	0	2	2	-2	1	1	-1	2	0	-1	1	0	0	2	-1	0	2	-1	0	2	-3	2	1
34	Anmol Bhatt	-1	1	2	-1	0	2	0	0	2	0	0	2	1	0	2	2	-1	2	1	-1	2	1	-1	2	0	0	2	0	0	2	-1	0	2	-2	1	2
35	Vipul Bhatt	-2	1	2	-1	1	2	-1	0	2	1	-1	2	1	-1	2	3	-2	2	1	-1	2	1	-1	2	1	0	2	-1	0	2	-1	0	2	-2	2	1
36	Tej Kumar	0	1	2	-1	0	2	0	0	2	0	0	2	1	0	2	2	-1	2	1	-1	2	0	0	2	0	0	2	0	0	2	0	0	2	-2	1	2
37	Deepshikha	-3	2	2	-1	1	2	-1	0	2	0	0	2	2	-1	2	3	-2	1	2	-1	2	1	-1	2	0	-1	2	-1	0	2	-1	1	2	-3	2	1
38	Sunita	-1	1	2	-1	0	2	-1	0	2	1	-1	1	2	-2	1	3	-2	1	3	-2	1	2	-1	2	1	-1	2	0	0	2	-1	1	2	-2	2	1
39	Shalu Luthra	-3	1	2	-1	1	2	-1	0	2	1	-1	2	3	-1	1	3	-2	1	2	-1	1	1	0	2	0	0	2	-1	0	2	-1	0	2	-2	1	2
40	Kavita Aggarwal	-1	1	2	-1	0	2	0	0	2	1	-1	2	2	-2	2	3	-1	2	3	-2	1	2	-1	2	0	-1	2	0	0	2	-1	0	2	-2	1	2
41	Anju Sharma	-3	2	1	-1	1	2	-1	1	2	0	0	2	1	-1	2	2	-2	1	1	-1	2	0	0	2	0	0	2	-1	0	2	-2	1	2	-3	2	1
42	Renu Vashisht	-3	1	2	-1	0	2	-1	0	2	0	0	2	2	-1	2	3	-2	1	1	-2	2	0	-1	2	0	0	2	0	0	2	0	1	2	-2	2	2
43	Ritu Vyas	-1	1	2	-1	1	2	0	0	2	0	-1	2	2	-1	2	2	-2	1	2	-1	2	1	0	2	0	0	2	-1	0	2	-1	0	2	-2	2	1
44	Jagandeep Kohli	-1	1	2	-1	0	2	-1	0	2	1	-1	2	1	-1	2	3	-2	2	2	-1	2	1	-1	2	0	0	2	0	0	2	-1	0	2	-3	2	2

45	Navneet Kohli	-2	2	2	-1	1	2	-1	0	2	0	-1	2	2	-1	1	2	-1	2	2	-1	2	1	-1	2	1	0	2	0	0	2	-1	1	2	-3	2	1
46	Reema Mahajan	-3	2	1	-2	1	2	-1	1	2	0	0	2	1	0	2	3	-2	1	2	-1	2	2	-1	1	1	0	2	0	0	2	-1	0	2	-2	2	2
47	Joy Mahajan	-2	1	2	-1	0	1	0	0	2	0	0	2	1	0	2	2	-2	1	2	-1	2	1	-1	2	1	0	2	0	0	2	-1	1	2	-3	2	1
48	Manohar Kashyap	-1	1	2	-1	1	2	-1	0	2	0	0	2	0	0	2	2	-2	2	1	-1	2	1	-1	2	1	-1	2	0	0	2	0	0	2	-3	2	2
49	Shashi Pandey	-1	1	2	-2	1	2	0	0	2	0	0	2	3	-1	1	3	-2	1	2	-1	2	1	-1	2	0	0	2	-1	0	2	-1	1	2	-2	2	1
50	Anuradha	-1	0	2	-1	1	2	-1	1	2	0	0	2	2	-2	2	2	-2	2	1	-1	2	1	0	2	0	0	2	0	0	2	-1	1	2	-2	1	2
51	Y K Gupta	-2	1	2	-1	1	2	-1	1	2	1	0	2	2	-1	2	2	-1	1	2	-1	2	1	-1	2	0	0	2	0	0	2	-1	0	2	-2	1	1
52	Premlata Thakur	-2	1	2	-3	2	1	0	1	2	0	0	2	2	-1	2	3	-1	2	2	-1	2	1	-1	1	0	-1	2	1	0	2	-1	0	2	-3	2	1
53	Rekha Singh	-1	1	2	-1	1	2	0	0	2	1	-1	1	2	-1	2	2	-2	2	1	-2	2	1	-1	2	1	-1	2	0	0	2	-1	0	2	-3	1	1
54	Sandeep Singh	-3	2	2	-1	1	2	-1	1	2	0	0	2	1	-1	2	3	-2	1	2	-1	2	1	-1	2	1	0	2	0	0	2	-1	1	2	-2	1	1
55	Saurabh Singh	-2	1	2	-1	0	2	-1	1	2	1	-1	2	1	-1	2	3	-2	1	2	-1	1	1	-1	1	1	0	2	0	0	2	0	0	2	-3	2	1
56	Balram	-1	1	1	-2	0	2	-1	0	2	1	-1	2	2	-2	2	2	-2	2	1	-1	2	1	-1	2	0	-1	2	1	0	2	-1	0	2	-2	1	2
57	Kalyani Singh	-3	2	2	-3	1	2	-2	1	2	1	-1	2	3	-1	2	3	-2	1	2	-1	1	2	-1	1	1	-1	2	0	0	2	-2	1	1	-3	2	1
58	Vir Singh	0	0	2	-1	1	2	0	0	2	0	0	2	1	-1	2	2	-1	2	1	0	2	1	0	2	0	0	2	-1	0	2	-1	0	2	-2	1	1
59	Nitu Singh	-1	1	2	-2	1	2	-1	0	2	1	0	2	3	-2	2	3	-2	1	1	-2	1	1	-1	1	0	-1	2	0	0	2	-2	0	2	-2	2	1
60	Pallavi	-1	1	2	-2	1	2	0	0	2	0	0	2	1	-1	2	2	-2	1	2	-2	2	1	-1	1	0	0	2	0	0	2	-1	0	2	-2	1	2
61	Shivangi	0	1	2	-2	1	2	0	0	2	1	-1	2	3	-2	1	3	-1	1	1	-1	2	0	-1	2	0	0	2	-1	0	2	-1	0	2	-2	2	2
62	Kiran Bala Wason	-1	1	2	-1	0	2	0	0	2	0	-1	2	3	-1	2	3	-1	2	1	-1	2	1	0	2	0	0	2	0	0	2	-1	0	2	-3	1	2
63	Hardeep Kaur	-1	1	2	-3	1	1	-1	1	2	1	-1	2	2	-1	2	3	-2	1	3	-1	1	1	-1	1	0	-1	2	1	-1	2	-1	1	2	-3	2	1
64	Mahima Aggarwal	-1	0	2	-1	1	2	0	0	2	1	-1	2	2	-1	2	2	-1	2	2	-1	2	0	0	2	0	0	2	-1	0	2	-2	1	2	-2	1	1
65	Vibhu Aggarwal	-2	2	2	-1	0	2	-1	0	2	1	0	2	2	-1	2	3	-2	2	2	-1	2	1	0	2	0	0	2	-1	0	2	-1	1	2	-3	2	2
66	Surinder Arora	-1	1	2	-2	1	2	-1	1	2	0	0	2	0	0	2	3	-1	1	1	-1	2	1	0	2	0	0	2	-1	0	2	-1	1	2	-3	2	1
67	Navneet Arora	-1	0	2	-1	1	2	0	0	2	1	-1	2	1	-1	2	2	-1	1	1	-1	2	0	0	2	0	0	2	0	0	2	-1	0	2	-3	1	2
68	Swapnaja Hote	0	1	2	-2	1	2	0	0	2	1	-1	2	2	-1	2	3	-2	1	2	-1	2	1	-1	1	0	-1	2	-1	0	2	-2	1	2	-3	1	1
69	Mudita Pandey	-1	0	2	-2	1	2	-1	0	2	1	0	2	2	-1	1	2	-1	2	1	-1	2	2	-1	1	1	-1	2	0	0	2	-1	0	2	-2	2	2
70	Sunanda Pandey	-2	1	2	-1	1	2	-1	1	2	0	0	2	2	0	2	2	-1	2	2	-1	2	1	0	2	0	0	2	-1	0	2	-1	1	2	-3	2	1
71	Supriya Kaushal	-1	0	2	-2	1	1	0	0	2	1	-1	2	2	-1	1	2	-1	1	1	-1	2	1	-1	2	0	0	2	-1	0	2	-1	1	2	-2	1	2
72	Raj Sharma	0	1	2	-2	1	2	0	0	2	1	-1	2	2	-1	2	3	-2	1	2	-2	1	0	-1	2	0	0	2	0	0	2	-1	1	2	-3	2	1
73	Akriti Sharma	-2	1	2	-1	1	2	-1	1	2	1	0	2	1	-1	2	2	-1	1	2	-1	1	1	-1	2	0	0	2	-1	0	2	-1	1	2	-2	1	2
74	Arshi Rastogi	0	1	2	-1	1	2	0	0	2	0	-1	2	3	-2	2	3	-2	1	2	-2	1	1	-1	1	0	0	2	0	0	2	-1	1	2	-2	1	1
75	Sakshi	-1	1	2	-3	1	1	-1	1	2	1	-1	2	2	-1	2	2	-2	2	1	0	2	2	-1	1	0	-1	2	-1	0	2	-2	2	1	-3	2	1
76	Anil Kumar	-1	1	2	-2	1	2	-1	0	2	0	-1	2	2	-1	2	2	-1	2	1	0	2	0	-1	2	0	0	2	-1	0	2	-1	0	2	-2	1	2
77	Rashmi Maheshwar	-1	0	2	-1	1	2	0	0	2	1	-1	2	1	-1	1	3	-1	1	1	-1	2	2	-1	1	1	-1	2	0	0	2	0	0	2	-3	1	2
78	Garima	-1	1	2	-3	1	2	-1	0	2	1	0	2	2	-2	1	3	-2	1	2	-1	2	1	0	2	0	0	2	0	0	2	-1	1	2	-3	2	1
79	Tripti Chatterji	-1	0	2	-3	1	2	0	0	2	1	-1	2	3	-2	1	3	-2	1	2	-2	1	2	-1	1	0	-1	2	0	0	2	-2	1	2	-3	2	1
80	Partha Kaushal	-1	1	2	-1	1	2	-1	0	2	0	0	2	1	-1	2	2	-2	2	1	0	2	1	-1	2	0	0	2	-1	0	2	-2	0	2	-2	2	1
81	Rajdeep Chatterji	-2	2	2	-2	1	2	-1	0	2	0	0	2	1	-1	2	3	-2	1	2	-2	1	1	-1	2	0	-1	2	0	0	2	-1	0	2	-3	1	1
82	Roma Bannerji	-1	1	2	-3	1	2	-1	0	2	0	0	2	1	0	2	3	-2	1	2	-2	2	1	-2	2	1	-1	2	0	0	2	0	0	2	-3	2	1

Table 1.4a Summary of Seasonal Outdoor Environmental Conditions for the Surveyed Period

	Chandigarh				Roorkee			
	Winters							
	Mean	**Min**	**Max**	**StDev**	**Mean**	**Min**	**Max**	**StDev**
Toutside	15.14	5.00	25.10	2.15	16.24	7.50	26.00	1.67
RH (%)	61.44	45.00	83.00	3.22	64.94	49.00	84.00	2.69
	Summer							
	Mean	**Min**	**Max**	**StDev**	**Mean**	**Min**	**Max**	**StDev**
Toutside	30.01	12.20	41.30	5.81	27.31	10.20	41.50	5.87
RH (%)	42.88	30.00	60.00	3.93	40.00	29.00	58.00	3.45
	Monsoon							
	Mean	**Min**	**Max**	**StDev**	**Mean**	**Min**	**Max**	**StDev**
Toutside	28.36	18.00	36.30	2.66	28.74	20.20	35.20	1.56
RH (%)	71.00	52.00	100.00	8.67	71.13	51.00	98.00	8.31

Toutside: Outside Temperature
RH : Relative Humidity

Table 1.4b Summary of Seasonal Indoor Environmental Conditions for the Surveyed Period

	Chandigarh				Roorkee			
	Winters							
	Ta	**RH**	**Av**	**Tg**	**Ta**	**RH**	**Av**	**Tg**
Tmean	17.88	56.75	0.02	18.48	18.36	59.01	0.00	18.87
Tmin	14.20	42.10	0.00	15.00	14.10	44.35	0.00	14.90
Tmax	23.20	70.80	0.40	23.70	24.00	68.10	0.20	24.30
StDev	2.35	6.75	0.08	2.29	3.00	4.82	0.02	2.90
	Summer							
	Ta	**RH**	**Av**	**Tg**	**Ta**	**RH**	**Av**	**Tg**
Tmean	29.90	39.18	0.42	30.31	29.53	36.33	0.36	29.90
Tmin	21.10	23.60	0.00	21.50	21.10	22.80	0.00	21.60
Tmax	35.90	58.30	1.20	36.20	35.70	52.00	1.00	35.80
StDev	5.10	9.04	0.32	5.10	4.72	6.70	0.29	4.72
	Monsoon							
	Ta	**RH**	**Av**	**Tg**	**Ta**	**RH**	**Av**	**Tg**
Tmean	30.46	61.73	0.83	30.98	29.94	61.82	0.77	30.45
Tmin	26.20	47.70	0.00	26.80	26.00	46.60	0.00	26.90
Tmax	34.90	84.80	2.50	35.20	34.50	81.80	1.80	34.80
StDev	2.34	10.33	0.39	2.35	2.38	10.65	0.44	2.33

Tmean : Mean Indoor Temperature ; Tmin : Minimum Indoor Temperature ; Tmax : Maximum indoor Temperature ; StDev : Standard Deviation

Table 1.5 a GMR - DETAIL OF ENERGY CONSUMPTION OF EACH DWELLING UNIT

Flat No.	2011 (kwh/bimonthly)							2012 (kwh/bimonthly)						
	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec	Total	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec	Total
101	0	0	0	0	0	0	**0**	8	45	45	0	0	0	**98**
103	761	480	1020	1221	640	617	**4739**	650	438	920	1123	587	818	**4536**
105	60	60	90	90	100	122	**522**	10	13	0	0	0	0	**23**
106	423	302	790	1023	405	311	**3254**	379	335	574	754	154	91	**2287**
201	641	263	887	1298	590	528	**4207**	559	298	642	953	313	438	**3203**
202	544	311	64	40	397	442	**1798**	441	239	587	768	360	150	**2545**
203	363	278	145	40	402	542	**1770**	1109	534	1220	1512	734	1020	**6129**
204	0	0	0	0	0	0	**0**	743	325	821	928	394	688	**3899**
205	542	374	782	1106	512	339	**3655**	757	377	957	1323	481	778	**4673**
206	60	60	100	365	457	542	**1584**	421	278	596	788	274	212	**2569**
301	100	124	602	929	327	429	**2511**	654	321	546	711	350	189	**2771**
302	423	231	569	859	308	545	**2935**	1144	564	1022	1354	716	903	**5703**
303	862	480	1120	1201	457	633	**4753**	1096	687	1298	1487	943	1284	**6795**
304	0	0	0	0	0	0	**0**	1059	765	1298	1487	659	1284	**6552**
305	0	0	0	0	0	0	**0**	1141	675	1369	1485	659	1263	**6592**
306	589	366	853	1071	530	601	**4010**	745	365	331	265	188	143	**2037**
401	40	40	90	343	343	541	**1397**	1109	768	1137	1475	738	967	**6194**
402	443	325	833	1067	358	538	**3564**	647	147	287	743	343	490	**2657**
403	507	202	461	322	224	355	**2071**	195	189	323	732	311	664	**2414**
404	486	309	632	584	260	60	**2331**	454	342	694	943	401	440	**3274**
405	424	317	710	943	150	90	**2634**	1493	1159	1758	1872	1155	1284	**8721**
406	667	466	789	1019	545	576	**4062**	614	230	573	923	172	90	**2602**
502	576	387	986	283	150	150	**2532**	150	186	654	892	285	437	**2604**
503	90	100	100	100	150	258	**798**	0	0	0	0	0	0	**0**
504	745	480	1230	1480	645	820	**5400**	574	392	329	238	90	65	**1688**
505	60	60	100	543	336	482	**1581**	90	90	100	449	384	586	**3902**
602	1278	687	1487	1689	878	1067	**7086**	2087	1389	2267	2431	1278	1845	**11297**
603	502	262	625	963	90	90	**2532**	2938	1959	2365	2728	1976	2854	**14820**
604	0	0	0	0	0	0	**0**	7	0	0	0	0	0	**7**
605	4	4	4	0	0	0	**12**	40	40	170	102	0	0	**352**
606	861	494	1022	1321	435	768	**4901**	1167	554	1209	1486	789	1007	**6212**
701	663	344	823	1100	523	547	**4000**	1434	969	1794	1835	989	1242	**8263**
702	0	0	10	4	0	0	**14**	0	0	0	0	0	0	**0**
703	90	90	100	449	384	586	**1699**	565	212	45	45	45	45	**957**
705	486	312	475	552	140	100	**2065**	423	312	790	1023	405	321	**3274**
706	751	469	1088	1355	656	865	**5184**	1278	895	1594	1885	991	1169	**7812**
801	862	545	1190	1488	744	1031	**5860**	1299	767	1589	1875	889	1196	**7615**
802	200	200	343	762	312	664	**2481**	889	480	1230	1480	641	765	**5485**
803	534	401	585	100	90	90	**1800**	524	231	530	807	276	422	**2790**
804	0	0	0	0	0	0	**0**	758	344	823	1098	520	589	**4132**
805	784	432	1022	1244	735	787	**5004**	1455	969	1794	1837	978	1354	**8387**
806	1568	1199	1789	1887	1185	1491	**9119**	1598	1042	1787	1834	1169	1476	**8906**
90	704	532	822	1121	566	512	**4257**	1288	758	1305	1488	679	1059	**6577**
Total	**18693**	**11986**	**24338**	**29962**	**15024**	**18119**	**118122**	**33992**	**20683**	**37373**	**45159**	**22316**	**29628**	**191354**

Table 1.5 b TR - DETAIL OF ENERGY CONSUMPTION OF EACH DWELLING UNIT

	2011 (kwh/bimonthly)							2012 (kwh/bimonthly)						
Account Number	**Jan-Feb**	**Mar-Apr**	**May-Jun**	**Jul-aug**	**Sep-Oct**	**Nov-Dec**	**Total**	**Jan-Feb**	**Mar-Apr**	**May-Jun**	**Jul-aug**	**Sep-Oct**	**Nov-Dec**	**Total**
BS30/614	669	520	1020	994	592	400	**4195.0**	589	513	864	1002	673	583	**4224.0**
BS30/613	300	430	802	950	757	515	**3754.0**	408	546	1120	993	792	479	**4338.0**
BS30/545	110	79	841	903	571	602	**3106.0**	274	362	735	624	529	472	**2996.0**
BS30/562	1020	323	892	660	671	302	**3868.0**	864	382	638	829	613	492	**3818.0**
BS30/571	703	211	689	655	343	477	**3078.0**	926	362	723	829	674	379	**3893.0**
BS30/526	893	402	1112	743	576	435	**4161.0**	728	362	956	1129	872	472	**4519.0**
BS30/527	0	0	0	0	0	0	**0.0**	264	382	384	582	725	284	**2621.0**
BS30/511	767	324	698	614	353	75	**2831.0**	753	323	629	372	343	100	**2520.0**
BS30/490	70	50	690	917	781	80	**2588.0**	70	324	658	456	278	100	**1886.0**
BS30/487	980	546	978	758	457	645	**4364.0**	847	482	1022	784	501	592	**4228.0**
BS30/473	879	423	654	989	786	529	**4260.0**	755	433	559	527	386	529	**3189.0**
BS30/474	0	0	0	0	0	0	**0.0**	0	0	0	0	0	0	**0.0**
BS30/469	623	497	822	987	587	478	**3994.0**	623	497	822	925	735	478	**4080.0**
BS30/463	498	322	434	751	576	120	**2701.0**	526	385	454	667	725	70	**2827.0**
BS30/461	0	0	0	0	0	0	**0.0**	0	0	0	0	0	0	**0.0**
BS30/435	170	223	653	753	557	686	**3042.0**	493	354	548	702	472	160	**2729.0**
BS30/436	0	0	0	0	0	0	**0.0**	0	0	0	0	0	0	**0.0**
BS30/437	0	0	0	0	0	0	**0.0**	0	0	0	0	0	0	**0.0**
BS30/438	0	0	0	0	0	0	**0.0**	0	0	0	0	0	0	**0.0**
BS30/441	0	0	0	0	101	70	**171.0**	0	0	0	320	220	70	**610.0**
BS30/453	839	482	919	629	307	691	**3867.0**	1022	533	728	791	691	535	**4300.0**
BS30/409	630	356	794	467	375	535	**3157.0**	782	472	1134	1004	872	682	**4946.0**
BS30/391	529	321	649	532	320	539	**2890.0**	638	392	677	725	482	682	**3596.0**
BS30/385	130	287	398	503	392	121	**1831.0**	120	120	120	583	729	738	**2410.0**
BS30/384	0	0	0	0	0	70	**70.0**	0	0	0	0	0	70	**70.0**
BS30/369	580	325	979	563	378	578	**3403.0**	682	464	1028	1003	826	573	**4576.0**
BS30/360	793	397	1010	683	428	70	**3381.0**	892	338	947	926	639	684	**4426.0**
BS30/339	515	379	883	683	389	537	**3386.0**	532	479	943	948	739	632	**4273.0**
BS30/337	476	264	520	492	386	552	**2690.0**	676	353	752	847	538	648	**3814.0**
BS30/336	234	420	880	413	313	745	**3005.0**	537	372	736	693	620	573	**3531.0**
BS30/335	553	810	719	532	212	629	**3455.0**	625	725	826	972	629	348	**4125.0**
BS30/331	201	717	921	587	122	456	**3004.0**	392	482	725	1002	839	527	**3967.0**
BS30/321	449	694	812	321	319	424	**3019.0**	324	725	963	825	462	100	**3399.0**
BS30/322	0	0	0	0	0	0	**0.0**	0	0	0	0	0	0	**0.0**
BS30/320	324	653	774	428	412	382	**2973.0**	524	374	625	628	572	592	**3315.0**
BS30/318	267	547	854	411	312	389	**2780.0**	382	428	682	837	625	482	**3436.0**
BS30/309	987	458	421	454	543	428	**3291.0**	862	345	527	725	736	499	**3694.0**
BS30/307	160	330	760	1141	875	70	**3336.0**	120	120	70	223	292	70	**895.0**
BS30/302	365	577	1006	645	437	592	**3622.0**	472	452	822	926	682	527	**3881.0**
BS30/303	466	765	867	1073	635	629	**4435.0**	372	642	735	782	692	629	**3852.0**
BS30/280	387	519	683	478	289	352	**2708.0**	526	472	1082	1031	753	482	**4346.0**
BS30/279	432	383	339	930	635	120	**2839.0**	422	495	628	528	322	592	**2987.0**
BS30/277	0	0	0	0	0	0	**0.0**	0	0	0	0	0	0	**0.0**

BS30/273	738	1180	783	686	589	382	**4358.0**	638	463	837	882	372	482	**3674.0**
BS30/272	0	0	0	121	121	120	**362.0**	0	0	0	0	0	0	**0.0**
BS30/263	570	839	1129	1001	862	434	**4835.0**	627	538	839	938	462	526	**3930.0**
BS30/262	566	857	966	535	435	527	**3886.0**	633	367	692	927	362	472	**3453.0**
BS30/425	736	725	1022	438	392	722	**4035.0**	826	468	1002	839	281	633	**4049.0**
BS30/426	523	356	637	482	334	529	**2861.0**	452	292	537	472	294	582	**2629.0**
BS30/257	699	279	1033	783	498	623	**3915.0**	826	382	863	729	382	682	**3864.0**
BS30/244	530	183	168	650	486	120	**2137.0**	624	372	436	682	456	528	**3098.0**
BS30/243	70	0	0	70	70	70	**280.0**	0	0	0	0	0	140	**140.0**
BS30/244	0	0	0	0	0	0	**0.0**	0	0	0	0	0	0	**0.0**
BS30/245	0	0	0	0	0	0	**0.0**	0	0	0	0	0	0	**0.0**
BS30/239	589	896	1250	1210	873	620	**5438.0**	624	352	927	829	382	582	**3696.0**
BS30/222	698	926	1172	834	593	529	**4752.0**	826	352	922	739	382	592	**3813.0**
BS30/164	460	740	656	937	322	499	**3614.0**	527	324	826	723	294	382	**3076.0**
BS30/151	368	592	630	852	692	107	**3241.0**	482	392	725	684	392	326	**3001.0**
BS30/139	472	527	726	837	420	529	**3511.0**	592	394	1062	946	372	527	**3893.0**
BS30/119	502	423	826	1029	468	639	**3887.0**	672	382	735	826	392	529	**3536.0**
BS30/120	0	0	0	0	0	0	**0.0**	0	0	0	0	0	0	**0.0**
BS30/121	0	0	0	119	263	0	**382.0**	0	0	0	0	0	0	**0.0**
BS30/114	722	382	762	1005	754	583	**4208.0**	836	482	629	826	293	629	**3695.0**
BS30/70	492	339	573	823	572	289	**3088.0**	528	392	652	629	257	392	**2850.0**
BS30/69	700	310	199	487	397	522	**2615.0**	629	283	485	528	264	429	**2618.0**
BS30/67	450	257	211	623	515	635	**2691.0**	572	382	582	762	326	522	**3146.0**
BS30/65	503	261	302	591	602	528	**2787.0**	624	372	528	624	285	120	**2553.0**
BS30/61	660	271	319	767	702	862	**3581.0**	120	120	70	372	375	70	**1127.0**
BS30/29	655	343	322	991	677	742	**3730.0**	127	120	70	365	437	724	**1843.0**
BS30/45	743	576	454	823	535	628	**3759.0**	826	382	826	629	380	629	**3672.0**
BS30/51	214	353	121	667	415	120	**1890.0**	628	372	692	547	283	70	**2592.0**
BS30/2	569	320	613	756	622	645	**3525.0**	472	425	921	735	220	394	**3167.0**
Total	**30228.0**	**25969.0**	**40347.0**	**40756.0**	**28996.0**	**26327.0**	**192623.0**	**32733.0**	**22898.0**	**40720.0**	**42973.0**	**29221.0**	**26887.0**	**195432.0**

Table 1.5c BMD - DETAIL OF ENERGY CONSUMPTION OF EACH DWELLING UNIT

Flat No.	Dwelling Unit	2011 (kwh/bimonthly)							2012 (kwh/bimonthly)						
		Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec	Total	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec	Total
101	Jyoti Chaufla	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**
102	Pramod Sharma	1929	221	1480	1422	790	344	**6186**	166	91	353	1427	1185	895	**4117**
103	Tej Kumar	597	648	1699	673	254	34	**3905**	0	21	692	1207	467	790	**3177**
104	Rajeev Singh	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**
201	Lalit Katoch	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**
202	Neelam Chopra	10	9	15	17	3	0	**54**	0	32	203	1170	843	0	**2248**
203	Ritu Vyas	0	0	700	460	7	856	**2023**	100	0	159	699	1055	535	**2548**
204	Nitin Gupta	0	0	0	2249	0	0	**2249**	150	249	683	414	550	80	**2126**
301	Deepshikha	197	115	328	271	58	75	**1044**	146	154	1577	2500	751	642	**5770**
302	Renu Vashisht	1345	800	1053	1769	1749	679	**7395**	804	694	2459	3199	1637	933	**9726**
303	Munish Gupta	0	0	0	0	0	0	**0**	0	0	0	0	20	80	**100**
304	Raj Kaur	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**
401	Preet Kaur Ahuja	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**
402	Mohan Jit Singh	0	0	0	0	0	0	**0**	0	0	0	0	0	120	**120**
403	Ajay Kumar	0	1608	1108	1511	1293	0	**5520**	600	518	2026	2301	3104	933	**9482**
404	Kanta Rani	5	0	64	77	65	0	**211**	152	328	42	4	0	0	**526**
501	Shalu Luthra	1200	2400	1585	966	575	607	**7333**	1121	781	948	1700	916	739	**6205**
502	Anju Sharma		205	488	996	349	319	**2357**	80	707	221	996	746	543	**3293**
503	Kavita Aggarwal	308	210	299	1434	968	270	**3489**	185	244	363	1434	968	363	**3557**
504	Arvind Bhardwaj	1000	823	486	596	388	302	**3595**	313	342	716	978	715	373	**3437**
601	Ratan Kaushik	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**
602	Vandana Upmanyu	629	330	0	1227	607	305	**3098**	1113	475	700	3379	1398	713	**7778**
603	Balbir Singh	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**
604	Devender Kaur	0	0	0	0	820	800	**1620**	0	0	0	0	0	0	**0**
701	Reema Mahajan	42	1000	1000	1000	2000	2000	**7042**	539	320	1868	2056	690	213	**5686**
702	Manohar Kashyap	0	0	0	0	0	20	**20**	0	0	0	0	0	0	**0**
703	Harbans Kaur	68	56	153	375	130	61	**843**	26	16	405	1662	323	23	**2455**
704	Rakesh Trehan	0	0	0	0	0	0	**0**	0	0	0	0	354	409	**763**
801	Jagandeep Kohli	0	0	1	0	10	3	**14**	0	0	0	30	16	164	**210**
802	Sunita	115	515	1200	700	200	150	**2880**	0	0	79	194	185	95	**553**

Table 1.5 d HV - DETAIL OF ENERGY CONSUMPTION OF EACH DWELLING UNIT (2012)

Flat No.	Dwelling Unit	2011 (kwh/month)													2012 (kwh/month)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
A1	Dr. Sri Niwas	640	520	100	180	40	240	520	240	360	240	320	360	**3760**	640	480	240	280	240	200	440	280	320	160	240	360	**3880**
A2	Dr. D.D. Das	360	400	280	160	40	200	280	320	480	280	280	200	**3280**	480	360	240	120	240	320	480	280	280	280	160	200	**3440**
A3	Dr. R.N. Goel	490	490	490	490	20	20	20	20	20	20	20	10	**2110**	380	260	240	200	240	380	300	240	240	160	100	180	**2920**
A4	P.N.Aggarwal	200	438	286	234	146	493	338	448	456	327	127	180	**3673**	0	0	0	249	367	599	47	377	557	414	202	285	**3097**
A5	Dr. M.N. Wiladkar	379	665	338	359	539	320	490	243	415	429	291	411	**4879**	671	414	375	241	302	368	491	333	321	315	227	332	**4390**
A6	Dr. H.R.Wason	280	280	240	360	400	480	440	440	440	440	320	480	**4600**	280	200	280	320	440	440	520	400	360	400	320	360	**4320**
A7	Dr. Deepak Kashyap	400	440	320	360	400	640	480	440	280	400	360	480	**5000**	640	520	520	400	360	480	440	400	440	400	360	400	**5360**
A8	Dr. Indu Mehrotra	440	840	520	880	760	880	900	780	780	840	540	800	**8960**	680	600	480	480	820	880	820	680	900	860	480	920	**8600**
A9	Dr. U.B. Chitranshi	524	524	524	524	140	420	180	200	160	300	120	220	**3836**	246	250	44	44	262	262	262	262	262	262	262	262	**2680**
A10	Dr.A.K.Jain	390	539	259	264	153	845	917	946	708	635	193	338	**6187**	442	576	331	205	472	504	696	590	666	784	215	338	**5819**
A11	Dr.Veer Singh	700	840	580	500	460	320	580	500	380	480	340	520	**6200**	780	740	560	380	540	460	140	420	640	560	360	600	**6180**
A12	Dr. N.K.Goel	272	343	223	295	341	1186	1096	615	488	417	263	392	**5931**	375	299	236	213	346	620	582	361	568	412	204	290	**4506**
A13	Dr. Sandeep Singh	1602	1093	544	600	1172	1623	1898	1578	1286	1405	492	928	**14221**	1374	1431	614	448	1113	963	1420	1272	1310	820	425	488	**11678**
A14	Dr.Jagdish Prasad	300	260	140	160	20	20	20	20	190	380	200	228	**1938**	220	220	200	200	300	260	300	280	420	240	160	220	**3020**
B1	Dr. A.K.Jain	177	177	177	177	259	480	504	291	225	217	100	144	**2928**	73	73	73	73	177	177	177	177	177	177	177	177	**1708**
B2	Dr.V.K.Gupta	40	80	40	80	120	40	40	80	80	120	80	120	**920**	40	40	40	80	120	160	280	120	80	120	120	80	**1280**
B3	Dr.Y.K. Gupta	360	400	200	240	160	880	960	240	40	180	212	560	**4432**	360	320	280	240	240	400	320	240	240	120	160	200	**3120**
B4	Dr.Bharat Gupta	671	806	113	40	40	40	100	180	180	250	220	23	**2663**	489	539	329	236	350	487	559	334	351	314	194	229	**4411**
B5	Dr.Jagdish Rai	1037	822	340	261	299	484	185	858	851	827	333	478	**6775**	97	2	1	1	3	37	661	579	644	403	250	270	**2948**
B6	Dr.S. Mukherji	138	289	299	230	219	336	376	323	213	309	226	346	**3304**	123	292	254	212	268	301	307	241	241	240	190	277	**2946**
B7	Dr.R.P. Gakhar	373	638	392	442	375	718	922	57	57	57	57	130	**4218**	482	453	366	314	276	368	497	390	410	403	331	498	**4788**
B8	Dr.Mahendra Singh	271	399	273	309	278	539	541	407	357	442	199	380	**4395**	394	359	322	158	318	401	566	302	403	395	223	289	**4130**
B9	Dr. A.K Aggarwal	484	541	263	214	315	346	363	274	207	236	150	501	**3894**	470	553	338	172	229	231	223	178	211	216	147	258	**3226**
B10	Dr. Ashok Mathur	231	339	259	465	574	1120	1105	781	468	545	289	454	**6630**	257	231	240	272	452	501	386	303	271	279	299	276	**3767**
B11	Dr.A.K. Sen	802	1146	505	492	680	608	1642	1382	1136	1177	456	488	**10514**	372	321	287	341	728	1088	1373	1129	1317	1248	555	535	**9294**
B12	Dr.P.K. Patel	20	20	20	20	20	20	20	20	20	100	100	40	**420**	40	40	40	40	100	80	60	20	20	20	20	20	**500**
B13	Dr. Ramesh Chandra	560	660	420	420	360	400	620	540	260	360	300	520	**5420**	540	540	520	380	380	420	400	340	380	320	300	500	**5020**
B14	Dr. A.K.Chaudhary	443	479	231	316	425	752	982	864	1012	657	415	368	**6944**	526	447	407	395	618	525	701	538	747	583	225	386	**6098**
Total		**12584**	**14468**	**8376**	**9072**	**8755**	**14450**	**16519**	**13087**	**11549**	**12070**	**7003**	**10099**	**138032**	**11471**	**10560**	**7857**	**6694**	**10301**	**11912**	**13448**	**11066**	**12776**	**10905**	**6906**	**9230**	**123126**

Table 1.5 e CV- DETAIL OF ENERGY CONSUMPTION OF EACH DWELLING UNIT (2012)

Flat N	Dwelling Unit	2012 (kwh/month)													2013 (kwh/month)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
A101	Dr.Pankaj Aggarwal	579	220	138	124	271	673	947	522	408	368	206	260	**4716**	547	402	329	275	313	614	696	759	398	450	347	297	**5427**
A102	M. Parunad	212	52	39	39	60	51	74	78	76	80	46	46	**853**	260	231	195	117	91	57	87	99	58	74	152	147	**1568**
A103	Dr. Anil Kumar	208	638	278	370	736	1072	1345	957	671	251	409	216	**7151**	270	198	172	96	63	0	614	533	305	324	346	315	**3236**
A201	Dr.Navneet Arora	40	40	40	120	234	353	561	291	279	297	164	182	**2601**	528	433	301	259	255	407	551	402	243	281	327	274	**4261**
A202	N.P. Padhi	1410	386	201	190	316	432	450	347	266	273	219	260	**4750**	632	452	182	254	326	423	152	306	200	276	370	303	**3876**
A203	Dr.Anand Joshi	1279	421	200	155	292	482	1077	592	560	640	202	256	**6156**	518	575	372	254	624	706	921	907	567	725	390	300	**6859**
A301	Dr.R.P. Maheshwari	793	150	149	135	191	279	440	302	35	87	141	171	**2873**	498	334	307	251	236	404	175	132	37	158	279	232	**3043**
A302	Dr. D.B. Karnikar	15	15	29	225	243	527	120	434	295	334	252	539	**3028**	674	717	520	302	334	328	431	605	355	415	406	543	**5630**
A303	Dr.Jitendra Madan	14	14	14	107	0	258	219	407	293	275	134	189	**1924**	630	671	360	162	37	0	0	0	0	0	179	177	**2216**
A401	Dr. Partha Roy	549	169	110	88	132	56	56	130	145	171	106	166	**1878**	387	331	279	214	199	89	173	190	118	165	226	226	**2597**
A402	Dr.Yogesh Hote	1067	322	130	134	236	359	540	333	227	238	151	141	**3878**	599	478	311	238	223	137	246	342	181	250	265	457	**3727**
A403	Dr. G.K.Rastogi	924	350	218	157	339	402	789	556	314	371	217	283	**4920**	604	462	409	330	474	734	537	582	396	475	404	368	**5775**
A501	Dr.Alok Pandey	769	250	198	161	224	290	508	371	343	324	214	266	**3918**	435	783	353	383	558	505	519	568	348	422	411	284	**5569**
A502	Dr.A.J.Mishra	492	246	151	87	325	621	136	598	470	356	104	184	**3770**	610	542	299	168	293	463	46	403	188	232	172	150	**3566**
A503	Dr.B.K. Kaushik	451	166	104	98	228	252	400	361	258	225	95	160	**2798**	401	283	243	191	295	266	319	404	210	200	235	228	**3275**
A601	Dr.P.Arumdizom	557	428	159	140	199	123	57	272	224	182	112	137	**2590**	403	572	427	306	195	57	78	315	254	240	189	217	**3253**
A602	Dr.Anuj Sharma	843	441	163	95	235	174	476	361	290	289	117	770	**4254**	897	506	290	199	338	518	294	452	223	308	217	318	**4560**
A603	Dr.Rajdeep Chatterji	1345	1095	208	94	154	619	402	339	187	209	92	181	**4925**	587	664	250	196	313	493	406	362	199	235	235	218	**4158**
Total		**11547**	**5403**	**2529**	**2519**	**4415**	**7023**	**8597**	**7251**	**5341**	**4970**	**2981**	**4407**	**66983**	**9480**	**8634**	**5599**	**4195**	**5167**	**6201**	**6245**	**7361**	**4280**	**5230**	**5150**	**5054**	**72596**

Table 1.6 a, b, c, d & e : Monthly comparison of simulated and measured electricity consumption(MWh)

Table 1.6a CV

Months	Measured		Average	Simulated
	2012	**2013**		
Jan	11.5	9.5	10.5	8.7
Feb	5.4	8.6	7.0	6.3
Mar	2.5	5.6	4.1	3.3
Apr	2.5	4.2	3.4	3.8
May	4.4	5.2	4.8	5.0
Jun	7.0	6.2	6.6	7.1
Jul	8.6	6.2	7.4	7.8
Aug	7.3	7.4	7.3	7.5
Sep	5.3	4.3	4.8	4.7
Oct	5.0	5.2	5.1	4.5
Nov	3.0	5.2	4.1	3.3
Dec	4.4	5.1	4.7	4.5
Total	**67.0**	**72.6**	**69.8**	**66.3**

Table 1.6b HV

Months	Measured		Average	Simulated
	2011	**2012**		
Jan	12.6	11.5	12.0	11.4
Feb	14.5	10.6	12.5	10.6
Mar	8.4	7.9	8.1	7.0
Apr	9.1	6.7	7.9	7.6
May	8.8	10.3	9.5	10.9
Jun	14.5	11.9	13.2	14.5
Jul	16.5	13.4	15.0	15.6
Aug	13.1	11.1	12.1	13.7
Sep	11.5	12.8	12.2	10.2
Oct	12.1	10.9	11.5	8.6
Nov	7.0	6.9	7.0	6.2
Dec	10.1	9.2	9.7	9.8
Total	**138.0**	**123.1**	**130.6**	**126.2**

Table 1.6c GMR

Months	Measured		Average	Simulated
	2011	**2012**		
Jan-Feb	18.7	34.0	26.3	23.0
Mar-Apr	12.0	20.7	16.3	15.9
May-Jun	24.3	37.4	30.9	34.3
Jul-Aug	30.0	45.2	37.6	36.4
Sep-Oct	15.0	22.3	18.7	15.9
Nov-Dec	18.1	29.6	23.9	21.2
Total	**118.1**	**189.2**	**153.6**	**146.7**

Table 1.6d BMD

Months	Measured		Average	Simulated
	2011	**2012**		
Jan-Feb	7.4	5.5	9.0	9.4
Mar-Apr	8.9	5.0	8.3	8.5
May-Jun	11.7	13.5	12.6	13.9
Jul-Aug	15.7	25.4	19.5	17.2
Sep-Oct	10.3	15.9	13.1	12.0
Nov-Dec	6.8	8.6	7.7	8.9
Total	**60.9**	**73.9**	**71.3**	**69.8**

Table 1.6e TR

Months	Measured		Average	Simulated
	2011	**2012**		
Jan-Feb	30.2	32.7	31.5	34.3
Mar-Apr	26.0	22.9	• 24.4	26.2
May-Jun	40.3	40.7	• 40.5	45.0
Jul-Aug	27.9	37.9	• 37.9	39.4
Sep-Oct	20.7	21.5	21.1	26.2
Nov-Dec	26.3	26.9	26.6	31.9
Total	**171.4**	**182.6**	**177.0**	**203.0**

Table 1.7a & b : Statistical Tolerances of the baseline models within Acceptable Limits (Utility Bills)

Table1.7 a Statistical Tolerances for baseline models of GMR,BMD & TR

	GMR			BMD			TR		
Months	**% Error**	**CV (RMSE)**	**MBE**	**% Error**	**CV (RMSE)**	**MBE**	**% Error**	**CV (RMSE)**	**MBE**
Jan-Feb	-12.60	**11.00**	**4.50**	3.66	**11.91**	**0.33**	9.1	**13.79**	**-4.63**
Mar-Apr	-2.88			2.07			7.04		
May-Jun	11.31			10.21			10.9		
Jul-Aug	-3.08			-16.09			19.96		
Sep-Oct	-14.66			-8.59			24.30		
Nov-Dec	-11.39			15.15			19.89		
TOTAL	-4.50			-2.06			14.68		

Table1.7b Statistical Tolerances for baseline models of CV & HV

	CV			HV		
Months	**% Error**	**CV (RMSE)**	**MBE**	**% Error**	**CV (RMSE)**	**MBE**
Jan	-17.27	**12.85**	**4.98**	-5.23	**13.87**	**3.36**
Feb	-10.76			-15.17		
Mar	-19.75			-14.18		
Apr	14.16			-3.32		
May	3.65			14.88		
Jun	6.67			10.25		
Jul	4.96			4.02		
Aug	2.64			13.64		
Sep	-3.25			-15.80		
Oct	-12.26			-25.32		
Nov	-18.13			-10.92		
Dec	-4.92			1.31		
Total	**-4.98**			-3.36		

Table 1.8a Measure of Goodness of Fit for simulated and measured data : Air Temperature (Ta)

	GMR		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	21.83	17.475	24.9	**0.15**	**19.4**
Feb	23.33	18.485	26.2		
Mar	28.34	22.185	27.7		
Apr	31.26	29.685	5.3		
May	33.35	33.415	-0.2		
Jun	34.19	34.69	-1.4		
Jul	31.88	34.02	-6.3		
Aug	31.77	30.41	4.5		
Sep	32.77	29.43	11.3		
Oct	33.79	28.56	18.3		
Nov	29.53	20.97	40.8		
Dec	24.45	15.34	59.4		
		26.22			

	(ysi-ym)	(ysi-ym)2
Jan	4.36	18.97
Feb	4.85	23.47
Mar	6.16	37.88
Apr	1.57	2.48
May	-0.07	0.00
Jun	-0.50	0.25
Jul	-2.14	4.58
Aug	1.36	1.85
Sep	3.34	11.16
Oct	5.23	27.35
Nov	8.56	73.27
Dec	9.11	82.99

∑(ysi-ym)	41.83
∑(ysi-ym)2	284.26
∑(ysi-ym)2/(n-p-1)	25.84
√∑(ysi-ym)2/(n-p-1)	5.08
1/ymean measured	0.04

	TR		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	20.28	15.89	27.6	**0.13**	**16.7**
Feb	22.34	18.39	21.5		
Mar	27.19	21.48	26.6		
Apr	31.99	29.22	9.5		
May	33.75	33.13	1.9		
Jun	34.43	35.22	-2.2		
Jul	32.52	34.25	-5.1		
Aug	**32.73**	30.02	9.0		
Sep	33.05	29.30	12.8		
Oct	31.46	28.37	10.9		
Nov	27.01	20.13	34.2		
Dec	22.23	15.24	45.9		
		25.89			

	(ysi-ym)	(ysi-ym)2
Jan	4.39	19.24
Feb	3.95	15.58
Mar	5.71	32.60
Apr	2.77	7.67
May	0.62	0.39
Jun	-0.79	0.62
Jul	-1.73	3.00
Aug	2.71	7.34
Sep	3.75	14.06
Oct	3.09	9.57
Nov	6.88	47.38
Dec	6.99	48.86

∑(ysi-ym)	38.34
∑(ysi-ym)2	206.33
∑(ysi-ym)2/(n-1)	18.76
√∑(ysi-ym)2/(n-1)	4.33
1/ymean measured	0.04

Monthly energy consumption (measured value) : y_m
Monthly energy consumption (simulated value) : y_{si}

Number of data points : n
Number of predictor variables : p

	BMD		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	20.27	16.22	24.9	**0.17**	**17.4**
Feb	21.79	18.48	17.9		
Mar	26.35	21.79	20.9		
Apr	34.04	29.46	15.5		
May	36.52	33.03	10.6		
Jun	37.69	35.43	6.4		
Jul	34.75	34.35	1.2		
Aug	**34.81**	29.95	16.2		
Sep	35.4	29.40	20.4		
Oct	31.76	27.12	17.1		
Nov	26.4	22.65	16.5		
Dec	21.88	15.23	43.7		
		26.09			

	(ysi-ym)	(ysi-ym)2
Jan	4.05	16.38
Feb	3.31	10.98
Mar	4.56	20.77
Apr	4.58	20.96
May	3.49	12.17
Jun	2.26	5.10
Jul	0.40	0.16
Aug	4.86	23.58
Sep	6.00	36.00
Oct	4.64	21.50
Nov	3.75	14.03
Dec	6.65	44.21

∑(ysi-ym)	48.54
∑(ysi-ym)2	225.86
∑(ysi-ym)2/(n-p-1)	20.53
√∑(ysi-ym)2/(n-p-1)	4.53
1/ymean measured	0.04

	CV		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	16.53	17.07	-3.2	**-0.03**	**7.6**
Feb	19.18	18.22	5.3		
Mar	23.29	22.52	3.4		
Apr	28.71	29.65	-3.2		
May	29.47	33.79	-12.8		
Jun	31.53	34.22	-7.8		
Jul	31.68	33.92	-6.6		
Aug	**30.6**	29.83	2.6		
Sep	29.73	28.87	3.0		
Oct	26.89	27.51	-2.2		
Nov	21.44	23.56	-9.0		
Dec	17.4	15.54	12.0		
		26.22			

	(ysi-ym)	(ysi-ym)2
Jan	-0.54	0.30
Feb	0.96	0.92
Mar	0.77	0.60
Apr	-0.94	0.88
May	-4.32	18.70
Jun	-2.69	7.21
Jul	-2.24	5.02
Aug	0.77	0.59
Sep	0.86	0.74
Oct	-0.62	0.38
Nov	-2.12	4.49
Dec	1.86	3.47

∑(ysi-ym)	-8.24
∑(ysi-ym)2	43.30
∑(ysi-ym)2/(n-p-1)	3.94
√∑(ysi-ym)2/(n-p-1)	1.98
1/ymean measured	0.04

Monthly energy consumption (measured value) : y_m

Monthly energy consumption (simulated value) : y_{si}

Number of data points : n

Number of predictor variables : p

	HV		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	18.35	16.19	13.3	**0.04**	**8.7**
Feb	20.84	17.96	16.0		
Mar	24.05	21.37	12.5		
Apr	28.66	29.25	-2.0		
May	30.05	32.51	-7.6		
Jun	31.88	32.38	-1.5		
Jul	31.99	33.31	-4.0		
Aug	**31.07**	29.83	4.2		
Sep	30.4	29.16	4.3		
Oct	28.78	27.03	6.5		
Nov	23.58	22.71	3.8		
Dec	19.75	15.39	28.3		
		25.59			

	(ysi-ym)	(ysi-ym)2
Jan	2.16	4.65
Feb	2.88	8.29
Mar	2.68	7.16
Apr	-0.59	0.35
May	-2.46	6.04
Jun	-0.50	0.25
Jul	-1.32	1.75
Aug	1.24	1.55
Sep	1.24	1.54
Oct	1.75	3.07
Nov	0.87	0.75
Dec	4.36	18.98

∑(ysi-ym)	12.30
∑(ysi-ym)2	54.39
∑(ysi-ym)2/(n-p-1)	4.94
√∑(ysi-ym)2/(n-p-1)	2.22
1/ymean measured	0.04

Monthly energy consumption (measured value) : y_m

Monthly energy consumption (simulated value) : y_{si}

Number of data points : n

Number of predictor variables : p

Table 1.8b Measure of Goodness of Fit for simulated and measured data : Radiant Temperature (Tr)

	GMR		**Measure of "Godness of Fit"**		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	21.59	18.28	18.1	**0.12**	**17.0**
Feb	23.17	19.29	20.1		
Mar	28.34	22.69	24.9		
Apr	32.3	30.48	6.0		
May	34.67	34.20	1.4		
Jun	35.72	35.90	-0.5		
Jul	33.19	35.98	-7.8		
Aug	33.05	32.21	2.6		
Sep	34.1	30.80	10.7		
Oct	34.29	29.98	14.4		
Nov	29.72	21.57	37.8		
Dec	24.36	15.98	52.4		
		27.28			

	(ysi-ym)	(ysi-ym)2
Jan	3.31	10.94
Feb	3.88	15.04
Mar	5.65	31.88
Apr	1.82	3.31
May	0.47	0.22
Jun	-0.18	0.03
Jul	-2.79	7.81
Aug	0.84	0.70
Sep	3.30	10.89
Oct	4.31	18.56
Nov	8.15	66.47
Dec	8.38	70.22

∑(ysi-ym)	37.13
∑(ysi-ym)2	236.09
∑(ysi-ym)2/(n-p-1)	21.46
√∑(ysi-ym)2/(n-p-1)	4.63
1/ymean measured	0.04

	TR		**Measure of "Godness of Fit"**		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	20.1	16.43	22.4	**0.11**	**14.7**
Feb	22.17	18.97	16.9		
Mar	27.18	21.89	24.2		
Apr	32.49	30.13	7.8		
May	34.62	33.86	2.2		
Jun	35.47	36.86	-3.8		
Jul	33.35	35.93	-7.2		
Aug	**33.43**	31.64	5.7		
Sep	33.84	30.89	9.6		
Oct	32.02	29.51	8.5		
Nov	27.31	20.79	31.4		
Dec	22.66	15.92	42.3		
		26.90			

	(ysi-ym)	(ysi-ym)2
Jan	3.67	13.49
Feb	3.20	10.25
Mar	5.29	28.03
Apr	2.36	5.56
May	0.76	0.58
Jun	-1.39	1.93
Jul	-2.58	6.66
Aug	1.79	3.20
Sep	2.95	8.72
Oct	2.51	6.28
Nov	6.52	42.55
Dec	6.74	45.43

∑(ysi-ym)	31.82
∑(ysi-ym)2	172.68
∑(ysi-ym)2/(n-p-1)	15.70
√∑(ysi-ym)2/(n-p-1)	3.96
1/ymean measured	0.04

Monthly energy consumption (measured value) : y_m

Monthly energy consumption (simulated value) : y_{si}

Number of data points : n

Number of predictor variables : p

	BMD		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	20.14	17.03	18.3	**0.14**	**15.0**
Feb	21.78	19.11	14.0		
Mar	26.68	22.19	20.2		
Apr	34.11	30.47	12.0		
May	37.02	33.99	8.9		
Jun	38.37	36.32	5.6		
Jul	35.32	36.07	-2.1		
Aug	**35.26**	31.21	13.0		
Sep	35.9	30.57	17.4		
Oct	32.67	28.55	14.4		
Nov	27.13	23.12	17.3		
Dec	22.15	15.98	38.6		
		27.05			

	(ysi-ym)	(ysi-ym)2
Jan	3.11	9.70
Feb	2.67	7.12
Mar	4.49	20.14
Apr	3.64	13.27
May	3.03	9.16
Jun	2.05	4.21
Jul	-0.75	0.57
Aug	4.05	16.39
Sep	5.33	28.40
Oct	4.12	16.94
Nov	4.01	16.06
Dec	6.17	38.01

∑(ysi-ym)	41.90
∑(ysi-ym)2	179.96
∑(ysi-ym)2/(n-p-1)	16.36
√∑(ysi-ym)2/(n-p-1)	4.04
1/ymean measured	0.04

	CV		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	16.62	17.66	-5.9	**-0.03**	**6.9**
Feb	19.39	18.83	2.9		
Mar	23.61	22.88	3.2		
Apr	29.41	30.28	-2.9		
May	30.32	34.38	-11.8		
Jun	32.6	35.03	-6.9		
Jul	32.71	35.12	-6.9		
Aug	31.54	31.31	0.7		
Sep	30.67	30.22	1.5		
Oct	27.81	28.52	-2.5		
Nov	22.02	23.97	-8.1		
Dec	17.73	16.13	9.9		
		27.03			

	(ysi-ym)	(ysi-ym)2
Jan	-1.04	1.07
Feb	0.56	0.31
Mar	0.73	0.53
Apr	-0.87	0.76
May	-4.06	16.49
Jun	-2.43	5.90
Jul	-2.41	5.82
Aug	0.23	0.05
Sep	0.45	0.20
Oct	-0.71	0.50
Nov	-1.95	3.82
Dec	1.60	2.57

∑(ysi-ym)	-9.90
∑(ysi-ym)2	38.02
∑(ysi-ym)2/(n-1)	3.46
√∑(ysi-ym)2/(n-1)	1.86
1/ymean measured	0.04

Monthly energy consumption (measured value) : y_m

Monthly energy consumption (simulated value) : y_{si}

Number of data points : n

Number of predictor variables : p

	HV		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	18.11	16.53	9.6	**0.01**	**7.5**
Feb	20.63	18.52	11.4		
Mar	23.97	21.72	10.4		
Apr	29.1	30.09	-3.3		
May	30.55	33.79	-9.6		
Jun	32.63	33.62	-3.0		
Jul	32.7	34.91	-6.3		
Aug	**31.58**	31.85	-0.9		
Sep	30.84	30.43	1.4		
Oct	29.09	28.17	3.3		
Nov	23.76	22.98	3.4		
Dec	19.66	16.11	22.1		
		26.56			

	(ysi-ym)	(ysi-ym)2
Jan	1.58	2.51
Feb	2.11	4.46
Mar	2.25	5.06
Apr	-0.99	0.99
May	-3.24	10.49
Jun	-0.99	0.99
Jul	-2.21	4.88
Aug	-0.27	0.07
Sep	0.41	0.17
Oct	0.92	0.84
Nov	0.78	0.61
Dec	3.55	12.63

∑(ysi-ym)	3.90
∑(ysi-ym)2	43.68
∑(ysi-ym)2/(n-p-1)	3.97
√∑(ysi-ym)2/(n-p-1)	1.99
1/ymean measured	0.04

Monthly energy consumption (measured value) : y_m

Monthly energy consumption (simulated value) : y_{si}

Number of data points : n

Number of predictor variables : p

Table 1.8 c Measure of Goodness of Fit for simulated and measured data : Operative Temperature (To)

	GMR		Measure of "Godness of Fit"		
	Simulated (°C)	Measured (°C)	% Error	NMBE	CV (RMSE)
Jan	21.71	17.85	21.6	**0.14**	**18.4**
Feb	23.25	18.86	23.3		
Mar	28.34	22.42	26.4		
Apr	31.78	30.01	5.9		
May	34.01	33.71	0.9		
Jun	34.96	35.09	-0.4		
Jul	32.53	34.61	-6.0		
Aug	32.41	30.95	4.7		
Sep	33.43	29.92	11.7		
Oct	34.04	29.04	17.2		
Nov	29.62	21.26	39.4		
Dec	24.4	15.66	55.8		
		26.61			

	(ysi-ym)	(ysi-ym)2
Jan	3.86	14.91
Feb	4.39	19.29
Mar	5.92	35.01
Apr	1.77	3.14
May	0.30	0.09
Jun	-0.13	0.02
Jul	-2.08	4.32
Aug	1.46	2.13
Sep	3.51	12.35
Oct	5.00	25.00
Nov	8.36	69.97
Dec	8.74	76.39

∑(ysi-ym)	41.12
∑(ysi-ym)2	262.61
∑(ysi-ym)2/(n-p-1)	23.87
√∑(ysi-ym)2/(n-p-1)	4.89
1/ymean measured	0.04

	TR		Measure of "Godness of Fit"		
	Simulated (°C)	Measured (°C)	% Error	NMBE	CV (RMSE)
Jan	20.19	16.16	24.9	**0.13**	**15.7**
Feb	22.26	18.67	19.2		
Mar	27.19	21.68	25.4		
Apr	32.24	29.61	8.9		
May	34.18	33.41	2.3		
Jun	34.95	35.73	-2.2		
Jul	32.94	34.76	-5.2		
Aug	**33.08**	30.51	8.4		
Sep	33.44	29.89	11.9		
Oct	31.74	28.78	10.3		
Nov	27.16	20.46	32.8		
Dec	22.24	15.58	42.7		
		26.27			

	(ysi-ym)	(ysi-ym)2
Jan	4.03	16.24
Feb	3.59	12.87
Mar	5.51	30.37
Apr	2.63	6.93
May	0.77	0.59
Jun	-0.78	0.61
Jul	-1.82	3.30
Aug	2.57	6.62
Sep	3.55	12.57
Oct	2.96	8.79
Nov	6.70	44.93
Dec	6.66	44.36

∑(ysi-ym)	36.38
∑(ysi-ym)2	188.19
∑(ysi-ym)2/(n-p-1)	17.11
√∑(ysi-ym)2/(n-p-1)	4.14
1/ymean measured	0.04

Monthly energy consumption (measured value) : y_m

Monthly energy consumption (simulated value) : y_{si}

Number of data points : n

Number of predictor variables : p

	BMD		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	20.21	16.62	21.6	**0.16**	**16.5**
Feb	21.78	18.79	15.9		
Mar	26.52	21.99	20.6		
Apr	34.08	29.88	14.1		
May	36.77	33.41	10.1		
Jun	38.03	35.73	6.4		
Jul	35.04	34.86	0.5		
Aug	**35.03**	30.35	15.4		
Sep	35.65	29.87	19.4		
Oct	32.22	27.67	16.4		
Nov	26.77	22.89	17.0		
Dec	22.02	15.61	41.1		
		26.47			

	(ysi-ym)	(ysi-ym)2
Jan	3.59	12.86
Feb	2.99	8.91
Mar	4.53	20.50
Apr	4.20	17.66
May	3.36	11.31
Jun	2.30	5.28
Jul	0.18	0.03
Aug	4.68	21.93
Sep	5.78	33.43
Oct	4.55	20.70
Nov	3.88	15.07
Dec	6.41	41.12

∑(ysi-ym)	46.44
∑(ysi-ym)2	208.79
∑(ysi-ym)2/(n-p-1)	18.98
√∑(ysi-ym)2/(n-p-1)	4.36
1/ymean measured	0.04

	CV		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	16.58	17.36	-4.5	**-0.03**	**7.1**
Feb	19.29	18.53	4.1		
Mar	23.45	22.70	3.3		
Apr	29.06	29.90	-2.8		
May	29.89	34.04	-12.2		
Jun	32.06	34.53	-7.1		
Jul	32.19	34.28	-6.1		
Aug	**31.07**	30.29	2.6		
Sep	30.2	29.38	2.8		
Oct	27.35	27.95	-2.2		
Nov	21.73	23.77	-8.6		
Dec	17.57	15.83	11.0		
		26.55			

	(ysi-ym)	(ysi-ym)2
Jan	-0.78	0.62
Feb	0.76	0.58
Mar	0.75	0.56
Apr	-0.84	0.71
May	-4.15	17.21
Jun	-2.47	6.09
Jul	-2.09	4.37
Aug	0.78	0.61
Sep	0.82	0.68
Oct	-0.60	0.36
Nov	-2.04	4.14
Dec	1.74	3.02

∑(ysi-ym)	-8.12
∑(ysi-ym)2	38.96
∑(ysi-ym)2/(n-1)	3.54
√∑(ysi-ym)2/(n-1)	1.88
1/ymean measured	0.04

Monthly energy consumption (measured value) : y_m

Monthly energy consumption (simulated value) : y_{si}

Number of data points : n

Number of predictor variables : p

	HV		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	18.23	16.36	11.4	**0.03**	**7.9**
Feb	20.73	18.24	13.7		
Mar	24.01	21.55	11.4		
Apr	28.88	29.60	-2.4		
May	30.3	33.02	-8.2		
Jun	32.26	32.81	-1.7		
Jul	32.35	33.81	-4.3		
Aug	**31.32**	30.43	2.9		
Sep	30.62	29.60	3.4		
Oct	28.93	27.44	5.4		
Nov	23.67	22.85	3.6		
Dec	19.71	15.75	25.1		
		25.95			

	(ysi-ym)	(ysi-ym)2
Jan	1.87	3.50
Feb	2.49	6.20
Mar	2.46	6.07
Apr	-0.72	0.51
May	-2.72	7.37
Jun	-0.55	0.30
Jul	-1.46	2.14
Aug	0.89	0.79
Sep	1.02	1.03
Oct	1.49	2.21
Nov	0.82	0.68
Dec	3.96	15.68

∑(ysi-ym)	9.55
∑(ysi-ym)2	46.47
∑(ysi-ym)2/(n-p-1)	4.22
√∑(ysi-ym)2/(n-p-1)	2.06
1/ymean measured	0.04

Monthly energy consumption (measured value) : y_m

Monthly energy consumption (simulated value) : y_{si}

Number of data points : n

Number of predictor variables : p

Table 1.8 d Measure of Goodness of Fit for simulated and measured data : Relative Humidity (RH)

	GMR		Measure of "Godness of Fit"		
	Simulated (°C)	Measured (°C)	% Error	NMBE	CV (RMSE)
Jan	54.26	50.13	8.2	**-0.004**	**18.3**
Feb	56.3	56.06	0.4		
Mar	48.05	39.065	23.0		
Apr	33.89	34.89	-2.9		
May	46.64	27.555	69.3		
Jun	50.46	54.585	-7.6		
Jul	61.57	55.42	11.1		
Aug	65.54	77.99	-16.0		
Sep	57.48	59.205	-2.9		
Oct	48.51	51.105	-5.1		
Nov	44.11	46.055	-4.2		
Dec	46.66	63.62	-26.7		
		51.31			

	(ysi-ym)	(ysi-ym)2
Jan	4.13	17.06
Feb	0.24	0.06
Mar	8.99	80.73
Apr	-1.00	1.00
May	19.09	364.24
Jun	-4.12	17.02
Jul	6.15	37.82
Aug	-12.45	155.00
Sep	-1.73	2.98
Oct	-2.60	6.73
Nov	-1.94	3.78
Dec	-16.96	287.64

∑(ysi-ym)	-2.21
∑(ysi-ym)2	974.06
∑(ysi-ym)2/(n-p-1)	88.55
√∑(ysi-ym)2/(n-p-1)	9.41
1/ymean measured	0.02

	TR		Measure of "Godness of Fit"		
	Simulated (°C)	Measured (°C)	% Error	NMBE	CV (RMSE)
Jan	52.13	59.49	-12.4	**-0.09**	**19.9**
Feb	53.29	57.55	-7.4		
Mar	44.61	43.07	3.6		
Apr	33.13	42.01	-21.1		
May	45.66	28.19	62.0		
Jun	49.62	48.92	1.4		
Jul	60.03	58.07	3.4		
Aug	**63.75**	79.46	-19.8		
Sep	57	58.74	-3.0		
Oct	48.74	53.55	-9.0		
Nov	42.44	55.51	-23.5		
Dec	45.1	64.15	-29.7		
		54.06			

	(ysi-ym)	(ysi-ym)2
Jan	-7.36	54.12
Feb	-4.26	18.18
Mar	1.54	2.38
Apr	-8.88	78.80
May	17.47	305.32
Jun	0.70	0.49
Jul	1.96	3.83
Aug	-15.71	246.80
Sep	-1.74	3.03
Oct	-4.81	23.10
Nov	-13.07	170.91
Dec	-19.05	363.03

∑(ysi-ym)	-53.21
∑(ysi-ym)2	1269.99
∑(ysi-ym)2/(n-p-1)	115.45
√∑(ysi-ym)2/(n-p-1)	10.74
1/ymean measured	0.02

Monthly energy consumption (measured value) : y_m
Monthly energy consumption (simulated value) : y_{si}

Number of data points : n
Number of predictor variables : p

	BMD		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	53.25	49.52	7.5	**-0.08**	**21.7**
Feb	55.13	57.20	-3.6		
Mar	46.06	40.65	13.3		
Apr	36.38	35.70	1.9		
May	43.69	29.14	49.9		
Jun	45.23	45.82	-1.3		
Jul	55.66	56.42	-1.3		
Aug	**59.83**	79.26	-24.5		
Sep	53.44	57.63	-7.3		
Oct	47.69	55.21	-13.6		
Nov	42.71	62.38	-31.5		
Dec	45.58	63.88	-28.6		
		52.73			

	(ysi-ym)	(ysi-ym)2
Jan	3.73	13.95
Feb	-2.07	4.28
Mar	5.41	29.31
Apr	0.68	0.46
May	14.55	211.75
Jun	-0.59	0.35
Jul	-0.76	0.57
Aug	-19.43	377.58
Sep	-4.19	17.56
Oct	-7.52	56.52
Nov	-19.67	386.79
Dec	-18.30	334.78

∑(ysi-ym)	-48.14
∑(ysi-ym)2	1433.90
∑(ysi-ym)2/(n-p-1)	130.35
√∑(ysi-ym)2/(n-p-1)	11.42
1/ymean measured	0.02

	CV		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	59.05	59.59	-0.9	**0.12**	**26.9**
Feb	48.79	57.64	-15.4		
Mar	52.87	35.79	47.7		
Apr	44.12	33.44	32.0		
May	53.6	28.18	90.2		
Jun	58.45	36.47	60.3		
Jul	67	56.18	19.3		
Aug	**75.91**	79.58	-4.6		
Sep	71.35	57.79	23.5		
Oct	56.76	52.99	7.1		
Nov	49.67	60.66	-18.1		
Dec	54.05	62.71	-13.8		
		51.75			

	(ysi-ym)	(ysi-ym)2
Jan	-0.54	0.29
Feb	-8.85	78.36
Mar	17.08	291.74
Apr	10.68	114.13
May	25.42	645.96
Jun	21.98	483.19
Jul	10.82	116.98
Aug	-3.67	13.46
Sep	13.56	183.75
Oct	3.77	14.22
Nov	-10.99	120.85
Dec	-8.66	74.91

∑(ysi-ym)	70.59
∑(ysi-ym)2	2137.84
∑(ysi-ym)2/(n-1)	194.35
√∑(ysi-ym)2/(n-1)	13.94
1/ymean measured	0.02

Monthly energy consumption (measured value) : y_m
Monthly energy consumption (simulated value) : y_{si}

Number of data points : n
Number of predictor variables : p

	HV		Measure of "Godness of Fit"		
	Simulated (°C)	**Measured (°C)**	**% Error**	**NMBE**	**CV (RMSE)**
Jan	53.41	49.16	8.6	**0.03**	**23.3**
Feb	44.98	54.95	-18.1		
Mar	51.67	48.23	7.1		
Apr	44.25	35.49	24.7		
May	52.36	31.03	68.8		
Jun	57.03	45.09	26.5		
Jul	64.97	55.44	17.2		
Aug	**73.8**	80.14	-7.9		
Sep	68.61	57.59	19.1		
Oct	52.1	55.04	-5.3		
Nov	43.95	64.15	-31.5		
Dec	47.35	61.97	-23.6		
		53.19			

	(ysi-ym)	(ysi-ym)2
Jan	4.25	18.03
Feb	-9.97	99.33
Mar	3.44	11.81
Apr	8.76	76.80
May	21.33	455.11
Jun	11.94	142.64
Jul	9.53	90.82
Aug	-6.34	40.20
Sep	11.02	121.51
Oct	-2.94	8.64
Nov	-20.20	407.91
Dec	-14.62	213.84

∑(ysi-ym)	16.21
∑(ysi-ym)2	1686.65
∑(ysi-ym)2/(n-p-1)	153.33
√∑(ysi-ym)2/(n-p-1)	12.38
1/ymean measured	0.02

Monthly energy consumption (measured value) : y_m

Monthly energy consumption (simulated value) : y_{si}

Number of data points : n

Number of predictor variables : p

Table 1.9a Detailed Summary of Estimated Neutral Temperature (all Seasons)

Winters										
S.No.	**F.No.**	**SUBJECT**	**Tgm**	**TSm**	**Stdev Tg**	**Stdev TS**	**correl (r)**	**slope (b)**	**intercept (a)**	**Tn**
1	406B	Neer Jhamra	18.7	-1.5	2.3	0.6	0.8	0.2	-5.2	26.3
2	201 A	Shilpi Sharma	17.6	-2.5	2.5	0.6	0.9	0.2	-6.3	29.3
3	803 C	Surinder Nath	18.9	-1.5	2.1	0.6	0.7	0.2	-5.4	26.1
4	404 C	Malabika Roy	18.6	-2.0	2.1	1.2	0.7	0.4	-9.6	23.5
5	404C	Debaratta Roy	18.6	-1.8	2.1	0.5	0.7	0.2	-5.0	28.5
6	303 C	Meenakshi Mudgal	18.4	-1.0	2.4	0.8	0.4	0.1	-3.3	26.2
7	203 C	Aashi Goyal	18.3	-1.5	2.5	1.3	-0.5	-0.3	3.3	**12.6**
8	204 C	Jayaprakash Dhull	18.5	-1.5	2.4	1.3	-0.5	-0.3	3.4	**12.8**
9	206B	Archana Sethia	17.9	-1.5	2.8	0.6	-0.3	-0.1	-0.5	**-8.3**
10	305 B	Rajnish Dhanda	18.9	-0.8	2.6	1.0	0.3	0.1	-3.2	24.7
11	705 B	Rashi Gupta	19.1	-2.3	2.5	1.0	-0.1	0.0	-1.7	**-59.1**
12	705 B	R.K. Gupta	19.1	-1.3	2.5	0.5	0.8	0.2	-4.2	27.3
13	706 B	Minakshi	18.6	-1.8	2.1	0.5	-0.1	0.0	-1.4	**-79.6**
14	706 B	Rajeev Kumar	18.6	-1.3	2.1	0.5	0.8	0.2	-5.0	24.9
15	705B	Mridul Gupta	19.1	-1.5	2.5	0.6	0.7	0.2	-4.8	27.8
16	903C	Rohit Bhatia	18.9	-1.8	2.2	1.0	0.9	0.4	-9.3	23.3
17	903C	Naina Bhatia	18.9	-1.5	2.2	1.3	0.5	0.3	-6.6	24.5
18	903C	Ritul Bhatia	18.9	-1.8	2.2	1.0	0.9	0.4	-9.3	23.3
19	901A	Vivek Sharma	18.7	-1.8	2.1	1.0	0.6	0.3	-6.6	25.4
20	901A	Shaily Sharma	18.7	-1.8	2.1	1.0	0.9	0.4	-9.5	22.9
21	438	Bharat Bhushan	18.5	-0.8	1.9	1.0	0.8	0.4	-8.6	20.3
22	413	Rekha Bora	18.2	-2.3	2.5	1.0	0.6	0.2	-6.5	27.8
23	454	Shabnam Thakur	18.4	-1.3	2.5	1.0	-0.3	-0.1	1.0	**8.2**
24	448	Orana Das	18.3	-1.0	2.1	0.8	0.3	0.1	-2.9	28.1
25	412	Geeta Sharma	18.0	-2.5	2.5	0.6	0.9	0.2	-6.5	29.3
26	406	Surinder Gupta	17.7	-1.5	2.5	0.6	1.0	0.2	-5.5	24.3
27	470	Aashima	17.9	-1.3	2.0	1.3	0.3	0.2	-4.4	25.1
28	410	Monica	17.8	-1.5	2.4	1.0	0.6	0.3	-6.0	23.6
29	431	Ritu	17.9	-1.5	2.3	0.6	-0.2	-0.1	-0.6	**-11.2**
30	426	Poonam Sharma	18.2	-2.3	2.4	1.0	1.0	0.4	-9.5	23.8
31	461	Lalit Katoch	17.8	-1.5	2.2	0.6	1.0	0.2	-5.9	23.8
32	461	Preet Katoch	17.8	-1.3	2.2	0.5	0.6	0.1	-3.6	27.4
33	444	Rimjhim Bhatt	18.0	-1.8	2.3	1.0	0.9	0.4	-8.1	22.9
34	444	Anmol Bhatt	18.0	-1.3	2.3	0.5	0.6	0.1	-3.4	28.4
35	444	Vipul Bhatt	18.0	-1.5	2.3	0.6	0.9	0.2	-5.7	24.4
36	103 A	Tej Kumar	18.6	-0.8	2.7	1.0	0.6	0.2	-5.0	21.9
37	301 A	Deepshikha	18.7	-2.0	3.0	1.2	0.8	0.3	-7.7	25.3
38	802 A	Sunita	19.4	-1.3	3.0	0.5	0.7	0.1	-3.4	30.5
39	501 A	Shalu Luthra	18.7	-1.8	3.2	1.0	0.7	0.2	-5.9	26.5
40	503 A	Kavita Aggarwal	18.9	-1.3	3.1	0.5	0.6	0.1	-3.0	32.1
41	502 A	Anju Sharma	18.3	-2.3	4.0	1.0	0.6	0.1	-4.8	34.5
42	302 A	Renu Vashisht	18.2	-1.5	3.9	1.3	0.9	0.3	-7.1	23.0
43	203 A	Ritu Vyas	18.7	-1.3	2.8	0.5	0.6	0.1	-3.3	29.8
44	801	Jagandeep Kohli	19.3	-1.5	2.9	1.0	0.7	0.2	-6.2	25.4
45	801	Navneet Kohli	19.3	-1.8	2.9	1.0	0.8	0.3	-7.0	25.7
46	701	Reema Mahajan	18.8	-2.0	3.1	0.8	0.8	0.2	-6.0	28.3
47	701	Joy Mahajan	18.8	-1.8	3.1	1.0	0.8	0.2	-6.4	25.9
48	702	Manohar Kashyap	18.7	-1.3	3.6	1.3	0.8	0.3	-6.2	23.3
49	A1	Shashi Pandey	17.6	-1.5	3.3	0.6	0.4	0.1	-2.7	38.8
50	B3	Anuradha	18.0	-1.3	3.0	0.5	0.5	0.1	-2.7	33.6
51	B3	Y K Gupta	18.0	-1.5	3.0	0.6	0.8	0.2	-4.3	27.7
52	A6	Premlata Thakur	18.6	-2.3	3.0	1.0	0.7	0.2	-6.6	28.1
53	A13	Rekha Singh	18.8	-1.5	3.1	1.0	0.5	0.2	-4.7	27.6
54	A13	Sandeep Singh	18.8	-1.8	3.1	1.0	0.7	0.2	-5.9	26.8

55	A13	Saurabh Singh	18.8	-1.5	3.1	1.3	0.9	0.4	-8.8	22.7
56	B14	Balram	18.7	-1.5	3.2	0.6	0.5	0.1	-3.1	36.4
57	B14	Kalyani Singh	18.7	-2.8	3.2	0.5	0.9	0.1	-5.5	37.2
58	A11	Vir Singh	18.9	-1.0	3.0	0.8	0.1	0.0	-1.6	**51.3**
59	A11	Nitu Singh	18.9	-1.8	3.0	0.5	-0.4	-0.1	-0.6	**-11.0**
60	A12	Pallavi	18.5	-1.5	3.5	0.6	0.5	0.1	-2.9	**38.2**
61	A12	Shivangi	18.5	-1.3	3.5	1.0	0.1	0.0	-1.5	**96.0**
62	A6	Kiran Bala Wason	18.6	-1.5	2.9	1.0	0.4	0.1	-4.3	28.7
63	B8	Hardeep Kaur	18.6	-2.0	3.2	1.2	0.5	0.2	-5.1	30.6
64	101A	Mahima Aggarwal	18.8	-1.5	3.7	0.6	-0.4	-0.1	-0.4	**-7.3**
65	101A	Vibhu Aggarwal	18.8	-1.8	3.7	1.0	0.8	0.2	-5.4	27.8
66	201A	Surinder Arora	19.2	-1.8	3.6	1.0	0.6	0.2	-5.0	29.5
67	201A	Navneet Arora	19.2	-1.5	3.6	1.0	0.6	0.2	-4.5	28.6
68	402 A	Swapnaja Hote	18.9	-1.8	3.5	1.3	-0.1	0.0	-1.1	30.1
69	501 A	Mudita Pandey	19.5	-1.5	3.4	0.6	0.6	0.1	-3.6	33.2
70	501A	Sunanda Pandey	19.5	-1.8	3.4	1.0	0.8	0.2	-6.0	27.5
71	503 A	Supriya Kaushal	19.4	-1.5	3.2	0.6	0.6	0.1	-3.6	33.4
72	602A	Raj Sharma	19.2	-1.5	3.3	1.3	0.4	0.2	-4.5	28.9
73	602A	Akriti Sharma	19.2	-1.5	3.3	0.6	0.7	0.1	-4.0	30.8
74	403 A	Arshi Rastogi	18.9	-1.0	2.9	0.8	0.2	0.1	-2.2	34.8
75	403A	Sakshi	18.9	-2.3	2.9	1.0	0.2	0.1	-3.6	**50.2**
76	103 A	Anil Kumar	18.8	-1.5	3.6	0.6	0.5	0.1	-3.1	36.7
77	301A	Rashmi Maheshwari	19.3	-1.3	3.6	1.3	0.8	0.3	-7.0	23.5
78	303A	Garima	19.3	-2.0	3.5	1.2	0.5	0.2	-5.3	31.1
79	603A	Tripti Chatterji	19.1	-2.3	3.5	1.0	0.2	0.1	-3.4	**55.0**
80	503A	Partha Kaushal	19.4	-1.5	3.2	0.6	-0.3	-0.1	-0.5	**-8.9**
81	603A	Rajdeep Chatterji	19.1	-2.0	3.5	0.8	1.0	0.2	-6.3	28.0
82	603A	Roma Bannerji	19.1	-1.8	3.5	1.5	0.8	0.3	-8.1	24.4

Tn: Neutral Temperature
r: Correlation Coefficient
R: Regression Coefficient
Tgm: Mean Globe Temperature
TSm: Mean Thermal Sensation

TnG1,TnG2,TnG3,TnG4: Griffith's Neutral Temperature using regression coefficent obtained Madhavi's study (.31) , Griffith's regression coefficent (.25 & .33) and finally the one obtained in this study (.21)

Table 1.9b Detailed Summary of Estimated Neutral Temperature (all Seasons)

Summers

S.No.	F.No.	SUBJECT	Tgm	TSm	Stdev Tg	Stdev TS	correl (r)	slope (b)	intercept (a)	Tn
1	406B	Neer Jhamra	30.6	0.8	5.7	1.7	0.9	0.3	-7.5	27.8
2	201 A	Shilpi Sharma	29.5	0.5	5.6	1.3	0.8	0.2	-5.1	26.8
3	803 C	Surinder Nath	30.6	1.8	5.4	1.5	1.0	0.3	-6.3	24.0
4	404 C	Malabika Roy	30.2	1.0	5.8	1.6	0.9	0.3	-6.8	26.3
5	404C	Debaratta Roy	30.2	1.0	5.8	1.6	0.9	0.3	-6.8	26.3
6	303 C	Meenakshi Mudgal	30.0	1.3	5.9	1.3	0.8	0.2	-4.0	22.8
7	203 C	Aashi Goyal	29.8	1.0	5.9	1.8	0.9	0.3	-7.7	26.4
8	204 C	Jayaprakash Dhull	30.1	1.0	5.9	1.4	0.7	0.2	-4.3	24.3
9	206B	Archana Sethia	30.0	1.0	5.9	1.6	0.9	0.3	-6.7	26.1
10	305 B	Rajnish Dhanda	30.3	0.8	5.5	1.0	0.4	0.1	-1.3	19.1
11	705 B	Rashi Gupta	30.7	1.3	5.6	1.3	0.8	0.2	-4.3	23.8
12	705 B	R.K. Gupta	30.7	1.0	5.6	0.8	0.9	0.1	-3.1	23.1
13	706 B	Minakshi	30.6	1.3	5.4	1.5	0.8	0.2	-5.8	25.2
14	706 B	Rajeev Kumar	30.6	0.8	5.4	1.7	0.9	0.3	-7.7	27.9
15	705B	Mridul Gupta	30.7	0.8	5.6	1.7	0.9	0.3	-7.5	27.9
16	903C	Rohit Bhatia	30.8	1.0	5.5	1.6	0.9	0.3	-7.3	27.1
17	903C	Naina Bhatia	30.8	0.8	5.5	1.7	0.9	0.3	-7.7	28.1
18	903C	Ritul Bhatia	30.8	0.8	5.5	1.0	0.8	0.1	-3.6	25.4
19	901A	Vivek Sharma	30.6	0.5	5.7	1.3	0.9	0.2	-6.1	28.2
20	901A	Shaily Sharma	30.6	0.8	5.7	1.7	0.9	0.3	-7.4	27.7
21	438	Bharat Bhushan	30.6	0.8	5.7	1.3	1.0	0.2	-5.7	27.0
22	413	Rekha Bora	30.0	0.8	6.0	1.7	0.9	0.3	-7.0	27.1
23	454	Shabnam Thakur	30.3	1.0	5.9	1.6	0.9	0.3	-6.9	26.5
24	448	Orana Das	30.4	1.3	6.2	1.3	0.9	0.2	-4.1	23.2
25	412	Geeta Sharma	30.7	1.3	6.4	2.1	0.9	0.3	-7.9	26.5
26	406	Surinder Gupta	30.6	1.3	6.4	1.7	1.0	0.3	-6.8	25.8
27	470	Aashima	30.4	0.8	6.0	1.7	0.9	0.3	-7.0	27.5
28	410	Monica	30.3	1.0	6.2	1.2	0.8	0.2	-3.7	23.8
29	431	Ritu	30.0	1.0	6.1	1.6	0.9	0.3	-6.5	26.0
30	426	Poonam Sharma	30.2	0.8	6.2	1.7	0.9	0.3	-6.9	27.2
31	461	Lalit Katoch	29.8	0.5	5.8	1.3	1.0	0.2	-5.9	27.5
32	461	Preet Katoch	29.8	0.8	5.8	1.7	0.9	0.3	-7.1	27.0
33	444	Rimjhim Bhatt	29.9	0.5	6.2	1.3	1.0	0.2	-5.6	27.5
34	444	Anmol Bhatt	29.9	0.8	6.2	1.0	0.8	0.1	-3.1	24.2
35	444	Vipul Bhatt	29.9	1.0	6.2	1.6	0.9	0.2	-6.4	25.9
36	103 A	Tej Kumar	30.0	0.8	6.0	1.0	0.8	0.1	-3.1	24.2
37	301 A	Deepshikha	30.2	1.0	6.0	1.8	0.9	0.3	-7.6	26.7
38	802 A	Sunita	30.8	1.3	5.7	1.7	1.0	0.3	-8.0	26.6
39	501 A	Shalu Luthra	30.2	1.5	6.2	1.9	1.0	0.3	-7.6	25.2
40	503 A	Kavita Aggarwal	30.1	1.5	6.1	1.3	1.0	0.2	-4.6	22.7
41	502 A	Anju Sharma	30.0	0.5	6.1	1.3	1.0	0.2	-5.6	27.6
42	302 A	Renu Vashisht	30.0	1.0	6.0	1.8	0.9	0.3	-7.7	26.6
43	203 A	Ritu Vyas	30.1	1.0	6.2	1.2	0.8	0.2	-3.6	23.6
44	801	Jagandeep Kohli	30.9	1.0	5.5	1.6	0.9	0.3	-7.6	27.3
45	801	Navneet Kohli	30.9	0.8	5.5	1.5	1.0	0.3	-7.3	28.0
46	701	Reema Mahajan	30.4	0.8	5.9	1.7	0.9	0.3	-7.1	27.5
47	701	Joy Mahajan	30.4	0.8	5.9	1.0	0.8	0.1	-3.2	24.7
48	702	Manohar Kashyap	30.3	0.3	6.1	1.3	0.9	0.2	-5.1	28.8
49	A1	Shashi Pandey	29.2	1.5	5.3	1.7	0.9	0.3	-6.7	23.8
50	B3	Anuradha	29.1	0.8	5.5	1.5	1.0	0.3	-6.9	26.2
51	B3	Y K Gupta	29.1	1.0	5.5	1.4	1.0	0.3	-6.4	25.2
52	A6	Premlata Thakur	29.4	1.3	5.5	1.5	0.8	0.2	-5.0	23.5
53	A13	Rekha Singh	29.2	1.3	5.1	1.0	1.0	0.2	-4.0	22.3
54	A13	Sandeep Singh	29.2	0.8	5.1	1.7	0.7	0.3	-6.6	26.2
55	A13	Saurabh Singh	29.2	1.0	5.1	1.6	0.8	0.3	-6.7	25.4

56	B14	Balram	29.4	1.0	5.3	1.4	1.0	0.3	-6.8	25.6
57	B14	Kalyani Singh	29.4	1.3	5.3	2.4	1.0	0.4	-11.7	26.5
58	A11	Vir Singh	29.3	0.8	5.2	1.0	0.7	0.1	-2.9	23.2
59	A11	Nitu Singh	29.3	1.5	5.2	1.9	1.0	0.4	-8.9	25.0
60	A12	Pallavi	29.4	0.8	5.4	1.0	0.7	0.1	-2.8	23.2
61	A12	Shivangi	29.4	1.8	5.4	1.5	0.9	0.3	-5.8	22.5
62	A6	Kiran Bala Wason	29.4	1.5	5.5	1.7	0.8	0.3	-5.9	23.4
63	B8	Hardeep Kaur	29.9	1.3	5.5	1.7	1.0	0.3	-7.8	25.7
64	101A	Mahima Aggarwal	29.8	1.3	5.7	1.0	1.0	0.2	-3.7	22.2
65	101A	Vibhu Aggarwal	29.8	1.3	5.7	1.7	1.0	0.3	-7.5	25.5
66	201A	Surinder Arora	30.2	0.5	5.4	1.7	0.7	0.2	-6.7	28.1
67	201A	Navneet Arora	30.2	1.0	5.4	0.8	0.9	0.1	-3.1	22.9
68	402 A	Swapnaja Hote	29.9	1.5	5.5	1.3	0.9	0.2	-5.0	23.0
69	501 A	Mudita Pandey	30.4	1.0	5.3	1.4	1.0	0.3	-7.1	26.6
70	501A	Sunanda Pandey	30.4	0.8	5.3	1.5	1.0	0.3	-7.4	27.6
71	503 A	Supriya Kaushal	30.3	1.3	5.2	1.0	1.0	0.2	-4.2	23.4
72	602A	Raj Sharma	30.9	1.5	5.8	1.3	0.9	0.2	-4.9	23.7
73	602A	Akriti Sharma	30.9	0.8	5.8	1.3	0.9	0.2	-5.4	27.2
74	403 A	Arshi Rastogi	30.1	1.5	5.2	1.7	0.8	0.3	-6.7	24.5
75	403A	Sakshi	30.1	1.0	5.2	1.4	1.0	0.3	-7.1	26.4
76	103 A	Anil Kumar	29.6	0.8	5.6	1.5	0.9	0.3	-6.7	26.7
77	301A	Rashmi Maheshwari	30.1	1.3	5.0	1.3	0.8	0.2	-4.7	23.8
78	303A	Garima	30.2	1.3	4.7	1.7	1.0	0.4	-9.5	26.7
79	603A	Tripti Chatterji	31.3	1.8	5.6	1.5	1.0	0.3	-6.4	24.6
80	503A	Partha Kaushal	30.3	0.5	5.2	1.3	0.9	0.2	-6.5	28.1
81	603A	Rajdeep Chatterji	31.3	0.8	5.6	1.7	0.9	0.3	-7.6	28.5
82	603A	Roma Bannerji	31.3	0.8	5.6	1.7	0.9	0.3	-7.6	28.5

Tn: Neutral Temperature
r: Correlation Coefficient
R: Regression Coefficient
Tgm: Mean Globe Temperature
TSm: Mean Thermal Sensation

TnG1,TnG2,TnG3,TnG4: Griffith's Neutral Temperature using regression coefficent obtained Madhavi's study (.31) , Griffith's regression coefficent (.25 & .33) and finally the one obtained in this study (.21)

Table 1.9c Detailed Summary of Estimated Neutral Temperature (all Seasons)

Monsoon										
S.No.	**F.No.**	**SUBJECT**	**Tgm**	**TSm**	**Stdev Tg**	**Stdev TS**	**correl (r)**	**slope (b)**	**intercept (a)**	**Tn**
1	406B	Neer Jhamra	31.1	0.5	2.5	1.3	0.9	0.5	-13.9	30.0
2	201 A	Shilpi Sharma	30.3	0.0	2.4	0.8	0.9	0.3	-9.5	30.3
3	803 C	Surinder Nath	31.4	1.3	2.6	1.0	0.8	0.3	-7.8	27.0
4	404 C	Malabika Roy	31.2	0.5	2.4	2.1	1.0	0.8	-25.0	30.6
5	404C	Debaratta Roy	31.2	0.8	2.4	1.7	1.0	0.7	-20.9	30.1
6	303 C	Meenakshi Mudgal	31.1	1.0	2.2	0.8	0.9	0.3	-8.8	27.9
7	203 C	Aashi Goyal	30.8	0.8	2.2	1.0	0.8	0.4	-10.4	28.7
8	204 C	Jayaprakash Dhull	30.8	0.3	2.3	0.5	1.0	0.2	-6.2	29.6
9	206B	Archana Sethia	30.7	0.5	3.0	0.6	0.8	0.2	-4.1	27.4
10	305 B	Rajnish Dhanda	30.8	0.0	2.7	0.8	0.3	0.1	-2.9	30.8
11	705 B	Rashi Gupta	31.4	0.8	2.2	1.3	0.8	0.5	-13.8	29.8
12	705 B	R.K. Gupta	31.4	0.8	2.2	1.0	1.0	0.4	-12.1	29.6
13	706 B	Minakshi	31.2	0.5	2.3	0.6	0.8	0.2	-5.5	28.6
14	706 B	Rajeev Kumar	31.2	0.8	2.3	1.0	1.0	0.4	-11.6	29.3
15	705B	Mridul Gupta	31.4	0.8	2.2	1.0	1.0	0.4	-12.1	29.6
16	903C	Rohit Bhatia	31.6	1.3	2.5	1.3	1.0	0.5	-13.9	29.0
17	903C	Naina Bhatia	31.6	1.0	2.5	1.8	0.9	0.7	-19.8	30.1
18	903C	Ritul Bhatia	31.6	0.8	2.5	1.5	0.8	0.5	-14.1	30.0
19	901A	Vivek Sharma	31.3	1.0	2.6	0.8	0.9	0.3	-8.2	27.8
20	901A	Shaily Sharma	31.3	1.3	2.6	1.5	0.9	0.5	-15.4	28.9
21	438	Bharat Bhushan	30.6	0.3	3.1	0.5	0.9	0.2	-4.5	29.0
22	413	Rekha Bora	30.8	0.3	2.8	1.3	1.0	0.4	-13.1	30.2
23	454	Shabnam Thakur	31.2	1.0	2.7	0.8	1.0	0.3	-8.0	27.7
24	448	Orana Das	31.6	1.3	2.5	0.5	0.0	0.0	1.5	**186.0**
25	412	Geeta Sharma	31.4	0.5	2.3	1.0	1.0	0.4	-12.8	30.2
26	406	Surinder Gupta	31.4	0.3	2.4	1.3	1.0	0.5	-15.6	30.9
27	470	Aashima	31.3	0.3	2.3	1.0	0.7	0.3	-8.7	30.4
28	410	Monica	30.8	0.8	2.9	1.0	0.9	0.3	-8.6	28.3
29	431	Ritu	30.7	0.3	2.9	1.0	0.8	0.2	-7.3	29.6
30	426	Poonam Sharma	31.1	0.8	2.6	1.0	0.9	0.3	-9.7	28.8
31	461	Lalit Katoch	30.7	0.5	2.8	1.3	0.9	0.4	-12.7	29.6
32	461	Preet Katoch	30.7	0.0	2.8	0.8	0.9	0.3	-8.5	30.7
33	444	Rimjhim Bhatt	31.0	0.0	2.4	0.8	0.9	0.3	-9.6	31.0
34	444	Anmol Bhatt	31.0	0.5	2.4	0.6	0.7	0.2	-4.5	27.8
35	444	Vipul Bhatt	31.0	0.5	2.4	1.0	0.5	0.2	-6.0	28.6
36	103 A	Tej Kumar	30.6	0.3	3.0	0.5	1.0	0.2	-4.5	28.9
37	301 A	Deepshikha	30.7	0.5	2.9	1.3	0.9	0.4	-12.3	29.5
38	802 A	Sunita	30.9	1.5	2.9	1.3	0.9	0.4	-11.2	27.3
39	501 A	Shalu Luthra	30.7	0.5	3.1	1.3	0.9	0.4	-11.6	29.4
40	503 A	Kavita Aggarwal	30.7	1.3	2.9	1.5	0.9	0.5	-13.5	28.1
41	502 A	Anju Sharma	30.2	0.0	3.2	0.8	1.0	0.2	-7.5	30.2
42	302 A	Renu Vashisht	30.7	0.3	2.9	0.5	0.9	0.2	-4.7	29.1
43	203 A	Ritu Vyas	30.5	0.5	3.3	1.3	1.0	0.4	-10.7	29.1
44	801	Jagandeep Kohli	30.9	0.8	2.9	1.0	0.9	0.3	-8.4	28.4
45	801	Navneet Kohli	30.9	1.0	2.9	0.8	1.0	0.3	-7.2	27.2
46	701	Reema Mahajan	30.9	1.3	3.0	1.0	0.8	0.3	-6.7	26.0
47	701	Joy Mahajan	30.9	1.0	3.0	0.8	1.0	0.3	-7.2	27.1
48	702	Manohar Kashyap	30.6	0.8	3.0	0.5	0.7	0.1	-2.7	23.8
49	A1	Shashi Pandey	30.0	0.5	2.7	1.3	1.0	0.5	-13.5	28.9
50	B3	Anuradha	30.1	0.5	2.8	0.6	0.8	0.2	-4.3	27.0
51	B3	Y K Gupta	30.1	0.8	2.8	1.0	0.9	0.3	-8.6	27.7
52	A6	Premlata Thakur	30.0	1.0	2.9	0.8	0.6	0.2	-4.5	24.5
53	A13	Rekha Singh	30.6	0.8	2.6	0.5	0.7	0.1	-3.7	25.4
54	A13	Sandeep Singh	30.6	1.0	2.6	0.8	1.0	0.3	-8.7	27.5
55	A13	Saurabh Singh	30.6	1.0	2.6	0.8	1.0	0.3	-8.7	27.5

56	B14	Balram	30.5	0.8	2.5	0.5	0.2	0.0	-0.5	**11.7**
57	B14	Kalyani Singh	30.5	1.3	2.5	1.0	0.9	0.3	-8.7	26.6
58	A11	Vir Singh	30.6	0.3	2.4	1.0	0.8	0.3	-10.2	29.8
59	A11	Nitu Singh	30.6	0.5	2.4	0.6	0.8	0.2	-5.3	27.9
60	A12	Pallavi	30.3	0.8	2.7	1.0	0.9	0.3	-9.5	28.0
61	A12	Shivangi	30.3	0.0	2.7	0.8	1.0	0.3	-8.9	30.3
62	A6	Kiran Bala Wason	30.1	0.5	2.9	0.6	0.8	0.2	-4.1	26.8
63	B8	Hardeep Kaur	30.5	1.3	2.7	1.3	0.8	0.4	-10.1	27.1
64	101A	Mahima Aggarwal	30.3	0.3	3.0	1.3	1.0	0.4	-12.3	29.6
65	101A	Vibhu Aggarwal	30.3	0.5	3.0	1.3	1.0	0.4	-12.0	29.0
66	201A	Surinder Arora	30.2	0.3	2.8	1.0	0.8	0.3	-7.8	29.2
67	201A	Navneet Arora	30.2	0.3	2.8	0.5	0.9	0.2	-4.8	28.7
68	402 A	Swapnaja Hote	30.5	0.5	2.4	1.3	0.9	0.5	-14.5	29.5
69	501 A	Mudita Pandey	30.6	1.0	2.6	0.8	0.3	0.1	-2.1	20.7
70	501A	Sunanda Pandey	30.6	0.5	2.6	1.3	0.9	0.5	-13.9	29.5
71	503 A	Supriya Kaushal	30.5	0.3	2.7	1.0	0.7	0.3	-7.8	29.5
72	602A	Raj Sharma	30.8	0.5	2.7	1.0	0.9	0.3	-9.9	29.3
73	602A	Akriti Sharma	30.8	0.5	2.7	1.3	1.0	0.5	-13.4	29.7
74	403 A	Arshi Rastogi	30.4	0.8	2.8	1.0	0.9	0.3	-9.2	28.1
75	403A	Sakshi	30.4	0.5	2.8	1.3	0.6	0.3	-7.7	28.5
76	103 A	Anil Kumar	30.5	0.0	2.4	0.8	0.9	0.3	-9.1	30.5
77	301A	Rashmi Maheshwari	30.8	1.0	2.1	0.8	0.1	0.0	0.0	**-1.5**
78	303A	Garima	30.5	0.8	2.5	1.0	1.0	0.4	-10.6	28.5
79	603A	Tripti Chatterji	30.9	1.0	2.7	1.2	0.8	0.3	-9.2	27.9
80	503A	Partha Kaushal	30.5	0.3	2.7	1.0	0.7	0.3	-7.8	29.5
81	603A	Rajdeep Chatterji	30.9	0.8	2.7	1.0	1.0	0.3	-9.7	28.7
82	603A	Roma Bannerji	30.9	1.0	2.7	0.8	0.9	0.3	-7.6	27.3

Tn: Neutral Temperature
r: Correlation Coefficient
R: Regression Coefficient
Tgm: Mean Globe Temperature
TSm: Mean Thermal Sensation

TnG1,TnG2,TnG3,TnG4: Griffith's Neutral Temperature using regression coefficent obtained Madhavi's study (.31) , Griffith's regression coefficent (.25 & .33) and finally the one obtained in this study (.21)

Table 1.10a Detailed Summary of Estimated Griffith's Neutral Temperature (all Seasons)

Winters									
F.No.	**SUBJECT**	**Regression**		**Mean**		**Griffith's Temperature (°C)**			
		Tn	**r**	**Tgm**	**TSm**	**TnG$_1$**	**TnG$_2$**	**TnG$_3$**	**TnG$_4$**
						0.31	**0.25**	**0.33**	**0.21**
406B	Neer Jhamra	26.3	0.8	18.7	-1.5	23.5	24.7	23.2	25.8
201 A	Shilpi Sharma	29.3	0.9	17.6	-2.5	25.7	27.6	25.2	29.5
803 C	Surinder Nath	26.1	0.7	18.9	-1.5	23.8	24.9	23.5	26.1
404 C	Malabika Roy	23.5	0.7	18.6	-2.0	25.0	26.6	24.6	28.1
404C	Debaratta Roy	28.5	0.7	18.6	-1.8	24.2	25.6	23.9	26.9
303 C	Meenakshi Mudgal	26.2	0.4	18.4	-1.0	21.6	22.4	21.4	23.1
203 C	Aashi Goyal	**12.6**	-0.5	18.3	-1.5	**23.1**	**24.3**	**22.8**	**25.4**
204 C	Jayaprakash Dhull	**12.8**	-0.5	18.5	-1.5	**23.3**	**24.5**	**23.0**	**25.6**
206B	Archana Sethia	**-8.3**	-0.3	17.9	-1.5	**22.7**	**23.9**	**22.4**	**25.0**
305 B	Rajnish Dhanda	24.7	0.3	18.9	-0.8	21.3	21.9	21.1	22.4
705 B	Rashi Gupta	**-59.1**	-0.1	19.1	-2.3	**26.3**	**28.1**	**25.9**	**29.8**
705 B	R.K. Gupta	27.3	0.8	19.1	-1.3	23.1	24.1	22.9	25.0
706 B	Minakshi	**-79.6**	-0.1	18.6	-1.8	**24.3**	**25.6**	**23.9**	**27.0**
706 B	Rajeev Kumar	24.9	0.8	18.6	-1.3	22.7	23.6	22.4	24.6
705B	Mridul Gupta	27.8	0.7	19.1	-1.5	23.9	25.1	23.6	26.2
903C	Rohit Bhatia	23.3	0.9	18.9	-1.8	24.6	25.9	24.2	27.3
903C	Naina Bhatia	24.5	0.5	18.9	-1.5	23.8	24.9	23.5	26.1
903C	Ritul Bhatia	23.3	0.9	18.9	-1.8	24.6	25.9	24.2	27.3
901A	Vivek Sharma	25.4	0.6	18.7	-1.8	24.3	25.7	24.0	27.0
901A	Shaily Sharma	22.9	0.9	18.7	-1.8	24.3	25.7	24.0	27.0
438	Bharat Bhushan	20.3	0.8	18.5	-0.8	20.9	21.5	20.8	22.1
413	Rekha Bora	27.8	0.6	18.2	-2.3	25.4	27.2	25.0	28.9
454	Shabnam Thakur	**8.2**	-0.3	18.4	-1.3	**22.4**	**23.4**	**22.2**	**24.3**
448	Orana Das	28.1	0.3	18.3	-1.0	21.6	22.3	21.4	23.1
412	Geeta Sharma	29.3	0.9	18.0	-2.5	26.1	28.0	25.6	29.9
406	Surinder Gupta	24.3	1.0	17.7	-1.5	22.5	23.7	22.2	24.8
470	Aashima	25.1	0.3	17.9	-1.3	21.9	22.9	21.7	23.9
410	Monica	23.6	0.6	17.8	-1.5	22.6	23.8	22.3	24.9
431	Ritu	**-11.2**	-0.2	17.9	-1.5	**22.7**	**23.9**	**22.4**	**25.0**
426	Poonam Sharma	23.8	1.0	18.2	-2.3	25.5	27.2	25.0	28.9
461	Lalit Katoch	23.8	1.0	17.8	-1.5	22.6	23.8	22.3	24.9
461	Preet Katoch	27.4	0.6	17.8	-1.3	21.8	22.8	21.5	23.7
444	Rimjhim Bhatt	22.9	0.9	18.0	-1.8	23.6	25.0	23.3	26.3
444	Anmol Bhatt	28.4	0.6	18.0	-1.3	22.0	23.0	21.7	23.9
444	Vipul Bhatt	24.4	0.9	18.0	-1.5	22.8	24.0	22.5	25.1
103 A	Tej Kumar	21.9	0.6	18.6	-0.8	21.0	21.6	20.9	22.2
301 A	Deepshikha	25.3	0.8	18.7	-2.0	25.2	26.7	24.8	28.2
802 A	Sunita	30.5	0.7	19.4	-1.3	23.4	24.4	23.2	25.3
501 A	Shalu Luthra	26.5	0.7	18.7	-1.8	24.3	25.7	24.0	27.0
503 A	Kavita Aggarwal	32.1	0.6	18.9	-1.3	22.9	23.9	22.6	24.8
502 A	Anju Sharma	34.5	0.6	18.3	-2.3	25.5	27.3	25.1	29.0
302 A	Renu Vashisht	23.0	0.9	18.2	-1.5	23.0	24.2	22.7	25.3
203 A	Ritu Vyas	29.8	0.6	18.7	-1.3	22.7	23.7	22.4	24.6
801	Jagandeep Kohli	25.4	0.7	19.3	-1.5	24.1	25.3	23.8	26.4
801	Navneet Kohli	25.7	0.8	19.3	-1.8	24.9	26.3	24.6	27.6
701	Reema Mahajan	28.3	0.8	18.8	-2.0	25.3	26.8	24.9	28.3
701	Joy Mahajan	25.9	0.8	18.8	-1.8	24.4	25.8	24.1	27.1
702	Manohar Kashyap	23.3	0.8	18.7	-1.3	22.7	23.7	22.4	24.6
A1	Shashi Pandey	38.8	0.4	17.6	-1.5	22.4	23.6	22.1	24.7
B3	Anuradha	33.6	0.5	18.0	-1.3	22.0	23.0	21.8	24.0
B3	Y K Gupta	27.7	0.8	18.0	-1.5	22.9	24.0	22.6	25.2
A6	Premlata Thakur	28.1	0.7	18.6	-2.3	25.8	27.6	25.4	29.3
A13	Rekha Singh	27.6	0.5	18.8	-1.5	23.7	24.8	23.4	26.0

A13	Sandeep Singh	26.8	0.7	18.8	-1.8	24.5	25.8	24.1	27.1
A13	Saurabh Singh	22.7	0.9	18.8	-1.5	23.7	24.8	23.4	26.0
B14	Balram	36.4	0.5	18.7	-1.5	23.5	24.7	23.2	25.8
B14	Kalyani Singh	37.2	0.9	18.7	-2.8	27.5	29.7	27.0	31.8
A11	Vir Singh	**51.3**	0.1	18.9	-1.0	**22.1**	**22.9**	**21.9**	**23.6**
A11	Nitu Singh	**-11.0**	-0.4	18.9	-1.8	**24.5**	**25.9**	**24.2**	**27.2**
A12	Pallavi	**38.2**	0.5	18.5	-1.5	**23.4**	**24.5**	**23.1**	**25.7**
A12	Shivangi	**96.0**	0.1	18.5	-1.3	**22.6**	**23.5**	**22.3**	**24.5**
A6	Kiran Bala Wason	28.7	0.4	18.6	-1.5	23.5	24.6	23.2	25.8
B8	Hardeep Kaur	30.6	0.5	18.6	-2.0	25.0	26.6	24.6	28.1
101A	Mahima Aggarwal	**-7.3**	-0.4	18.8	-1.5	**23.7**	**24.8**	**23.4**	**26.0**
101A	Vibhu Aggarwal	27.8	0.8	18.8	-1.8	24.5	25.8	24.1	27.2
201A	Surinder Arora	29.5	0.6	19.2	-1.8	24.8	26.2	24.5	27.5
201A	Navneet Arora	28.6	0.6	19.2	-1.5	24.0	25.2	23.7	26.3
402 A	Swapnaja Hote	30.1	-0.1	18.9	-1.8	24.5	25.9	24.2	27.2
501 A	Mudita Pandey	33.2	0.6	19.5	-1.5	24.3	25.5	24.0	26.6
501A	Sunanda Pandey	27.5	0.8	19.5	-1.8	25.1	26.5	24.8	27.8
503 A	Supriya Kaushal	33.4	0.6	19.4	-1.5	24.3	25.4	24.0	26.6
602A	Raj Sharma	28.9	0.4	19.2	-1.5	24.0	25.2	23.7	26.3
602A	Akriti Sharma	30.8	0.7	19.2	-1.5	24.0	25.2	23.7	26.3
403 A	Arshi Rastogi	34.8	0.2	18.9	-1.0	22.2	22.9	22.0	23.7
403A	Sakshi	**50.2**	0.2	18.9	-2.3	**26.2**	**27.9**	**25.7**	**29.6**
103 A	Anil Kumar	36.7	0.5	18.8	-1.5	23.7	24.8	23.4	26.0
301A	Rashmi Maheshwari	23.5	0.8	19.3	-1.3	23.3	24.3	23.1	25.3
303A	Garima	31.1	0.5	19.3	-2.0	25.7	27.3	25.3	28.8
603A	Tripti Chatterji	**55.0**	0.2	19.1	-2.3	**26.4**	**28.1**	**25.9**	**29.8**
503A	Partha Kaushal	**-8.9**	-0.3	19.4	-1.5	**24.3**	**25.4**	**24.0**	**26.6**
603A	Rajdeep Chatterji	28.0	1.0	19.1	-2.0	25.6	27.1	25.2	28.6
603A	Roma Bannerji	24.4	0.8	19.1	-1.8	24.7	26.1	24.4	27.4

TnG= Tgm +(0- TSm)/R

TnG: Griffith's Neutral Temperature, Tgm : mean globe temperature, TSm : mean thermal sensation vote & R : Griffith's coefficient

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Tn: Neutral Temperature
r: Correlation Coefficient
R: Regression Coefficient
Tgm: Mean Globe Temperature
TSm: Mean Thermal Sensation

TnG1,TnG2,TnG3,TnG4: Griffith's Neutral Temperature using regression coefficent obtained Madhavi's study (.31) , Griffith's regression coefficent (.25 & .33) and finally the one obtained in this study (.21)

Table 1.10b Detailed Summary of Estimated Griffith's Neutral Temperature (all Seasons)

Summer									
F.No.	SUBJECT	Regression		Mean		Griffith's Temperature (°C)			
		Tn	r	Tgm	TSm	TnG1	TnG2	TnG3	TnG4
						0.31	0.25	0.33	0.21
406B	Neer Jhamra	27.8	0.9	30.6	0.8	28.1	27.6	28.3	27.0
201 A	Shilpi Sharma	26.8	0.8	29.5	0.5	27.9	27.5	28.0	27.1
803 C	Surinder Nath	24.0	1.0	30.6	1.8	25.0	23.6	25.3	22.3
404 C	Malabika Roy	26.3	0.9	30.2	1.0	27.0	26.2	27.2	25.4
404C	Debaratta Roy	26.3	0.9	30.2	1.0	27.0	26.2	27.2	25.4
303 C	Meenakshi Mudgal	22.8	0.8	30.0	1.3	25.9	25.0	26.2	24.0
203 C	Aashi Goyal	26.4	0.9	29.8	1.0	26.6	25.8	26.8	25.0
204 C	Jayaprakash Dhull	24.3	0.7	30.1	1.0	26.8	26.1	27.0	25.3
206B	Archana Sethia	26.1	0.9	30.0	1.0	26.8	26.0	27.0	25.2
305 B	Rajnish Dhanda	19.1	0.4	30.3	0.8	27.8	27.3	28.0	26.7
705 B	Rashi Gupta	23.8	0.8	30.7	1.3	26.6	25.7	26.9	24.7
705 B	R.K. Gupta	23.1	0.9	30.7	1.0	27.4	26.7	27.6	25.9
706 B	Minakshi	25.2	0.8	30.6	1.3	26.5	25.6	26.8	24.6
706 B	Rajeev Kumar	27.9	0.9	30.6	0.8	28.2	27.6	28.3	27.0
705B	Mridul Gupta	27.9	0.9	30.7	0.8	28.2	27.7	28.4	27.1
903C	Rohit Bhatia	27.1	0.9	30.8	1.0	27.5	26.8	27.7	26.0
903C	Naina Bhatia	28.1	0.9	30.8	0.8	28.4	27.8	28.5	27.2
903C	Ritul Bhatia	25.4	0.8	30.8	0.8	28.4	27.8	28.5	27.2
901A	Vivek Sharma	28.2	0.9	30.6	0.5	28.9	28.6	29.0	28.2
901A	Shaily Sharma	27.7	0.9	30.6	0.8	28.1	27.6	28.3	27.0
438	Bharat Bhushan	27.0	1.0	30.6	0.8	28.2	27.6	28.4	27.1
413	Rekha Bora	27.1	0.9	30.0	0.8	27.6	27.0	27.8	26.5
454	Shabnam Thakur	26.5	0.9	30.3	1.0	27.1	26.3	27.3	25.5
448	Orana Das	23.2	0.9	30.4	1.3	26.3	25.4	26.6	24.4
412	Geeta Sharma	26.5	0.9	30.7	1.3	26.6	25.7	26.9	24.7
406	Surinder Gupta	25.8	1.0	30.6	1.3	26.5	25.6	26.8	24.6
470	Aashima	27.5	0.9	30.4	0.8	28.0	27.4	28.2	26.9
410	Monica	23.8	0.8	30.3	1.0	27.0	26.3	27.2	25.5
431	Ritu	26.0	0.9	30.0	1.0	26.8	26.0	27.0	25.3
426	Poonam Sharma	27.2	0.9	30.2	0.8	27.7	27.2	27.9	26.6
461	Lalit Katoch	27.5	1.0	29.8	0.5	28.2	27.8	28.3	27.4
461	Preet Katoch	27.0	0.9	29.8	0.8	27.4	26.8	27.6	26.3
444	Rimjhim Bhatt	27.5	1.0	29.9	0.5	28.3	27.9	28.4	27.5
444	Anmol Bhatt	24.2	0.8	29.9	0.8	27.5	26.9	27.7	26.4
444	Vipul Bhatt	25.9	0.9	29.9	1.0	26.7	25.9	26.9	25.2
103 A	Tej Kumar	24.2	0.8	30.0	0.8	27.6	27.0	27.7	26.4
301 A	Deepshikha	26.7	0.9	30.2	1.0	26.9	26.2	27.1	25.4
802 A	Sunita	26.6	1.0	30.8	1.3	26.8	25.8	27.0	24.9
501 A	Shalu Luthra	25.2	1.0	30.2	1.5	25.4	24.2	25.7	23.1
503 A	Kavita Aggarwal	22.7	1.0	30.1	1.5	25.3	24.1	25.6	23.0
502 A	Anju Sharma	27.6	1.0	30.0	0.5	28.4	28.0	28.5	27.6
302 A	Renu Vashisht	26.6	0.9	30.0	1.0	26.8	26.0	27.0	25.3
203 A	Ritu Vyas	23.6	0.8	30.1	1.0	26.9	26.1	27.1	25.3
801	Jagandeep Kohli	27.3	0.9	30.9	1.0	27.6	26.9	27.8	26.1
801	Navneet Kohli	28.0	1.0	30.9	0.8	28.5	27.9	28.6	27.3
701	Reema Mahajan	27.5	0.9	30.4	0.8	28.0	27.4	28.1	26.8
701	Joy Mahajan	24.7	0.8	30.4	0.8	28.0	27.4	28.1	26.8
702	Manohar Kashyap	28.8	0.9	30.3	0.3	29.4	29.3	29.5	29.1
A1	Shashi Pandey	23.8	0.9	29.2	1.5	24.3	23.2	24.6	22.0
B3	Anuradha	26.2	1.0	29.1	0.8	26.7	26.1	26.8	25.5
B3	Y K Gupta	25.2	1.0	29.1	1.0	25.8	25.1	26.0	24.3
A6	Premlata Thakur	23.5	0.8	29.4	1.3	25.4	24.4	25.6	23.5
A13	Rekha Singh	22.3	1.0	29.2	1.3	25.2	24.2	25.4	23.3
A13	Sandeep Singh	26.2	0.7	29.2	0.8	26.8	26.2	27.0	25.7

A13	Saurabh Singh	25.4	0.8	29.2	1.0	26.0	25.2	26.2	24.5
B14	Balram	25.6	1.0	29.4	1.0	26.1	25.4	26.3	24.6
B14	Kalyani Singh	26.5	1.0	29.4	1.3	25.3	24.4	25.6	23.4
A11	Vir Singh	23.2	0.7	29.3	0.8	26.8	26.3	27.0	25.7
A11	Nitu Singh	25.0	1.0	29.3	1.5	24.4	23.3	24.7	22.1
A12	Pallavi	23.2	0.7	29.4	0.8	26.9	26.4	27.1	25.8
A12	Shivangi	22.5	0.9	29.4	1.8	23.7	22.4	24.0	21.0
A6	Kiran Bala Wason	23.4	0.8	29.4	1.5	24.6	23.4	24.9	22.3
B8	Hardeep Kaur	25.7	1.0	29.9	1.3	25.8	24.9	26.1	23.9
101A	Mahima Aggarwal	22.2	1.0	29.8	1.3	25.7	24.8	26.0	23.8
101A	Vibhu Aggarwal	25.5	1.0	29.8	1.3	25.7	24.8	26.0	23.8
201A	Surinder Arora	28.1	0.7	30.2	0.5	28.6	28.2	28.7	27.8
201A	Navneet Arora	22.9	0.9	30.2	1.0	27.0	26.2	27.2	25.4
402 A	Swapnaja Hote	23.0	0.9	29.9	1.5	25.0	23.9	25.3	22.7
501 A	Mudita Pandey	26.6	1.0	30.4	1.0	27.2	26.4	27.4	25.6
501A	Sunanda Pandey	27.6	1.0	30.4	0.8	28.0	27.4	28.1	26.8
503 A	Supriya Kaushal	23.4	1.0	30.3	1.3	26.3	25.3	26.5	24.3
602A	Raj Sharma	23.7	0.9	30.9	1.5	26.1	24.9	26.4	23.8
602A	Akriti Sharma	27.2	0.9	30.9	0.8	28.5	27.9	28.7	27.4
403 A	Arshi Rastogi	24.5	0.8	30.1	1.5	25.2	24.1	25.5	22.9
403A	Sakshi	26.4	1.0	30.1	1.0	26.8	26.1	27.0	25.3
103 A	Anil Kumar	26.7	0.9	29.6	0.8	27.2	26.6	27.4	26.1
301A	Rashmi Maheshwari	23.8	0.8	30.1	1.3	26.0	25.1	26.3	24.1
303A	Garima	26.7	1.0	30.2	1.3	26.2	25.2	26.4	24.3
603A	Tripti Chatterji	24.6	1.0	31.3	1.8	25.7	24.3	26.0	23.0
503A	Partha Kaushal	28.1	0.9	30.3	0.5	28.7	28.3	28.8	27.9
603A	Rajdeep Chatterji	28.5	0.9	31.3	0.8	28.9	28.3	29.1	27.8
603A	Roma Bannerji	28.5	0.9	31.3	0.8	28.9	28.3	29.1	27.8

TnG= Tgm +(0- TSm)/R

TnG: Griffith's Neutral Temperature, Tgm : mean globe temperature, TSm : mean thermal sensation vote & R : Griffith's coefficient

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Tn: Neutral Temperature
r: Correlation Coefficient
R: Regression Coefficient
Tgm: Mean Globe Temperature
TSm: Mean Thermal Sensation

TnG1,TnG2,TnG3,TnG4: Griffith's Neutral Temperature using regression coefficent obtained Madhavi's study (.31) , Griffith's regression coefficent (.25 & .33) and finally the one obtained in this study (.21)

Table 1.10c Detailed Summary of Estimated Griffith's Neutral Temperature (all Seasons)

Monsoon									
F.No.	SUBJECT	Regression		Mean		Griffith's Temperature (°C)			
		Tn	r	Tgm	TSm	TnG1	TnG2	TnG3	TnG4
						0.31	**0.25**	**0.33**	**0.21**
406B	Neer Jhamra	30.0	0.9	31.1	0.5	29.5	29.1	29.6	28.7
201 A	Shilpi Sharma	30.3	0.9	30.3	0.0	30.3	30.3	30.3	30.3
803 C	Surinder Nath	27.0	0.8	31.4	1.3	27.3	26.4	27.6	25.4
404 C	Malabika Roy	30.6	1.0	31.2	0.5	29.6	29.2	29.7	28.8
404C	Debaratta Roy	30.1	1.0	31.2	0.8	28.8	28.2	28.9	27.6
303 C	Meenakshi Mudgal	27.9	0.9	31.1	1.0	27.9	27.1	28.1	26.3
203 C	Aashi Goyal	28.7	0.8	30.8	0.8	28.3	27.8	28.5	27.2
204 C	Jayaprakash Dhull	29.6	1.0	30.8	0.3	30.0	29.8	30.0	29.6
206B	Archana Sethia	27.4	0.8	30.7	0.5	29.1	28.7	29.2	28.3
305 B	Rajnish Dhanda	30.8	0.3	30.8	0.0	30.8	30.8	30.8	30.8
705 B	Rashi Gupta	29.8	0.8	31.4	0.8	29.0	28.4	29.1	27.8
705 B	R.K. Gupta	29.6	1.0	31.4	0.8	29.0	28.4	29.1	27.8
706 B	Minakshi	28.6	0.8	31.2	0.5	29.6	29.2	29.7	28.8
706 B	Rajeev Kumar	29.3	1.0	31.2	0.8	28.8	28.2	28.9	27.6
705B	Mridul Gupta	29.6	1.0	31.4	0.8	29.0	28.4	29.1	27.8
903C	Rohit Bhatia	29.0	1.0	31.6	1.3	27.6	26.6	27.8	25.6
903C	Naina Bhatia	30.1	0.9	31.6	1.0	28.4	27.6	28.6	26.8
903C	Ritul Bhatia	30.0	0.8	31.6	0.8	29.2	28.6	29.3	28.0
901A	Vivek Sharma	27.8	0.9	31.3	1.0	28.0	27.3	28.2	26.5
901A	Shaily Sharma	28.9	0.9	31.3	1.3	27.2	26.3	27.5	25.3
438	Bharat Bhushan	29.0	0.9	30.6	0.3	29.8	29.6	29.9	29.4
413	Rekha Bora	30.2	1.0	30.8	0.3	29.9	29.8	30.0	29.6
454	Shabnam Thakur	27.7	1.0	31.2	1.0	27.9	27.2	28.1	26.4
448	Orana Das	**186.0**	0.0	31.6	1.3	**27.5**	**26.6**	**27.8**	**25.6**
412	Geeta Sharma	30.2	1.0	31.4	0.5	29.8	29.4	29.9	29.0
406	Surinder Gupta	30.9	1.0	31.4	0.3	30.6	30.4	30.6	30.2
470	Aashima	30.4	0.7	31.3	0.3	30.5	30.3	30.5	30.1
410	Monica	28.3	0.9	30.8	0.8	28.3	27.8	28.5	27.2
431	Ritu	29.6	0.8	30.7	0.3	29.8	29.7	29.9	29.5
426	Poonam Sharma	28.8	0.9	31.1	0.8	28.7	28.1	28.8	27.5
461	Lalit Katoch	29.6	0.9	30.7	0.5	29.1	28.7	29.2	28.3
461	Preet Katoch	30.7	0.9	30.7	0.0	30.7	30.7	30.7	30.7
444	Rimjhim Bhatt	31.0	0.9	31.0	0.0	31.0	31.0	31.0	31.0
444	Anmol Bhatt	27.8	0.7	31.0	0.5	29.3	29.0	29.4	28.6
444	Vipul Bhatt	28.6	0.5	31.0	0.5	29.3	29.0	29.4	28.6
103 A	Tej Kumar	28.9	1.0	30.6	0.3	29.7	29.6	29.8	29.4
301 A	Deepshikha	29.5	0.9	30.7	0.5	29.1	28.7	29.2	28.3
802 A	Sunita	27.3	0.9	30.9	1.5	26.1	24.9	26.4	23.8
501 A	Shalu Luthra	29.4	0.9	30.7	0.5	29.0	28.7	29.1	28.3
503 A	Kavita Aggarwal	28.1	0.9	30.7	1.3	26.7	25.7	26.9	24.8
502 A	Anju Sharma	30.2	1.0	30.2	0.0	30.2	30.2	30.2	30.2
302 A	Renu Vashisht	29.1	0.9	30.7	0.3	29.9	29.7	29.9	29.5
203 A	Ritu Vyas	29.1	1.0	30.5	0.5	28.8	28.5	28.9	28.1
801	Jagandeep Kohli	28.4	0.9	30.9	0.8	28.5	27.9	28.7	27.4
801	Navneet Kohli	27.2	1.0	30.9	1.0	27.7	26.9	27.9	26.2
701	Reema Mahajan	26.0	0.8	30.9	1.3	26.9	25.9	27.1	24.9
701	Joy Mahajan	27.1	1.0	30.9	1.0	27.7	26.9	27.9	26.1
702	Manohar Kashyap	23.8	0.7	30.6	0.8	28.2	27.6	28.3	27.0
A1	Shashi Pandey	28.9	1.0	30.0	0.5	28.4	28.0	28.5	27.6
B3	Anuradha	27.0	0.8	30.1	0.5	28.5	28.1	28.6	27.7
B3	Y K Gupta	27.7	0.9	30.1	0.8	27.7	27.1	27.9	26.6
A6	Premlata Thakur	24.5	0.6	30.0	1.0	26.8	26.0	27.0	25.2
A13	Rekha Singh	25.4	0.7	30.6	0.8	28.2	27.6	28.4	27.1
A13	Sandeep Singh	27.5	1.0	30.6	1.0	27.4	26.6	27.6	25.9

A13	Saurabh Singh	27.5	1.0	30.6	1.0	27.4	26.6	27.6	25.9
B14	Balram	**11.7**	0.2	30.5	0.8	**28.1**	**27.5**	**28.2**	**26.9**
B14	Kalyani Singh	26.6	0.9	30.5	1.3	26.4	25.5	26.7	24.5
A11	Vir Singh	29.8	0.8	30.6	0.3	29.7	29.6	29.8	29.4
A11	Nitu Singh	27.9	0.8	30.6	0.5	28.9	28.6	29.0	28.2
A12	Pallavi	28.0	0.9	30.3	0.8	27.8	27.3	28.0	26.7
A12	Shivangi	30.3	1.0	30.3	0.0	30.3	30.3	30.3	30.3
A6	Kiran Bala Wason	26.8	0.8	30.1	0.5	28.4	28.1	28.5	27.7
B8	Hardeep Kaur	27.1	0.8	30.5	1.3	26.4	25.5	26.7	24.5
101A	Mahima Aggarwal	29.6	1.0	30.3	0.3	29.4	29.3	29.5	29.1
101A	Vibhu Aggarwal	29.0	1.0	30.3	0.5	28.6	28.3	28.7	27.9
201A	Surinder Arora	29.2	0.8	30.2	0.3	29.3	29.2	29.4	29.0
201A	Navneet Arora	28.7	0.9	30.2	0.3	29.3	29.2	29.4	29.0
402 A	Swapnaja Hote	29.5	0.9	30.5	0.5	28.9	28.5	29.0	28.1
501 A	Mudita Pandey	20.7	0.3	30.6	1.0	27.3	26.6	27.5	25.8
501A	Sunanda Pandey	29.5	0.9	30.6	0.5	28.9	28.6	29.0	28.2
503 A	Supriya Kaushal	29.5	0.7	30.5	0.3	29.7	29.5	29.7	29.3
602A	Raj Sharma	29.3	0.9	30.8	0.5	29.2	28.8	29.3	28.4
602A	Akriti Sharma	29.7	1.0	30.8	0.5	29.2	28.8	29.3	28.4
403 A	Arshi Rastogi	28.1	0.9	30.4	0.8	28.0	27.4	28.1	26.8
403A	Sakshi	28.5	0.6	30.4	0.5	28.8	28.4	28.9	28.0
103 A	Anil Kumar	30.5	0.9	30.5	0.0	30.5	30.5	30.5	30.5
301A	Rashmi Maheshwari	**-1.5**	0.1	30.8	1.0	**27.6**	**26.8**	**27.8**	**26.1**
303A	Garima	28.5	1.0	30.5	0.8	28.1	27.5	28.3	27.0
603A	Tripti Chatterji	27.9	0.8	30.9	1.0	27.7	26.9	27.9	26.2
503A	Partha Kaushal	29.5	0.7	30.5	0.3	29.7	29.5	29.7	29.3
603A	Rajdeep Chatterji	28.7	1.0	30.9	0.8	28.5	27.9	28.7	27.4
603A	Roma Bannerji	27.3	0.9	30.9	1.0	27.7	26.9	27.9	26.2

TnG= Tgm +(0- TSm)/R

TnG: Griffith's Neutral Temperature, Tgm : mean globe temperature, TSm : mean thermal sensation vote & R : Griffith's coefficient

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Tn: Neutral Temperature
r: Correlation Coefficient
R: Regression Coefficient
Tgm: Mean Globe Temperature
TSm: Mean Thermal Sensation

TnG1,TnG2,TnG3,TnG4: Griffith's Neutral Temperature using regression coefficent obtained Madhavi's study (.31) , Griffith's regression coefficent (.25 & .33) and finally the one obtained in this study (.21)

Table 1.10d Regression Analysis for Neutral Temperature of Subjects (All Data)

S.No.	F.No.	SUBJECT	Regression		Mean		Griffith's			
			Tn	r	Tgm	TSm	TnG$_1$	TnG$_2$	TnG$_3$	TnG$_4$
							0.31	0.25	0.33	0.21
1	406B	Neer Jhamra	28.6	0.9	26.8	-0.1	27.1	27.1	27.0	27.2
2	201 A	Shilpi Sharma	39.7	0.9	25.8	-0.7	27.9	28.5	27.8	29.0
3	803 C	Surinder Nath	17.7	1.0	27.0	0.5	25.3	25.0	25.4	24.6
4	404 C	Malabika Roy	29.3	0.9	26.6	-0.2	27.2	27.3	27.1	27.4
5	404C	Debaratta Roy	26.6	0.9	26.6	0.0	26.6	26.6	26.6	26.6
6	303 C	Meenakshi Mudgal	16.8	0.9	26.5	0.4	25.1	24.8	25.2	24.5
7	203 C	Aashi Goyal	25.6	0.8	26.3	0.1	26.0	26.0	26.0	25.9
8	204 C	Jayaprakash Dhull	25.6	0.7	26.4	-0.1	26.7	26.8	26.7	26.8
9	206B	Archana Sethia	26.3	0.9	26.2	0.0	26.2	26.2	26.2	26.2
10	305 B	Rajnish Dhanda	28.7	0.6	26.6	0.0	26.6	26.6	26.6	26.6
11	705 B	Rashi Gupta	27.8	0.9	27.0	-0.1	27.3	27.4	27.3	27.4
12	705 B	R.K. Gupta	22.0	0.9	27.0	0.2	26.5	26.4	26.5	26.2
13	706 B	Minakshi	25.8	0.9	26.8	0.0	26.8	26.8	26.8	26.8
14	706 B	Rajeev Kumar	27.0	0.9	26.8	0.1	26.5	26.5	26.5	26.4
15	705B	Mridul Gupta	25.4	0.9	27.0	0.0	27.0	27.0	27.0	27.0
16	903C	Rohit Bhatia	22.2	1.0	27.1	0.2	26.6	26.4	26.6	26.3
17	903C	Naina Bhatia	24.0	0.8	27.1	0.1	26.8	26.8	26.8	26.7
18	903C	Ritul Bhatia	28.0	0.9	27.1	-0.1	27.4	27.4	27.4	27.5
19	901A	Vivek Sharma	26.8	0.9	26.8	-0.1	27.1	27.2	27.1	27.2
20	901A	Shaily Sharma	23.7	0.9	26.8	0.1	26.6	26.5	26.6	26.4
21	438	Bharat Bhushan	26.0	0.8	26.6	0.1	26.3	26.3	26.3	26.2
22	413	Rekha Bora	36.6	0.9	26.3	-0.4	27.7	28.0	27.6	28.3
23	454	Shabnam Thakur	19.0	0.9	26.6	0.3	25.8	25.6	25.9	25.4
24	448	Orana Das	14.0	0.9	26.8	0.5	25.1	24.8	25.2	24.4
25	412	Geeta Sharma	30.0	1.0	26.7	-0.3	27.5	27.7	27.5	27.9
26	406	Surinder Gupta	24.0	0.9	26.6	0.0	26.6	26.6	26.6	26.6
27	470	Aashima	30.5	0.8	26.5	-0.1	26.8	26.9	26.8	26.9
28	410	Monica	25.8	0.9	26.3	0.1	26.0	25.9	26.0	25.9
29	431	Ritu	30.5	0.9	26.2	-0.1	26.5	26.5	26.4	26.6
30	426	Poonam Sharma	33.6	1.0	26.5	-0.3	27.3	27.5	27.2	27.7
31	461	Lalit Katoch	30.8	0.9	26.1	-0.2	26.6	26.8	26.6	26.9
32	461	Preet Katoch	29.5	0.8	26.1	-0.2	26.6	26.8	26.6	26.9
33	444	Rimjhim Bhatt	36.5	0.9	26.3	-0.4	27.6	27.9	27.5	28.3
34	444	Anmol Bhatt	28.7	0.9	26.3	0.0	26.3	26.3	26.3	26.3
35	444	Vipul Bhatt	29.3	0.9	26.3	0.0	26.3	26.3	26.3	26.3
36	103 A	Tej Kumar	23.7	0.8	26.4	0.1	26.1	26.1	26.1	26.0
37	301 A	Deepshikha	28.0	0.9	26.5	-0.2	27.1	27.2	27.0	27.3
38	802 A	Sunita	18.8	1.0	27.0	0.5	25.4	25.0	25.5	24.7
39	501 A	Shalu Luthra	23.7	0.9	26.5	0.1	26.2	26.2	26.2	26.1
40	503 A	Kavita Aggarwal	16.8	0.9	26.6	0.5	25.0	24.6	25.1	24.2
41	502 A	Anju Sharma	35.2	0.9	26.2	-0.6	28.0	28.5	27.9	28.9
42	302 A	Renu Vashisht	26.0	0.9	26.3	-0.1	26.6	26.6	26.5	26.7
43	203 A	Ritu Vyas	25.0	0.9	26.4	0.1	26.1	26.1	26.1	26.0
44	801	Jagandeep Kohli	25.2	0.9	27.0	0.1	26.8	26.7	26.8	26.6
45	801	Navneet Kohli	27.4	1.0	27.0	0.0	27.0	27.0	27.0	27.0
46	701	Reema Mahajan	24.5	1.0	26.7	0.0	26.7	26.7	26.7	26.7
47	701	Joy Mahajan	24.4	0.9	26.7	0.0	26.7	26.7	26.7	26.7

48	702	Manohar Kashyap	27.5	0.9	26.5	-0.1	26.8	26.8	26.7	26.9
49	A1	Shashi Pandey	23.4	0.9	25.6	0.2	25.0	24.9	25.1	24.8
50	B3	Anuradha	25.3	0.9	25.7	0.0	25.7	25.7	25.7	25.7
51	B3	Y K Gupta	22.0	1.0	25.7	0.1	25.5	25.4	25.5	25.3
52	A6	Premlata Thakur	26.7	0.9	26.0	0.0	26.0	26.0	26.0	26.0
53	A13	Rekha Singh	21.2	0.9	26.2	0.2	25.7	25.6	25.7	25.4
54	A13	Sandeep Singh	28.6	0.9	26.2	0.0	26.2	26.2	26.2	26.2
55	A13	Saurabh Singh	25.2	0.9	26.2	0.2	25.7	25.6	25.7	25.4
56	B14	Balram	22.2	0.9	26.2	0.1	25.9	25.8	25.9	25.8
57	B14	Kalyani Singh	25.8	1.0	26.2	-0.1	26.4	26.5	26.4	26.6
58	A11	Vir Singh	23.8	0.7	26.2	0.0	26.2	26.2	26.2	26.2
59	A11	Nitu Singh	23.7	0.9	26.2	0.1	26.0	25.9	26.0	25.8
60	A12	Pallavi	27.5	0.9	26.0	0.0	26.0	26.0	26.0	26.0
61	A12	Shivangi	23.4	0.7	26.0	0.2	25.5	25.4	25.5	25.3
62	A6	Kiran Bala Wason	24.6	0.8	26.0	0.2	25.5	25.4	25.5	25.2
63	B8	Hardeep Kaur	24.5	0.9	26.3	0.2	25.8	25.6	25.8	25.5
64	101A	Mahima Aggarwal	23.8	0.8	26.3	0.0	26.3	26.3	26.3	26.3
65	101A	Vibhu Aggarwal	24.3	0.9	26.3	0.0	26.3	26.3	26.3	26.3
66	201A	Surinder Arora	32.8	0.9	26.5	-0.3	27.6	27.8	27.5	28.1
67	201A	Navneet Arora	29.5	0.9	26.5	-0.1	26.8	26.8	26.8	26.9
68	402 A	Swapnaja Hote	23.8	0.8	26.4	0.1	26.1	26.1	26.2	26.0
69	501 A	Mudita Pandey	22.8	0.9	26.8	0.2	26.3	26.1	26.3	26.0
70	501A	Sunanda Pandey	31.4	0.9	26.8	-0.2	27.3	27.5	27.3	27.6
71	503 A	Supriya Kaushal	24.4	0.9	26.7	0.0	26.7	26.7	26.7	26.7
72	602A	Raj Sharma	24.4	0.9	27.0	0.2	26.4	26.3	26.5	26.2
73	602A	Akriti Sharma	31.5	0.9	27.0	-0.1	27.2	27.3	27.2	27.4
74	403 A	Arshi Rastogi	17.8	0.8	26.5	0.4	25.1	24.8	25.2	24.5
75	403A	Sakshi	30.2	0.9	26.5	-0.3	27.3	27.5	27.2	27.6
76	103 A	Anil Kumar	34.0	0.9	26.3	-0.3	27.1	27.3	27.1	27.5
77	301A	Rashmi Maheshwari	20.0	0.9	26.7	0.3	25.6	25.4	25.7	25.1
78	303A	Garima	27.5	0.9	26.7	0.0	26.7	26.7	26.7	26.7
79	603A	Tripti Chatterji	25.7	0.9	27.1	0.2	26.6	26.5	26.6	26.3
80	503A	Partha Kaushal	34.0	0.9	26.7	-0.3	27.5	27.7	27.5	27.9
81	603A	Rajdeep Chatterji	31.4	1.0	27.1	-0.2	27.7	27.8	27.6	27.9
82	603A	Roma Bannerji	29.0	0.9	27.1	0.0	27.1	27.1	27.1	27.1

TnG= Tgm +(0- TSm)/R

TnG: Griffith's Neutral Temperature, Tgm : mean globe temperature, TSm : mean thermal sensation vote & R : Griffith's coefficient

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Tn: Neutral Temperature

r: Correlation Coefficient

R: Regression Coefficient

Tgm: Mean Globe Temperature

TSm: Mean Thermal Sensation

TnG1,TnG2,TnG3,TnG4: Griffith's Neutral Temperature using regression coefficent obtained Madhavi's study (.31) , Griffith's regression coefficent (.25 & .33) and finally the one obtained in this study (.21)

Table 1.11 Estimated Tropical Summer Index (All Data)

TSI= 1/3Tw + 3/4Tg -2 (Av) ½

Tw is the wet bulb temperature, Tg is globe temperature & and Av is the air velocity *[M.R Sharma & S.Ali, 1985]*

S.No.	Subject	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		TSI (°C)	TSI (°C)	TSI (°C)	TSI (°C)	TSI (°C)	TSI (°C)	TSI (°C)	TSI (°C)	TSI (°C)	TSI (°C)	TSI (°C)	TSI (°C)
1	Neer Jhamra	17.6	18.8	20.9	16.2	21.5	28.5	30.7	34.8	34.0	31.9	29.5	27.8
2	Shilpi Sharma	16.3	18.6	20.2	15.1	21.1	28.6	29.8	33.1	32.9	31.0	29.0	28.3
3	Surinder Nath	18.4	18.6	19.7	15.8	22.0	28.1	30.4	34.8	33.9	32.0	29.9	28.1
4	Malabika Roy	18.3	18.7	19.9	15.9	21.0	27.8	30.7	34.5	33.8	31.9	29.8	28.9
5	Debaratta Roy	18.3	18.7	19.9	15.9	21.0	27.8	30.7	34.5	33.8	31.9	29.8	28.9
6	Meenakshi Mudgal	17.4	18.4	20.9	15.6	21.1	28.6	30.5	34.6	33.7	31.9	29.7	28.2
7	Aashi Goyal	16.7	19.2	21.0	15.8	21.1	25.9	30.6	33.9	33.1	31.1	29.4	28.1
8	Jayaprakash Dhull	16.6	19.1	20.7	16.0	21.3	28.1	30.5	34.5	33.8	30.9	29.2	28.9
9	Archana Sethia	15.5	18.8	20.7	15.9	21.2	28.6	30.3	34.4	34.2	31.7	29.2	28.1
10	Rajnish Dhanda	17.4	19.3	21.4	16.1	21.4	28.0	30.5	34.5	34.3	31.2	29.7	28.4
11	Rashi Gupta	17.7	18.9	21.6	16.4	21.7	28.2	31.1	34.6	34.2	32.3	29.8	28.0
12	R.K. Gupta	17.7	18.9	21.6	16.4	21.7	28.2	31.1	34.6	34.2	32.3	29.8	28.0
13	Minakshi	17.6	18.8	20.6	16.2	21.7	28.3	31.1	34.3	34.1	32.0	29.9	27.8
14	Rajeev Kumar	17.6	18.8	20.6	16.2	21.7	28.3	31.1	34.3	34.1	32.0	29.9	27.8
15	Mridul Gupta	17.7	18.9	21.6	16.4	21.7	28.2	31.1	34.6	34.2	32.3	29.8	28.0
16	Rohit Bhatia	17.7	19.3	20.9	15.8	21.6	27.8	30.5	34.9	34.3	32.3	29.8	28.3
17	Naina Bhatia	17.7	19.3	20.9	15.8	21.6	27.8	30.5	34.9	34.3	32.3	29.8	28.3
18	Ritul Bhatia	17.7	19.3	20.9	15.8	21.6	27.8	30.5	34.9	34.3	32.3	29.8	28.3
19	Vivek Sharma	18.1	19.2	20.6	15.9	21.2	27.9	30.5	35.0	34.1	32.2	29.9	28.2
20	Shaily Sharma	18.1	19.2	20.6	15.9	21.2	27.9	30.5	35.0	34.1	32.2	29.9	28.2
21	Bharat Bhushan	18.0	18.6	21.0	16.4	21.5	28.4	30.9	34.6	34.8	31.2	29.5	27.2
22	Rekha Bora	17.3	18.7	21.8	16.0	20.8	28.4	30.0	34.3	34.3	31.2	29.1	28.0
23	Shabnam Thakur	17.2	19.1	21.1	16.1	21.0	28.2	30.4	34.7	34.2	31.7	30.1	27.5
24	Orana Das	17.6	18.9	20.8	16.2	20.5	28.3	30.2	34.9	34.9	32.6	29.6	29.5
25	Geeta Sharma	16.2	19.2	20.6	15.4	21.0	29.1	31.3	34.5	33.8	32.2	29.6	28.9
26	Surinder Gupta	15.4	19.2	20.0	15.9	21.1	28.2	31.1	35.4	34.4	32.3	29.7	28.8
27	Aashima	16.2	18.6	20.3	16.3	20.9	28.3	30.8	34.6	34.2	31.7	30.1	28.1
28	Monica	16.0	19.1	20.8	15.8	21.1	28.5	30.3	34.4	34.2	32.0	29.7	27.3
29	Ritu	16.1	18.8	20.9	16.0	21.3	27.9	30.2	34.4	34.2	31.6	29.0	27.5
30	Poonam Sharma	16.2	19.3	20.8	16.2	21.1	29.1	30.4	35.0	34.7	31.2	29.8	28.5
31	Lalit Katoch	15.8	18.7	20.6	15.9	21.4	27.8	30.5	33.9	34.3	31.3	29.0	27.8
32	Preet Katoch	15.8	18.7	20.6	15.9	21.4	27.8	30.5	33.9	34.3	31.3	29.0	27.8
33	Rimjhim Bhatt	16.0	18.9	20.5	16.2	21.0	28.2	30.0	34.4	34.2	31.0	29.8	28.4
34	Anmol Bhatt	16.0	18.9	20.5	16.2	21.0	28.2	30.0	34.4	34.2	31.0	29.8	28.4
35	Vipul Bhatt	16.0	18.9	20.5	16.2	21.0	28.2	30.0	34.4	34.2	31.0	29.8	28.4
36	Tej Kumar	16.8	18.6	22.7	16.3	21.3	28.2	30.3	34.0	34.2	31.0	29.3	27.4
37	Deepshikha	16.4	18.6	23.4	16.4	20.9	28.4	30.2	34.5	34.2	31.5	29.6	27.3
38	Sunita	17.8	19.1	23.5	16.5	21.8	28.1	30.9	34.7	34.6	31.8	29.7	27.4
39	Shalu Luthra	16.2	19.0	23.4	16.1	20.8	27.8	30.4	34.4	34.2	31.4	29.9	26.6
40	Kavita Aggarwal	16.2	19.1	23.2	16.3	20.6	27.7	30.2	34.3	34.3	31.5	29.2	27.3
41	Anju Sharma	14.7	18.9	24.1	15.4	21.2	27.8	30.2	34.2	34.2	31.3	28.8	26.5
42	Renu Vashisht	14.8	19.0	23.8	15.3	21.4	27.9	30.5	33.9	34.3	31.3	29.6	27.1
43	Ritu Vyas	17.0	19.0	23.1	16.1	21.2	27.4	30.2	35.0	34.0	31.5	29.5	26.4
44	Jagandeep Kohli	17.8	19.2	23.6	15.9	22.1	28.6	31.0	34.1	34.4	31.3	29.8	27.7
45	Navneet Kohli	17.8	19.2	23.6	15.9	22.1	28.6	31.0	34.1	34.4	31.3	29.8	27.7
46	Reema Mahajan	16.6	19.1	23.5	16.2	21.2	27.8	30.6	34.3	34.2	31.7	29.8	27.2
47	Joy Mahajan	16.6	19.1	23.5	16.2	21.2	27.8	30.6	34.3	34.2	31.7	29.8	27.2
48	Manohar Kashyap	15.7	19.2	24.0	16.0	20.9	27.9	30.3	34.3	34.0	31.5	29.3	26.8
49	Shashi Pandey	15.3	17.9	22.9	14.5	21.5	27.1	30.7	31.7	32.5	31.5	28.7	27.4
50	Anuradha	15.5	17.8	22.9	15.8	21.3	26.6	30.2	31.3	33.3	31.3	29.1	26.4
51	Y K Gupta	15.5	17.8	22.9	15.8	21.3	26.6	30.2	31.3	33.3	31.3	29.1	26.4
52	Premlata Thakur	16.0	18.5	23.3	16.4	21.2	27.8	30.2	31.8	33.2	30.8	28.8	27.1
53	Rekha Singh	16.1	18.7	23.7	16.4	21.3	27.8	30.6	31.0	33.6	31.5	29.5	27.0
54	Sandeep Singh	16.1	18.7	23.7	16.4	21.3	27.8	30.6	31.0	33.6	31.5	29.5	27.0
55	Saurabh Singh	16.1	18.7	23.7	16.4	21.3	27.8	30.6	31.0	33.6	31.5	29.5	27.0
56	Balram	16.2	18.5	23.6	16.1	21.1	28.1	30.3	30.7	33.2	31.5	29.3	26.8
57	Kalyani Singh	16.2	18.5	23.6	16.1	21.1	28.1	30.3	30.7	33.2	31.5	29.3	26.8
58	Vir Singh	16.5	18.5	23.7	16.5	21.2	28.0	30.4	31.1	33.1	31.9	29.3	27.3
59	Nitu Singh	16.5	18.5	23.7	16.5	21.2	28.0	30.4	31.1	33.1	31.9	29.3	27.3
60	Pallavi	15.9	18.2	23.9	16.1	21.1	27.8	30.7	31.4	33.4	30.8	28.9	26.8
61	Shivangi	15.9	18.2	23.9	16.1	21.1	27.8	30.7	31.4	33.4	30.8	28.9	26.8
62	Kiran Bala Wason	16.0	18.5	23.3	16.8	21.2	27.8	30.2	31.8	33.2	31.0	28.8	27.1
63	Hardeep Kaur	16.1	18.0	23.6	16.4	21.6	27.9	30.5	31.7	33.4	31.0	29.2	26.8
64	Mahima Aggarwal	16.8	18.5	24.5	16.0	20.8	27.5	31.5	32.0	33.7	31.6	29.0	26.7
65	Vibhu Aggarwal	16.8	18.5	24.5	16.0	20.8	27.5	31.5	32.0	33.7	31.6	29.0	26.7
66	Surinder Arora	17.5	18.8	24.7	16.2	21.5	27.7	31.0	32.4	33.5	31.6	28.5	27.8
67	Navneet Arora	17.5	18.8	24.7	16.2	21.5	27.7	31.0	32.4	33.5	31.6	28.5	27.8
68	Swapnaja Hote	17.1	18.6	23.8	16.4	21.0	27.6	30.8	31.8	33.2	31.5	28.6	28.8
69	Mudita Pandey	18.2	18.8	24.4	16.3	21.7	27.8	31.2	32.2	33.7	31.3	29.1	28.2
70	Sunanda Pandey	18.2	18.8	24.4	16.3	21.7	27.8	31.2	32.2	33.7	31.3	29.1	28.2
71	Supriya Kaushal	18.1	19.0	24.4	16.6	21.7	27.9	31.7	32.1	33.8	31.0	29.3	28.2
72	Raj Sharma	18.0	18.7	24.3	16.5	21.6	27.8	31.7	32.7	33.8	31.6	29.2	27.5
73	Akriti Sharma	18.0	18.7	24.3	16.5	21.6	27.8	31.7	32.7	33.8	31.6	29.2	27.5
74	Arshi Rastogi	17.8	18.6	23.5	16.2	21.7	27.8	30.8	31.9	33.7	31.5	29.1	27.0
75	Sakshi	17.8	18.6	23.5	16.2	24.9	27.8	30.8	31.9	33.7	31.4	29.1	27.0
76	Anil Kumar	17.1	18.6	24.4	15.8	20.7	27.5	30.9	31.3	33.4	31.2	28.6	28.4
77	Rashmi Maheshwari	17.6	19.3	24.5	15.9	22.0	27.8	31.0	32.2	33.2	31.3	29.1	29.3

78	Garima	17.5	19.0	24.8	16.4	22.2	27.8	30.7	31.5	33.2	31.2	29.1	28.3
79	Tripti Chatterji	17.9	18.9	24.3	15.9	23.7	27.8	31.7	33.3	33.9	31.6	29.0	28.4
80	Partha Kaushal	18.1	19.0	24.4	16.6	21.7	27.9	31.7	32.1	33.8	31.0	29.3	28.2
81	Rajdeep Chatterji	17.9	18.9	24.3	15.9	23.4	27.8	31.7	33.3	33.9	31.6	29.0	28.4
82	Roma Bannerji	17.9	18.9	24.3	15.9	25.3	27.8	31.7	33.3	33.9	31.6	29.0	28.4

TSI= 1/3Tw + 3/4Tg -2 (Av) ½

Tw is the wet bulb temperature, Tg is globe temperature & and Av is the air velocity *[M.R Sharma & S.Ali, 1985]*

S.No.	Tg (°C)	Av (m/s)	Wet Bulb (°C)	T S (-3 to +3)	TSI (°C)
1	18.2	0.0	11.8	-2.0	17.6
2	16.3	0.0	12.3	-3.0	16.3
3	19.3	0.1	12.8	-1.0	18.4
4	18.7	0.0	12.8	-3.0	18.3
5	18.7	0.0	12.8	-2.0	18.3
981	28.5	0.0	20.9	0.0	28.4
982	28.2	0.0	21.0	-1.0	28.2
983	28.5	0.0	20.9	0.0	28.4
984	28.5	0.0	20.9	0.0	28.4

Table 1.12 Detailed Summary of Base-Case Models

PARAMETERS	GMR	TR	BMD	HV	CV
Orientation	NE-SW Axis	NE-SW Axis	NE-SW Axis	E-W Axis	N-S Axis
Window to Wall Ratio	N-.2, S-.2, E-.2, W-.2, NE-.3, SE-.23, NW-.12, SW-.3	SE- .4 , NW- .4	NE- .1 , SE-.2, NW-.2 , SW-.1	N-.2, S-.2, E-.05 , W-.05	N-.17 , S-.17 , E-.23, W-.22
Glazing Type	Single Glass Clear , Wooden Frame #U.F=7.1, #SHGC=0.82, #VLT=.76	Single Glass Clear , Wooden Frame #U.F=7.1, #SHGC=0.82, #VLT=.76	Single Glass Clear ,Wooden Frame #U.F=7.1, #SHGC=0.82, #VLT=.76	Single Glass Clear , Wooden Frame #U.F=7.1, #SHGC=0.82, #VLT=.76	Single Glass Clear ,Wooden Frame #U.F=7.1, #SHGC=0.82, #VLT=.76
Building Envelope					
Wall Materials (External)	Int. plaster+ Double Brickwork + Ext. Plaster U.F= 1.902 , #R.V = 0.526	Int. plaster+ Double Brickwork + Ext. Plaster U.F= 1.902 , #R.V = 0.526	Int. plaster+ Double Brickwork + Ext. Plaster U.F= 1.902 , #R.V = 0.526	Int. plaster+ Double Brickwork + Ext. Plaster U.F= 1.902 , #R.V = 0.526	Int. Plaster + Double Brickwork + Ext. Plaster U.F= 1.902 , #R.V = 0.526
Wall Materials (Semi-Exposed)	same as above	same as above	same as above	same as above	same as above
Air Tightness	Yes	Yes	Yes	Yes	Yes
Internal Partition	Int. plaster+ Brickwork + Ext. Plaster U.F = 2.33 R.V = 0.429	Int. plaster+ Brickwork + Ext. Plaster U.F = 2.33 R.V = 0.429	Int. plaster+ Brickwork + Ext. Plaster U.F = 2.33 R.V = 0.429	Int. plaster+ Brickwork + Ext. Plaster U.F = 2.33 R.V = 0.429	Int. plaster+ Brickwork + Ext. Plaster U.F = 2.33 R.V = 0.429
Roof	Int. plaster+ RCC slab+ Brickwork+ Glass wool + Dense cement plaster U.F= 2.389, R.V = 0.419	Int. plaster+ RCC slab+ Brickwork+ Glass wool + Dense cement plaster U.F= 2.389, R.V = 0.419	Int. plaster+ RCC slab+ Brickwork+ Glass wool + Dense cement plaster U.F= 2.389, R.V = 0.419	Int. plaster +RCC slab +Concrete cast+ Felt Bitumen +cement mortar +cement screed U.F = 2.104 , R.V = .475	Int. plaster +RCC slab +Concrete cast+ Felt Bitumen +cement mortar+ cement screed U.F = 2.104 , R.V = .475
Annual Energy Consumption (MWh)	146.72	203.02	69.84	126.2	66.32
Annual CO2 Production (kgx10^3)	100.51	139.07	47.84	86.44	45.43
Annual Heat Gain / Loss (MWh)					
Ext. Windows	524.03	341.15	188.55	211.51	215.37
Walls	-128.57	-66.14	-57.58	-80.04	-27.01
Roof	-3.17	-6.78	-3.39	-2.62	1.09
Glazing	-165.58	-141.79	-69.86	-89.26	-55.07
General Lighting	46.89	58.78	22.99	39.31	21.95

 # U.F(U-factor)=Thermal conductance,[W/m2C] , R.V(R-value)=Thermal resistance [m2.C/W], SHGC=Solar Heat Gain Coefficient Through Glass

Table 1.13a Fuel Total Output of Baseline Models (All Buildings)

	GMR	HV	TR	BMD	CV
Jan	13.35	11.40	18.64	5.21	8.70
Feb	9.67	10.62	15.70	4.17	6.26
Mar	8.06	6.97	13.29	4.31	3.26
Apr	7.80	7.62	12.87	4.18	3.83
May	15.81	10.95	20.47	6.47	4.97
Jun	18.54	14.53	23.38	7.39	7.05
Jul	19.83	15.59	22.81	10.04	7.79
Aug	16.57	13.72	15.80	7.20	7.50
Sep	7.84	10.24	12.89	6.31	4.65
Oct	8.09	8.58	13.32	5.66	4.47
Nov	7.80	6.20	12.87	4.18	3.33
Dec	13.35	9.79	19.03	4.73	4.50
Total	**146.72**	**126.20**	**201.07**	**69.84**	**66.32**

Table 1.13 b CO_2 Emission of Baseline Models (All Buildings)

	GMR	HV	TR	BMD	CV
Jan	9.15	7.81	12.77	3.57	5.96
Feb	6.62	7.27	10.76	2.85	4.29
Mar	5.52	4.77	9.10	2.95	2.23
Apr	5.34	5.22	8.81	2.86	2.63
May	10.83	7.50	14.02	4.44	3.40
Jun	12.70	9.95	16.02	5.06	4.83
Jul	13.58	10.68	15.62	6.88	5.34
Aug	11.35	9.40	10.82	4.93	5.14
Sep	5.37	7.02	8.83	4.32	3.19
Oct	5.54	5.88	9.12	3.88	3.07
Nov	5.34	4.24	8.81	2.86	2.28
Dec	9.15	6.71	13.04	3.24	3.08
Total	**100.51**	**86.44**	**137.73**	**47.84**	**45.43**

Table 1.14 a Heat Flow through Fabric & Ventilation-GMR

	Glazing	Walls	Ceiling	Roof	Floor (ext.)	Internal Natural Vent.	External Air	Mech.+Nat. Vent.+Infilteration
Jan	-20.02	-23.72	2.95	-3.43	-3.40	-0.91	-5.68	0.28
Feb	-16.57	-19.65	2.90	-2.80	-2.60	-0.70	-5.53	0.36
Mar	-17.27	-18.81	1.97	-1.82	-2.57	-1.06	-5.86	0.40
Apr	-9.16	-2.30	0.80	1.40	-0.42	-2.01	-37.66	3.22
May	-6.03	3.15	1.05	3.03	0.53	-1.75	-27.23	3.44
Jun	-4.53	4.47	1.74	2.83	0.43	-2.60	-24.71	4.40
Jul	-3.56	4.22	0.14	2.28	0.28	-1.76	-19.54	4.41
Aug	-6.04	1.66	0.49	1.41	-0.50	-1.61	-25.63	4.09
Sep	-9.77	-1.71	2.34	1.67	-1.05	-2.01	-38.83	4.09
Oct	-22.38	-20.79	6.71	-0.98	-3.45	-1.22	-6.77	0.66
Nov	-25.20	-26.51	8.22	-2.96	-3.91	-1.74	-7.59	0.35
Dec	-25.06	-28.57	7.31	-3.80	-4.15	-1.52	-7.49	0.33
Total	**-165.58**	**-128.57**	**36.62**	**-3.17**	**-20.81**	**-18.90**	**-212.50**	**2.17**

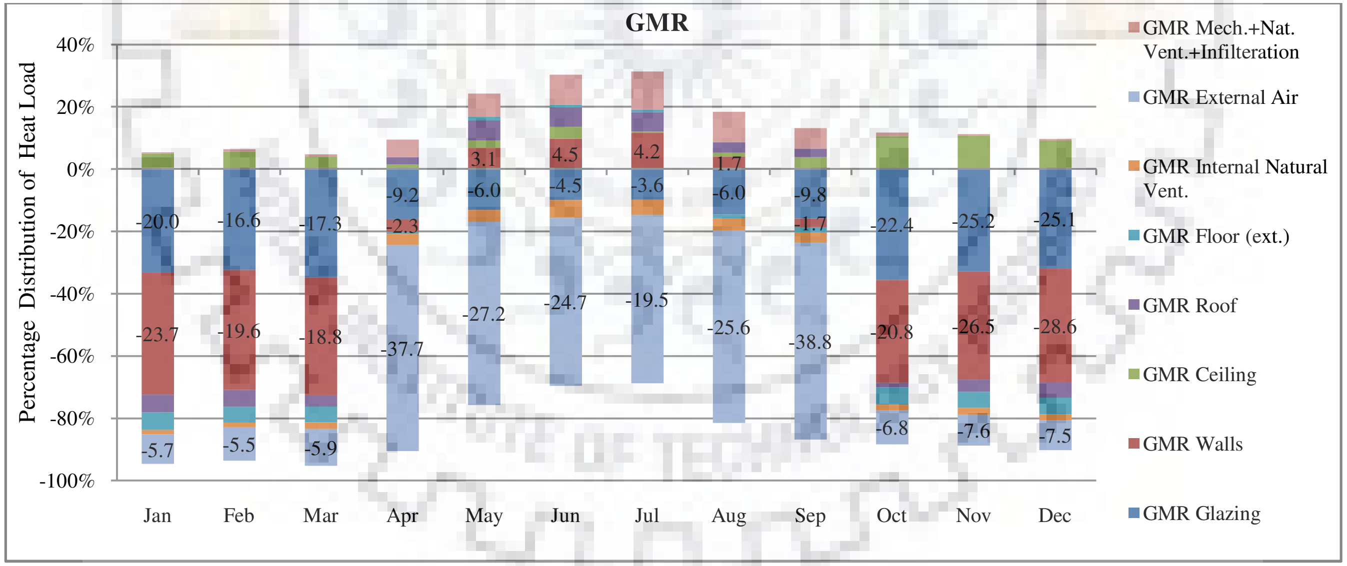


Fig1.4a

Table 1.14 b Heat Flow through Fabric & Ventilation-HV

	Glazing	Walls	Ceiling	Roof	Floor (ext.)	Internal Natural Vent.	External Air	Mech.+Nat. Vent.+Infilteration
Jan	-9.98	-14.48	2.70	-3.00	-1.61	-0.90	-4.02	0.23
Feb	-8.47	-10.94	0.70	-1.74	-1.26	-0.88	-4.28	0.33
Mar	-7.74	-9.56	0.84	-0.82	-0.80	-0.54	-4.46	0.40
Apr	-5.08	-1.94	0.26	1.16	0.33	-0.87	-15.31	1.15
May	-5.09	-2.39	0.80	1.20	0.17	-1.07	-14.50	1.48
Jun	-4.52	2.05	0.65	2.26	0.33	-1.01	-11.49	1.53
Jul	-4.49	0.70	0.99	1.42	0.08	-0.98	-10.17	1.65
Aug	-4.90	-1.57	0.41	1.04	-0.35	-0.89	-10.55	1.78
Sep	-5.82	-4.18	1.35	0.62	-0.52	-0.78	-11.95	1.67
Oct	-10.50	-10.18	3.92	-0.16	-1.14	-0.86	-6.07	0.71
Nov	-11.61	-12.39	4.52	-1.50	-1.62	-1.18	-7.19	0.30
Dec	-11.06	-15.16	3.71	-3.11	-1.77	-1.05	-4.92	0.28
Total	**-89.26**	**-80.04**	**20.85**	**-2.62**	**-8.18**	**-11.01**	**-104.92**	**0.96**

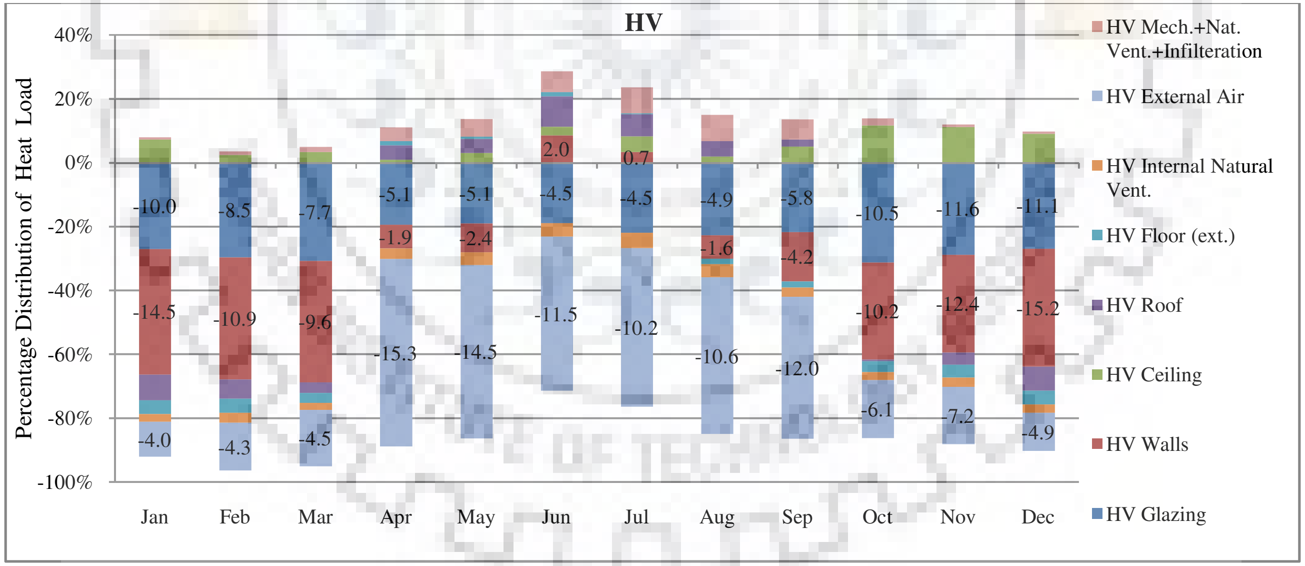


Fig1.4b

Table 1.14 c Heat Flow through Fabric & Ventilation - TR

	Glazing	Walls	Ceiling	Roof	Floor (ext.)	Internal Natural Vent.	External Air	Mech.+Nat. Vent.+Infilteration
Jan	-16.55	-10.48	6.47	-5.95	-2.76	-4.91	-10.06	0.61
Feb	-13.98	-9.24	4.98	-4.76	-2.18	-3.35	-8.28	0.66
Mar	-13.60	-8.69	4.40	-2.36	-1.22	-3.48	-7.97	0.69
Apr	-9.37	-3.78	2.24	2.11	0.46	-2.91	-20.11	1.61
May	-5.48	0.65	2.19	5.14	2.23	-1.75	-10.72	2.25
Jun	-3.88	2.27	2.57	4.95	2.29	-1.98	-8.70	2.62
Jul	-3.96	1.08	1.53	3.25	1.50	-1.87	-8.25	2.67
Aug	-7.59	-2.25	2.23	1.86	0.00	-1.27	-12.00	2.49
Sep	-9.75	-3.20	4.54	2.77	0.22	-2.10	-16.68	2.34
Oct	-16.16	-6.84	9.97	0.01	-0.75	-3.45	-8.89	1.24
Nov	-19.25	-9.44	11.89	-4.37	-2.01	-6.48	-12.44	0.71
Dec	-20.20	-11.96	11.16	-6.45	-3.30	-6.96	-13.77	0.71
Total	**-139.78**	**-61.87**	**64.16**	**-3.78**	**-5.51**	**-40.51**	**-137.87**	**1.55**

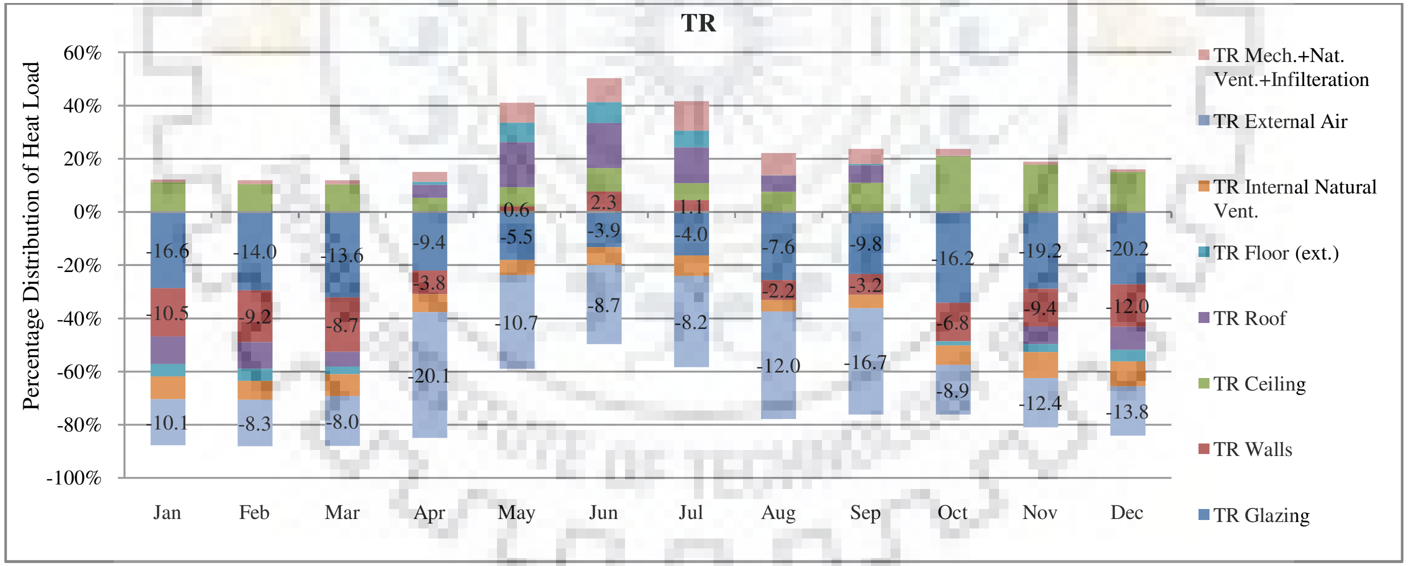


Fig1.4c

Table 1.14 d Heat Flow through Fabric & Ventilation- BMD

	Glazing	Walls	Ceiling	Roof	Floor (ext.)	Internal Natural Vent.	External Air	Mech.+Nat. Vent.+Infilteration
Jan	-6.33	-7.09	1.13	-1.23	-2.01	-0.91	-4.16	0.43
Feb	-5.07	-5.89	1.05	-0.96	-1.45	-0.66	-4.93	0.73
Mar	-4.70	-3.83	0.61	-0.32	-1.09	-0.89	-9.24	1.22
Apr	-6.18	-5.15	0.43	-0.08	-1.08	-0.71	-2.69	0.36
May	-5.53	-3.76	2.00	0.50	-0.67	-0.18	-2.17	0.72
Jun	-5.40	-3.61	3.03	0.39	-0.83	-0.14	-2.34	0.86
Jul	-4.30	-2.41	1.85	0.24	-0.70	-0.08	-1.94	1.01
Aug	-5.34	-4.06	1.77	-0.15	-1.24	-0.21	-2.28	0.93
Sep	-6.32	-4.56	2.40	0.03	-1.42	-0.43	-2.69	0.87
Oct	-6.70	-4.59	4.61	0.05	-1.73	-0.87	-13.49	1.65
Nov	-6.74	-5.35	4.35	-0.71	-1.98	-1.01	-14.24	1.26
Dec	-7.24	-7.28	3.29	-1.15	-2.41	-0.98	-8.75	0.78
Total	**-69.86**	**-57.58**	**26.52**	**-3.39**	**-16.60**	**-7.06**	**-68.92**	**0.90**

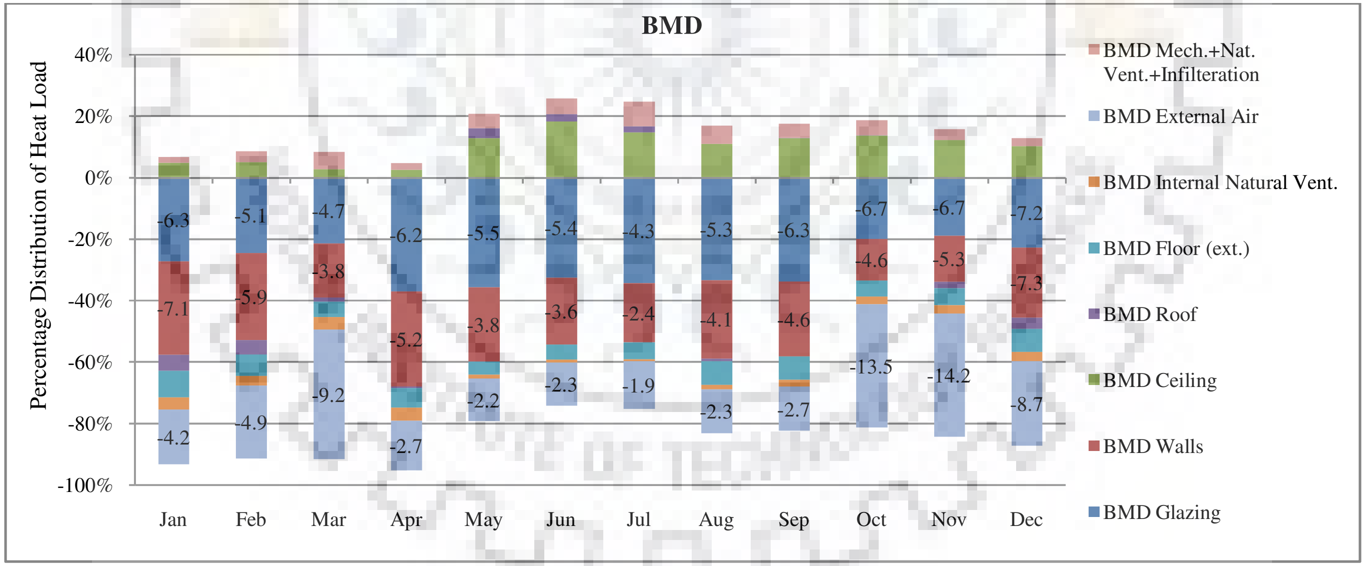


Fig1.4d

Table 1.14 e Heat Flow through Fabric & Ventilation- CV

	Glazing	Walls	Ceiling	Roof	Floor (ext.)	Internal Natural Vent.	External Air	Mech.+Nat. Vent.+Infilteration
Jan	-5.95	-6.27	1.71	-2.18	-1.23	-1.26	-10.69	2.62
Feb	-5.09	-4.30	0.69	-1.17	-0.79	-1.06	-10.45	2.95
Mar	-5.21	-4.74	1.01	-0.68	-0.79	-0.60	-10.26	2.77
Apr	-3.97	-1.38	0.55	0.85	0.06	-1.22	-17.25	3.63
May	-3.17	-0.20	0.54	1.28	0.23	-0.78	-13.65	4.60
Jun	-2.92	1.68	0.65	2.01	0.13	-1.06	-12.33	4.48
Jul	-2.97	0.60	0.96	1.24	-0.19	-0.67	-11.26	4.50
Aug	-3.13	-0.02	0.51	0.99	-0.55	-1.15	-11.00	4.45
Sep	-3.64	-1.27	1.26	0.69	-0.63	-1.00	-12.37	4.50
Oct	-5.90	-2.11	2.95	0.57	-0.70	-0.92	-12.37	3.54
Nov	-6.93	-3.74	3.30	-0.63	-0.97	-1.90	-15.26	2.87
Dec	-6.20	-5.27	2.44	-1.87	-1.09	-1.26	-12.40	2.79
Total	**-55.07**	**-27.01**	**16.57**	**1.09**	**-6.52**	**-12.87**	**-149.29**	**3.64**

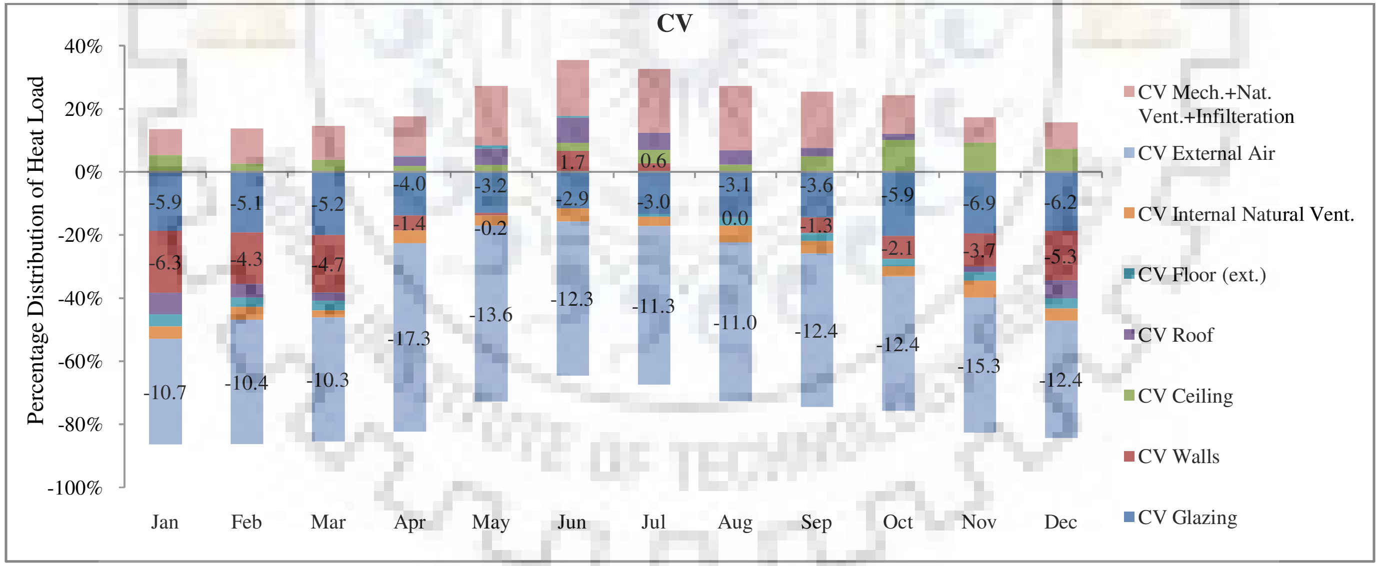


Fig1.4e

Table 1.15 (a,b,c,d &e) Internal Gains Output of Baseline Models (MWh)

Table 1.15a

	GMR					
	General Lighting	Miscellaneous	Occupancy	Soalr Gains Ext. Windows	Zone Sensible Heating	Zone Sensible Cooling
Jan	3.98	9.04	11.71	37.99	0.07	-0.46
Feb	3.60	5.78	9.72	28.97	0.03	-0.42
Mar	3.98	3.75	6.99	40.52	0.06	-0.29
Apr	3.85	3.63	4.38	43.77	0.17	-0.07
May	3.98	3.83	3.19	43.25	0.53	-26.14
Jun	3.85	3.71	2.68	46.06	0.41	-35.63
Jul	3.98	3.83	4.03	39.44	0.39	-34.07
Aug	3.98	3.83	4.27	42.84	0.13	-22.89
Sep	3.85	3.63	3.06	47.96	0.06	-4.68
Oct	3.98	3.75	2.58	54.52	0.03	-8.80
Nov	3.85	3.63	6.01	52.18	0.05	-0.50
Dec	3.98	9.04	10.09	46.53	0.03	-0.57
Total	**46.89**	**57.49**	**68.70**	**524.04**	**1.96**	**-134.51**

Table 1.15b

	HV					
	General Lighting	Miscellaneous	Occupancy	Soalr Gains Ext. Windows	Zone Sensible Heating	Zone Sensible Cooling
Jan	3.33	8.07	5.64	16.33	0.06	-0.09
Feb	3.01	7.61	4.71	17.60	0.08	-0.07
Mar	3.35	3.62	4.41	15.80	0.07	-0.05
Apr	3.22	2.97	2.92	16.08	0.13	-0.03
May	3.34	3.43	2.55	15.84	0.09	-2.86
Jun	3.23	3.63	1.95	16.62	0.61	-13.23
Jul	3.34	3.75	1.94	16.00	0.36	-13.52
Aug	3.34	3.75	2.16	15.34	0.15	-5.83
Sep	3.27	4.75	2.27	15.19	0.20	-3.26
Oct	3.38	4.91	2.94	21.39	0.32	-6.32
Nov	3.22	2.97	4.41	24.62	0.07	-0.08
Dec	3.27	6.52	5.45	20.72	0.07	-0.09
Total	**39.31**	**56.00**	**41.36**	**211.51**	**2.22**	**-45.43**

Table 1.15c

	TR					
	General Lighting	Miscellaneous	Occupancy	Soalr Gains Ext. Windows	Zone Sensible Heating	Zone Sensible Cooling
Jan	4.99	13.09	14.54	23.50	0.17	-2.12
Feb	4.51	10.69	11.95	18.25	0.08	-1.82
Mar	4.99	7.74	9.13	26.32	0.18	-1.62
Apr	4.83	7.49	4.19	30.15	0.27	-1.01
May	4.99	7.91	2.90	29.70	1.43	-32.82
Jun	4.83	7.65	2.52	30.24	1.48	-40.77
Jul	4.99	7.91	3.84	26.68	1.10	-32.85
Aug	4.99	7.91	3.60	28.28	0.29	-15.94
Sep	4.83	7.49	3.06	31.83	0.12	-11.75
Oct	4.99	7.74	4.81	34.66	0.15	-14.43
Nov	4.83	7.49	8.94	32.80	0.13	-2.45
Dec	4.99	13.48	13.23	28.73	0.08	-2.56
Total	**58.78**	**106.59**	**82.70**	**341.15**	**5.48**	**-160.14**

Table 1.15d

BMD

	General Lighting	Miscellaneous	Occupancy	Soalr Gains Ext. Windows	Zone Sensible Heating	Zone Sensible Cooling
Jan	1.95	3.26	6.28	13.58	0.00	-0.33
Feb	1.76	2.40	5.33	10.40	0.00	-0.24
Mar	1.95	2.36	4.32	14.75	0.00	-0.22
Apr	1.89	2.29	1.07	16.16	0.00	-0.24
May	1.95	2.70	0.51	15.52	0.05	-8.96
Jun	1.89	2.66	0.46	15.92	0.06	-12.14
Jul	1.95	4.13	0.89	14.14	0.08	-13.20
Aug	1.95	3.84	0.77	15.47	0.03	-8.31
Sep	1.89	3.72	0.53	17.57	0.01	-7.03
Oct	1.95	3.69	2.02	19.58	0.06	-3.88
Nov	1.89	2.29	4.17	18.71	0.00	-0.38
Dec	1.95	2.78	5.86	16.76	0.00	-0.39
Total	**22.99**	**36.10**	**32.22**	**188.55**	**0.29**	**-55.31**

Table 1.15e

CV

	General Lighting	Miscellaneous	Occupancy	Soalr Gains Ext. Windows	Zone Sensible Heating	Zone Sensible Cooling
Jan	1.73	6.87	5.41	12.98	0.12	-0.10
Feb	1.47	4.70	4.31	15.73	0.17	-0.07
Mar	1.63	1.53	3.88	17.55	0.12	-0.06
Apr	1.86	1.86	2.65	19.14	0.19	-0.01
May	1.94	1.56	2.52	17.94	1.12	-8.62
Jun	1.88	1.66	1.73	19.19	1.01	-12.85
Jul	1.94	2.03	1.77	18.48	0.50	-12.76
Aug	1.94	2.56	2.17	18.79	0.15	-9.67
Sep	1.86	2.68	2.27	18.57	0.22	-7.95
Oct	1.92	2.44	3.26	21.30	0.46	-11.17
Nov	1.86	1.36	4.91	19.89	0.17	-0.07
Dec	1.92	2.46	6.10	15.82	0.15	-0.09
Total	**21.95**	**31.72**	**40.99**	**215.37**	**4.38**	**-63.42**

Table 1.16 (a,b,c,d &e) Fuel Breakdown of Energy-Use of Baseline Models(in MWh)

Table 1.16a

	GMR					
	Room Electricity	Lighting	System Fan	System Pumps	Chiller	Heat Rejection
Jan	9.22	4.13	0.00	0.00	0.00	0.00
Feb	5.94	3.73	0.00	0.00	0.00	0.00
Mar	3.93	4.13	0.00	0.00	0.00	0.00
Apr	3.81	4.00	0.00	0.00	0.00	0.00
May	4.01	4.13	0.82	1.31	5.20	0.34
Jun	3.88	4.00	1.01	1.69	7.37	0.59
Jul	4.01	4.13	1.32	1.96	7.72	0.68
Aug	4.01	4.13	1.02	1.53	5.36	0.52
Sep	3.81	4.00	0.04	0.00	0.00	0.00
Oct	3.93	4.13	0.03	0.00	0.00	0.00
Nov	3.81	4.00	0.00	0.00	0.00	0.00
Dec	9.22	4.13	0.00	0.00	0.00	0.00
Total	**59.59**	**48.62**	**4.24**	**6.49**	**25.65**	**2.13**

Table 1.16b

	HV					
	Room Electricity	Lighting	System fan	System Pump	Chiller	Heat Rejection
Jan	8.07	3.33	0.00	0.00	0.00	0.00
Feb	7.61	3.01	0.00	0.00	0.00	0.00
Mar	3.62	3.35	0.00	0.00	0.00	0.00
Apr	2.97	3.22	0.00	0.37	1.01	0.04
May	3.43	3.34	0.26	1.02	2.77	0.13
Jun	3.63	3.23	0.63	1.67	5.00	0.37
Jul	3.75	3.34	0.65	1.78	5.49	0.57
Aug	3.75	3.34	0.50	1.51	4.13	0.48
Sep	4.75	3.27	0.14	0.52	1.41	0.14
Oct	4.91	3.38	0.14	0.04	0.10	0.01
Nov	2.97	3.22	0.00	0.00	0.00	0.00
Dec	6.52	3.27	0.00	0.00	0.00	0.00
Total	**56.00**	**39.31**	**2.32**	**6.91**	**19.91**	**1.75**

Table 1.16c

	TR					
	Room Electricity	Lighting	System Fan	System Pumps	Chiller	Heat Rejection
Jan	13.47	5.17	0.00	0.00	0.00	0.00
Feb	11.03	4.67	0.00	0.00	0.00	0.00
Mar	8.12	5.17	0.00	0.00	0.00	0.00
Apr	7.86	5.00	0.00	0.00	0.00	0.00
May	8.29	5.17	0.87	1.21	5.06	0.33
Jun	8.01	5.01	1.16	1.64	7.61	0.59
Jul	8.29	5.17	1.20	1.69	6.52	0.57
Aug	8.29	5.17	0.37	0.48	1.53	0.15
Sep	7.86	5.00	0.03	0.00	0.00	0.00
Oct	8.12	5.17	0.03	0.00	0.00	0.00
Nov	7.86	5.00	0.00	0.00	0.00	0.00
Dec	13.86	5.17	0.00	0.00	0.00	0.00
Total	**111.07**	**60.90**	**3.66**	**5.03**	**20.72**	**1.65**

Table 1.16d

	BMD					
	Room Electricity	**Lighting**	**System Fan**	**System Pump**	**Chiller (Electricity)**	**Heat Rejection**
Jan	3.26	1.95	0.00	0.00	0.00	0.00
Feb	2.40	1.76	0.00	0.00	0.00	0.00
Mar	2.36	1.95	0.00	0.00	0.00	0.00
Apr	2.29	1.89	0.00	0.00	0.00	0.00
May	2.70	1.95	0.22	0.33	1.19	0.08
Jun	2.66	1.89	0.32	0.47	1.89	0.16
Jul	4.13	1.95	0.49	0.73	2.52	0.21
Aug	3.84	1.95	0.18	0.24	0.90	0.09
Sep	3.72	1.89	0.07	0.08	0.51	0.04
Oct	3.69	1.95	0.02	0.00	0.00	0.00
Nov	2.29	1.89	0.00	0.00	0.00	0.00
Dec	2.78	1.95	0.00	0.00	0.00	0.00
Total	**36.10**	**22.99**	**1.30**	**1.86**	**7.01**	**0.58**

Table 1.16e

	CV					
	Room Electricity	**Lighting**	**System Fan**	**System Pump**	**Chiller (Electricity)**	**Heat Rejection**
Jan	6.94	1.76	0.00	0.00	0.00	0.00
Feb	4.77	1.50	0.00	0.00	0.00	0.00
Mar	1.60	1.66	0.00	0.00	0.00	0.00
Apr	1.94	1.89	0.00	0.00	0.00	0.00
May	1.65	1.98	0.21	0.29	0.81	0.03
Jun	1.74	1.91	0.48	0.68	2.11	0.13
Jul	2.11	1.98	0.49	0.71	2.30	0.20
Aug	2.64	1.98	0.42	0.61	1.69	0.15
Sep	2.76	1.89	0.00	0.00	0.00	0.00
Oct	2.52	1.95	0.00	0.00	0.00	0.00
Nov	1.44	1.89	0.00	0.00	0.00	0.00
Dec	2.54	1.95	0.00	0.00	0.00	0.00
Total	**32.65**	**22.34**	**1.61**	**2.29**	**6.92**	**0.51**

Table 1.17 (a,b,c,d &e) Indoor Environemntal & Comfort Output of Baseline Models (All Buildings)

Table 1.17a GMR

	Air Temperature	Radiant Temperature	Operative Temperature	Outisde Dry Bulb Temperature	Relative Humidity	Discomfort Hours	Fanger Pmv	Pierce Pmv ET	Pierce Pmv SET	Kansas Uni TSV
Jan	21.83	21.59	21.71	14.05	54.26	129.06	-0.82	-0.51	0.37	0.14
Feb	23.33	23.17	23.25	16.5	56.3	82.96	-0.36	-0.1	0.72	0.29
Mar	28.34	28.34	28.34	21.95	48.05	263.03	1.1	1.26	1.97	1.07
Apr	31.26	32.3	31.78	28.25	33.89	306.15	1.67	1.78	1.49	1.19
May	33.35	34.67	34.01	31.78	46.64	328.25	2.77	2.77	2.48	1.76
Jun	34.19	35.72	34.96	33.18	50.46	317.66	3.24	3.21	2.94	2
Jul	31.88	33.19	32.53	31.29	61.57	328.25	2.29	2.89	2.59	1.59
Aug	31.77	33.05	32.41	29.98	65.54	328.25	2.31	3.02	2.73	1.59
Sep	32.77	34.1	33.43	29.3	57.48	317.66	2.7	3.07	2.78	1.75
Oct	33.79	34.29	34.04	25.35	48.51	326.72	2.9	3.06	3.61	2.19
Nov	29.53	29.72	29.62	19.5	44.11	263.41	1.45	1.48	2.18	1.28
Dec	24.45	24.36	24.4	14.76	46.66	107.26	-0.08	0.09	0.9	0.43
Total	**29.71**	**30.38**	**30.04**	**24.66**	**51.12**	**3098.66**	**1.60**	**1.84**	**2.06**	**1.27**

Table 1.17b HV

	Air Temperature	Radiant Temperature	Operative Temperature	Outside Dry BulbTemperature	Relative Humidity	Discomfort Hours	Fanger Pmv	Pierce Pmv ET	Pierce Pmv SET	Kansas Uni TSV
Jan	18.35	18.11	18.23	11.57	53.41	230.7	-1.88	-1.28	-0.42	-0.39
Feb	20.84	20.63	20.73	14.45	44.98	98.62	-1.2	-0.79	-0.01	-0.06
Mar	24.05	23.97	24.01	19.11	51.67	48.95	-0.19	0.04	0.73	0.32
Apr	28.66	29.1	28.88	25.48	44.25	202.11	0.6	1.27	0.94	0.74
May	30.05	30.55	30.3	27.1	52.36	261.38	1.28	1.85	1.5	1.07
Jun	31.88	32.63	32.26	29.35	57.03	252.02	2.2	2.65	2.34	1.53
Jul	31.99	32.7	32.35	29.54	64.97	261.38	2.35	3.02	2.72	1.62
Aug	31.07	31.58	31.32	28.2	73.8	260.97	2.01	3.01	2.71	1.44
Sep	30.4	30.84	30.62	26.73	68.61	252.43	1.62	2.49	2.17	1.26
Oct	28.78	29.09	28.93	21.95	52.1	213.39	1.32	1.53	2.13	1.22
Nov	23.58	23.76	23.67	15.29	43.95	29.36	-0.36	-0.13	0.58	0.26
Dec	19.75	19.66	19.71	12.26	47.35	164.28	-1.49	-1	-0.19	-0.19
Total	**26.62**	**26.89**	**26.75**	**21.75**	**54.54**	**2275.59**	**0.52**	**1.06**	**1.27**	**0.74**

Table 1.17c TR

	Air Temperature	Radiant Temperature	Operative Temperature	Outside Dry Bulb Temperature	Relative Humidity	Discomfort	Fanger PMV	Pierce PMV ET	Pierce PMV SET	Kansas Uni TSV
Jan	20.47	20.32	20.39	14.05	51.69	134.05	-1.1	-0.85	0.09	0.01
Feb	22.31	22.13	22.22	16.5	53.59	42.34	-0.57	-0.4	0.48	0.24
Mar	27.01	26.97	26.99	21.95	45.17	194.7	0.74	0.77	1.54	0.89
Apr	31.62	32	31.81	28.25	34.08	296.92	1.74	1.78	1.47	1.26
May	33.45	34.17	33.81	31.78	46.59	313.02	2.71	2.69	2.38	1.78
Jun	34.24	35.12	34.68	33.18	50.09	302.92	3.13	2.71	2.69	1.69
Jul	32.36	33.05	32.7	31.29	60.54	313.02	2.41	2.9	2.6	1.69
Aug	32.49	33.01	32.75	29.98	64.54	313.02	2.53	3.14	2.85	1.74
Sep	32.83	33.48	33.16	29.3	57.83	302.92	2.62	2.98	2.68	1.76
Oct	31.21	31.72	31.46	25.35	49.5	300.53	2.12	2.26	2.91	1.79
Nov	27.02	27.32	27.17	19.5	42.56	167.94	0.75	0.73	1.51	0.9
Dec	22.52	22.6	22.56	14.76	44.42	66.42	-0.54	-0.41	0.47	0.25
Total	**28.96**	**29.32**	**29.14**	**24.66**	**50.05**	**2747.80**	**1.38**	**1.53**	**1.81**	**1.17**

Table 1.17d BMD

	Air Temperature	Radiant Temperature	Operative Temperature	Outside Dry Bulb Temp.	Relative Humidity %	Discomfort hours (all clothing)	Fanger PMV	Pierce PMV ET	Pierce PMV SET	Kansas Uni TSV
Jan	20.27	20.14	20.21	14.05	53.25	140.67	-1.11	-0.92	0.12	0.02
Feb	21.79	21.78	21.78	16.5	55.13	32.29	-0.65	-0.54	0.46	0.17
Mar	26.35	26.68	26.52	21.95	46.06	168.25	0.62	0.65	1.52	0.75
Apr	34.04	34.11	34.08	28.25	36.38	292.18	2.77	2.48	2.2	1.7
May	36.52	37.02	36.77	31.78	43.69	302.71	4.06	3.53	3.26	2.36
Jun	37.69	38.37	38.03	33.18	45.23	292.94	4.66	3.99	3.75	2.69
Jul	34.75	35.32	35.04	31.29	55.66	302.71	3.51	3.83	3.57	2.21
Aug	34.81	35.26	35.03	29.98	59.83	302.71	3.51	3.83	3.57	2.21
Sep	35.4	35.9	35.65	29.3	53.44	292.94	3.69	3.69	3.42	2.24
Oct	31.76	32.67	32.22	25.35	47.69	298.45	2.32	2.44	3.14	1.89
Nov	26.4	27.13	26.77	19.5	42.71	144.08	0.65	0.62	1.49	0.78
Dec	21.88	22.15	22.02	14.76	45.58	52.36	-0.66	-0.57	0.42	0.16
Total	**30.14**	**30.54**	**30.34**	**24.66**	**48.72**	**2622.29**	**1.95**	**1.92**	**2.24**	**1.43**

Table 1.17e CV

	Air Temperature	Radiant Temperature	Operative Temperature	Outside Dry Bulb Temp.	Relative Humidity %	Discomfort hours (all clothing)	Fanger PMV	Pierce PMV ET	Pierce PMV SET	Kansas Uni TSV
Jan	16.53	16.62	16.58	11.57	59.05	256.6	-2.04	-1.59	-0.55	-0.44
Feb	19.18	19.39	19.29	14.45	48.79	150.15	-1.35	-1.09	-0.14	-0.17
Mar	23.29	23.61	23.45	19.11	52.87	84.65	-0.18	-0.09	0.74	0.31
Apr	28.71	29.41	29.06	25.48	44.12	264.34	1.58	1.28	2.64	1.59
May	29.47	30.32	29.89	27.1	53.6	320.16	1.88	1.84	3.12	1.79
Jun	31.53	32.6	32.06	29.35	58.45	311.3	2.48	2.78	3.89	2.22
Jul	31.68	32.71	32.19	29.54	67	320.79	2.62	3.27	4.28	2.27
Aug	30.6	31.54	31.07	28.2	75.91	321.17	2.44	3.33	4.33	1.99
Sep	29.73	30.67	30.2	26.73	71.35	310.92	2.16	2.73	3.85	1.85
Oct	26.89	27.81	27.35	21.95	56.76	244.3	0.99	1.15	1.88	1.03
Nov	21.44	22.02	21.73	15.29	49.67	98	-0.66	-0.53	0.35	0.07
Dec	17.4	17.73	17.57	12.26	54.05	259.22	-1.8	-1.42	-0.41	-0.34
Total	**25.54**	**26.20**	**25.87**	**21.75**	**57.64**	**2941.6**	**0.68**	**0.97**	**2.00**	**1.01**

Table 1.18 Discomfort Hours

	Baseline Model	Model 1	Model 2	Model 3	Model 4	Model 5	Model 1 (% change)	Model 2 (% change)	Model 3 (% change)	Model 4 (% change)	Model 5 (% change)
GMR	3098.7	3264.0	3202.9	3157.8	3132.9	3110.4	5.3%	3.4%	1.9%	1.1%	0.4%
HV	2275.6	2120.5	2152.0	2181.2	2209.3	2243.0	-6.8%	-5.4%	-4.1%	-2.9%	-1.4%
TR	2763.3	2754.2	2753.1	2752.9	2753.0	2755.5	-0.3%	-0.4%	-0.4%	-0.4%	-0.3%
BMD	2622.3	2569.7	2576.4	2580.1	2584.8	2597.0	-2.0%	-1.8%	-1.6%	-1.4%	-1.0%
CV	2941.6	2882.0	2897.8	2909.3	2920.8	2934.3	-2.0%	-1.5%	-1.1%	-0.7%	-0.2%

Model 1 : XPS Insulated; Model 2: AAC blocks ; Model 3: Concrete+Air Gap+ Concrete ;
Model 4: Concrete+Air Gap+ Brick ; Model 5: Brick+Air Gap+ Brick

Table 1.19 Comparison of Actual TSV with the Simulated Thermal Sensation Output

GMR

	TSV	Fanger Pmv	Pierce Pmv ET	Pierce Pmv SET	Kansas Uni TSV
Jan	-1.55	-0.82	-0.51	0.37	0.14
Feb	-1.10	-0.36	-0.1	0.72	0.29
Mar	-0.60	1.1	1.26	1.97	1.07
Apr	0.50	1.67	1.78	1.49	1.19
May	1.20	2.77	2.77	2.48	1.76
Jun	2.65	3.24	3.21	2.94	2
Jul	1.95	2.29	2.89	2.59	1.59
Aug	1.05	2.31	3.02	2.73	1.59
Sep	0.30	2.7	3.07	2.78	1.75
Oct	-0.45	2.9	3.06	3.61	2.19
Nov	-1.45	1.45	1.48	2.18	1.28
Dec	-2.30	-0.08	0.09	0.9	0.43

STDev 1	STDev 2	STDev 3	STDev 4
0.5	0.7	1.4	1.2
0.5	0.7	1.3	1.0
1.2	1.3	1.8	1.2
0.8	0.9	0.7	0.5
1.1	1.1	0.9	0.4
0.4	0.4	0.2	0.5
0.2	0.7	0.5	0.3
0.9	1.4	1.2	0.4
1.7	2.0	1.8	1.0
2.4	2.5	2.9	1.9
2.1	2.1	2.6	1.9
1.6	1.7	2.3	1.9

HV

	TSV	Fanger Pmv	Pierce Pmv ET	Pierce Pmv SET	Kansas Uni TSV
Jan	-1.33	-1.88	-1.28	-0.42	-0.39
Feb	-1.73	-1.2	-0.79	-0.01	-0.06
Mar	-0.60	-0.19	0.04	0.73	0.32
Apr	0.53	0.6	1.27	0.94	0.74
May	2.07	1.28	1.85	1.5	1.07
Jun	2.60	2.2	2.65	2.34	1.53
Jul	1.60	2.35	3.02	2.72	1.62
Aug	1.00	2.01	3.01	2.71	1.44
Sep	0.27	1.62	2.49	2.17	1.26
Oct	0.00	1.32	1.53	2.13	1.22
Nov	-1.07	-0.36	-0.13	0.58	0.26
Dec	-2.40	-1.49	-1	-0.19	-0.19

STDev 1	STDev 2	STDev 3	STDev 4
0.4	0.0	0.6	0.7
0.4	0.7	1.2	1.2
0.3	0.5	0.9	0.7
0.0	0.5	0.3	0.1
0.6	0.2	0.4	0.7
0.3	0.0	0.2	0.8
0.5	1.0	0.8	0.0
0.7	1.4	1.2	0.3
1.0	1.6	1.3	0.7
0.9	1.1	1.5	0.9
0.5	0.7	1.2	0.9
0.6	1.0	1.6	1.6

TR

	TSV	Fanger Pmv	Pierce Pmv ET	Pierce Pmv SET	Kansas Uni TSV
Jan	-1.40	-1.1	-0.85	0.09	0.01
Feb	-1.13	-0.57	-0.4	0.48	0.24
Mar	-0.80	0.74	0.77	1.54	0.89
Apr	0.40	1.74	1.78	1.47	1.26
May	1.27	2.71	2.69	2.38	1.78
Jun	2.67	3.13	2.71	2.69	1.69
Jul	1.47	2.41	2.9	2.6	1.69
Aug	0.67	2.53	3.14	2.85	1.74
Sep	0.20	2.62	2.98	2.68	1.76
Oct	-0.47	2.12	2.26	2.91	1.79
Nov	-1.20	0.75	0.73	1.51	0.9
Dec	-2.40	-0.54	-0.41	0.47	0.25

STDev 1	STDev 2	STDev 3	STDev 4
0.2	0.4	1.1	1.0
0.4	0.5	1.1	1.0
1.1	1.1	1.7	1.2
0.9	1.0	0.8	0.6
1.0	1.0	0.8	0.4
0.3	0.0	0.0	0.7
0.7	1.0	0.8	0.2
1.3	1.7	1.5	0.8
1.7	2.0	1.8	1.1
1.8	1.9	2.4	1.6
1.4	1.4	1.9	1.5
1.3	1.4	2.0	1.9

BMD

	TSV	Fanger Pmv	Pierce Pmv ET	Pierce Pmv SET	Kansas Uni TSV
Jan	-1.85	-1.11	-0.92	0.12	0.02
Feb	-1.08	-0.65	-0.54	0.46	0.17
Mar	-0.69	0.62	0.65	1.52	0.75
Apr	0.31	2.77	2.48	2.2	1.7
May	1.54	4.06	3.53	3.26	2.36
Jun	2.54	4.66	3.99	3.75	2.69
Jul	1.85	3.51	3.83	3.57	2.21
Aug	1.00	3.51	3.83	3.57	2.21
Sep	0.38	3.69	3.69	3.42	2.24
Oct	-0.31	2.32	2.44	3.14	1.89
Nov	-0.85	0.65	0.62	1.49	0.78
Dec	-2.46	-0.66	-0.57	0.42	0.16

	STDev 1	STDev 2	STDev 3	STDev 4
Jan	0.5	0.7	1.4	1.3
Feb	0.3	0.4	1.1	0.9
Mar	0.9	0.9	1.6	1.0
Apr	1.7	1.5	1.3	1.0
May	1.8	1.4	1.2	0.6
Jun	1.5	1.0	0.9	0.1
Jul	1.2	1.4	1.2	0.3
Aug	1.8	2.0	1.8	0.9
Sep	2.3	2.3	2.1	1.3
Oct	1.9	1.9	2.4	1.6
Nov	1.1	1.0	1.7	1.1
Dec	1.3	1.3	2.0	1.9

CV

	TSV	Fanger Pmv	Pierce Pmv ET	Pierce Pmv SET	Kansas Uni TSV
Jan	-1.05	-2.04	-1.59	-0.55	-0.44
Feb	-1.79	-1.35	-1.09	-0.14	-0.17
Mar	-0.58	-0.18	-0.09	0.74	0.31
Apr	0.63	1.58	1.28	2.64	1.59
May	1.68	1.88	1.84	3.12	1.79
Jun	2.53	2.48	2.78	3.89	2.22
Jul	1.58	2.62	3.27	4.28	2.27
Aug	1.00	2.44	3.33	4.33	1.99
Sep	0.16	2.16	2.73	3.85	1.85
Oct	-0.53	0.99	1.15	1.88	1.03
Nov	-1.16	-0.66	-0.53	0.35	0.07
Dec	-2.63	-1.8	-1.42	-0.41	-0.34

	STDev 1	STDev 2	STDev 3	STDev 4
Jan	0.7	0.4	0.4	0.4
Feb	0.3	0.5	1.2	1.1
Mar	0.3	0.3	0.9	0.6
Apr	0.7	0.5	1.4	0.7
May	0.1	0.1	1.0	0.1
Jun	0.0	0.2	1.0	0.2
Jul	0.7	1.2	1.9	0.5
Aug	1.0	1.6	2.4	0.7
Sep	1.4	1.8	2.6	1.2
Oct	1.1	1.2	1.7	1.1
Nov	0.4	0.4	1.1	0.9
Dec	0.6	0.9	1.6	1.6

Table 1.20 Estimated Predicted Mean Vote (PMV) using CBE Thermal Comfort Tool (All Data)

[CBE Thermal Comfort Tool. Center for the Built Environment, University of California Berkeley]

	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
S.No.	**PMV (as per tool)**	**PPD (as per tool)**	**PMV (as per tool)**	**PPD (as per tool)**	**PMV (as per tool)**	**PPD (as per tool)**	**PMV (as per tool)**	**PPD (as per tool)**	**PMV (as per tool)**	**PPD (as per tool)**	**PMV (as per tool)**	**PPD (as per tool)**	**PMV (as per tool)**	**PPD (as per tool)**	**PMV (as per tool)**	**PPD (as per tool)**	**PMV (as per tool)**	**PPD (as per tool)**	**PMV (as per tool)**	**PPD (as per tool)**	**PMV (as per tool)**	**PPD (as per tool)**	**PMV (as per tool)**	**PPD (as per tool)**
1	0.89	22	0.44	9	-1.56	54	1.18	34	2.30	88	2.85	98	1.94	74	1.47	49	0.59	12	-1.04	28	0.51	10	-1.13	32
2	0.76	17	-1.97	75	-0.70	15	0.66	14	0.91	23	2.71	97	2.25	87	-1.16	33	1.24	37	-0.37	8	0.18	6	-0.48	10
3	-1.42	47	-1.43	47	-2.53	94	0.10	5	1.61	57	1.91	73	1.92	73	0.59	12	0.51	11	0.24	6	0.70	0	-1.96	75
4	-0.67	14	0.23	6	1.26	38	0.39	8	1.93	73	1.98	76	2.46	93	1.76	65	1.47	49	-0.40	8	-0.13	5	0.42	9
5	-1.57	55	-0.64	14	-2.12	82	0.90	22	1.45	48	2.20	85	1.49	50	-0.38	8	1.06	29	1.27	39	-1.20	35	-2.10	81
6	-0.13	5	-2.13	82	-1.30	5	1.88	71	1.11	31	3.18	100	2.67	96	1.41	46	1.65	59	1.52	52	-0.22	6	-0.64	14
7	-1.78	66	-0.91	22	-0.89	22	-0.46	9	1.28	39	1.78	66	0.90	22	-0.26	6	1.78	66	-0.16	6	-1.21	36	-1.23	37
8	-2.10	81	-0.38	8	-1.86	70	0.52	11	1.47	49	2.15	83	1.63	58	-1.64	59	0.24	6	1.61	57	0.95	24	-1.17	34
9	0.10	5	0.10	5	-0.32	7	1.70	62	1.55	54	2.79	98	2.39	91	1.56	54	0.25	6	1.34	42	-1.48	50	0.24	6
10	-3.27	100	-2.18	84	-1.39	45	0.13	5	2.17	84	1.91	73	1.12	32	-0.35	8	0.08	5	0.26	6	-2.10	81	-2.46	92
11	-0.61	13	0.47	10	0.86	21	1.29	40	1.55	54	1.79	67	2.52	94	1.74	64	0.36	8	1.05	28	0.53	11	-0.39	8
12	-2.71	97	-3.89	100	-1.74	64	0.45	9	2.65	96	1.96	75	1.36	43	-0.27	7	0.06	5	-0.11	5	-2.59	95	-2.39	91
13	-1.89	72	-0.99	26	-0.51	10	1.62	57	1.84	69	2.30	88	1.48	50	0.69	15	2.04	79	0.21	6	0.10	5	0.38	8
14	-1.44	48	-1.70	62	-1.69	61	-0.44	9	1.96	75	2.12	82	1.79	66	-0.54	11	0.25	6	-0.04	5	-0.09	5	-2.23	86
15	-1.31	41	0.25	6	-1.74	64	1.53	52	1.74	64	1.79	67	1.67	60	0.96	24	-0.50	10	0.08	5	-1.94	74	-0.51	10
16	-2.66	96	-1.32	41	-0.72	16	0.50	10	1.80	67	2.02	77	1.38	45	0.22	6	0.56	12	-0.68	15	-1.17	34	-2.16	83
17	0.45	9	-2.43	92	-1.93	74	0.31	7	2.47	93	2.06	79	1.56	54	1.50	51	-0.24	6	-0.13	5	-3.51	100	0.16	6
18	-0.78	18	-3.06	99	-2.25	87	0.90	22	1.55	54	2.02	77	1.79	67	0.47	10	0.08	5	-1.05	28	-1.75	64	-1.78	66
19	-1.16	34	-1.62	57	-2.20	85	0.76	17	1.64	58	1.74	64	1.21	36	-0.80	19	0.96	24	-0.41	9	-1.00	26	-2.22	86
20	-0.81	19	-2.22	86	-0.69	15	-0.06	5	1.50	51	2.71	97	1.65	59	-0.19	6	-0.06	5	1.23	37	-3.07	99	0.52	11
21	-0.56	11	-1.82	68	-0.56	12	1.35	43	2.32	89	2.52	94	2.42	92	-0.29	7	0.10	5	-0.14	5	-1.18	34	-0.39	8
22	0.37	8	0.21	6	0.09	5	0.56	12	2.38	91	2.20	85	2.55	94	1.42	47	0.11	5	-1.59	56	0.56	11	0.34	7
23	-3.03	99	-0.94	24	-0.10	5	0.83	20	1.55	54	2.72	97	1.42	47	1.41	46	1.52	52	0.26	6	-0.39	8	-1.87	71
24	-3.88	100	-2.29	88	0.42	9	1.84	69	1.09	30	2.31	88	2.06	79	1.64	59	0.06	5	1.77	65	0.05	5	-2.43	92
25	-2.00	77	0.44	9	-0.32	7	1.92	73	1.73	63	2.99	99	2.63	96	-0.50	10	1.53	53	1.96	75	-0.78	18	0.18	6
26	-2.89	99	-1.36	44	-0.92	23	1.89	71	1.84	69	2.74	97	1.72	63	0.04	5	-0.06	5	0.24	6	-1.09	30	-2.41	91
27	-3.47	100	-2.63	96	-1.82	68	0.35	8	1.38	44	2.74	97	1.26	38	1.75	64	1.84	69	-0.50	10	-0.80	19	0.38	8
28	0.13	5	-0.94	24	-1.58	55	0.49	10	1.39	45	2.23	86	1.67	60	1.44	48	-0.98	25	1.21	36	-1.38	44	0.07	5
29	-2.63	96	0.32	7	0.27	6	-0.33	7	1.05	28	2.13	82	1.54	53	1.60	57	1.41	46	-1.03	27	-2.25	87	-2.28	88
30	-2.59	95	-1.17	34	-0.88	21	1.86	70	2.52	94	2.20	85	1.55	53	-0.57	12	-0.48	10	-0.59	12	0.21	6	-0.43	9
31	-3.26		-2.59	95	-0.11	5	0.25	6	1.33	42	2.33	89	1.36	43	-0.95	24	-0.04	5	0.20	6	-1.45	48	-2.51	94
32	0.11	5	-0.82	19	-0.61	13	-0.61	13	1.85	70	1.99	76	1.66	60	1.34	42	-0.76	17	1.31	41	0.15	5	-1.17	34
33	-1.09	30	-0.80	19	-1.93	74	1.38	45	1.00	26	2,52	94	2.77	97	-0.11	5	0.32	7	-0.27	7	0.39	8	-2.23	86
34	-3.52	100	-0.77	18	-0.91	23	0.69	15	0.83	20	2.34	89	1.64	59	-1.00	26	0.08	5	0.39	8	-3.35	100	-0.81	19
35	-2.91	99	-0.80	90	-1.93	74	0.19	6	1.41	46	2.22	85	1.98	76	-0.11	5	0.32	7	-0.27	7	-1.45	48	-1.12	32
36	-1.12	31	-1.55	54	-0.88	21	1.10	30	1.63	58	2.78	98	1.65	59	-1.14	32	0.00	5	-1.24	37	-1.84	69	-2.69	97
37	0.66	14	0.17	6	0.56	12	1.57	55	1.43	47	2.83	98	2.59	95	1.35	43	1.77	65	1.25	38	-1.01	27	-1.06	29
38	-1.46	49	-1.98	76	-0.52	11	0.65	14	2.24	86	2.89	98	1.99	77	0.46	9	0.40	8	0.49	10	-0.42	9	-1.30	40
39	0.65	14	-1.97	75	-1.98	76	-0.23	6	2.16	83	2.40	91	1.73	63	-0.74	17	0.65	14	-1.71	62	0.00	5	0.50	10
40	-2.03	78	-1.36	43	-1.88	71	0.56	12	1.35	43	2.22	86	2.43	92	0.02	5	1.42	46	1.15	33	0.67	14	-0.41	8
41	-0.52	11	-2.31	89	-0.84	20	-0.44	9	1.05	28	3.04	99	1.37	44	-0.76	17	-0.62	13	1.01	3	-0.45	9	0.32	7
42	-0.88	21	-2.01	77	-2.43	92	1.79	66	2.51	94	2.16	84	2.13	82	-0.53	11	0.31	7	-0.13	5	0.60	13	-2.07	80
43	-1.01	26	-2.24	86	-1.66	59	0.24	6	1.87	70	2.48	93	1.87	71	0.37	8	0.31	7	1.45	48	0.72	16	-1.14	33
44	-2.48	93	-1.36	43	-0.27	6	1.53	53	1.64	58	2.14	83	1.65	.59.	-1.16	33	0.90	22	0.70	15	-0.74	17	-1.49	50
45	-1.79	67	-2.48	93	0.16	6	0.92	23	2.47	93	3.00	999	1.63	58	-0.90	22	-0.08	5	0.34	7	-2.03	78	0.46	9
46	-3.17	100	-2.50	93	-1.79	66	0.58	12	0.82	19	2.19	85	1.51	51	-0.92	23	-0.11	5	-1.23	37	0.02	5	-1.55	53
47	-3.01	99	-1.64	59	-2.06	80	1.14	32	1.09	30	2.19	84	1.24	37	-0.32	7	-0.41	8	0.04	5	-2.10	81	-0.83	20
48	-2.77	98	-1.38	44	-0.89	22	0.62	13	0.85	20	2.07	80	1.81	67	-0.44	9	0.24	6	-1.13	32	-0.04	5	-1.76	65

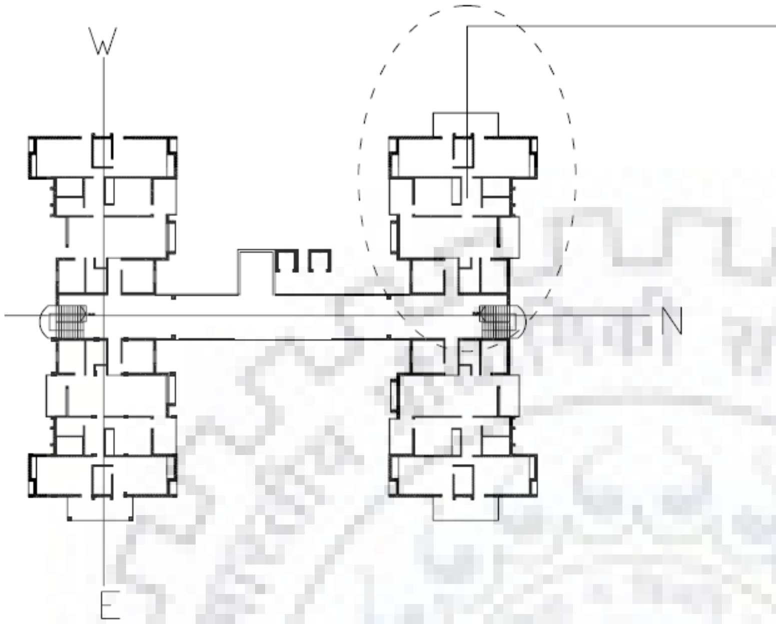
49	0.19	6	-0.88	21	0.24	6	0.21	6	2.30	88	2.15	83	1.51	52	-0.09	5	-0.24	6	1.08	30	-1.56	54	-1.41	46
50	-1.50	51	0.00	5	-0.68	15	0.91	23	1.20	35	1.35	43	1.35	43	-0.81	19	0.53	11	1.00	26	-2.13	82	-2.60	95
51	-3.39	100	-1.18	34	-1.15	33	0.05	5	1.20	35	1.65	59	1.50	51	0.47	10	-0.19	6	-0.22	6	-2.50	93	-3.43	100
52	-2.40	91	-1.29	40	-3.52	100	-0.28	7	2.40	91	1.62	57	2.31	89	1.04	28	-0.73	16	-1.17	34	-3.60	100	-2.40	91
53	0.75	17	-2.66	96	0.43	9	1.90	72	2.27	87	-0.58	12	2.46	93	-0.12	5	1.29	40	0.18	6	-3.36	100	-3.28	100
54	-1.28	39	-2.66	96	-2.08	80	0.73	16	1.63	58	0.09	5	1.27	39	0.52	11	-0.72	16	-0.11	5	-0.71	16	0.29	7
55	-2.92	99	-0.48	10	-0.80	19	0.37	8	1.07	29	0.57	12	1.27	39	-0.73	16	-0.03	5	-1.86	70	-0.71	16	-3.12	100
56	0.47	10	0.40	8	-0.14	5	1.87	71	2.43	92	2.02	78	1.41	46	-1.04	28	0.58	12	0.67	14	0.69	15	-0.34	7
57	0.33	7	-2.41	91	-0.88	21	0.38	8	1.53	52	0.66	14	1.41	46	0.35	8	0.25	6	-0.45	9	-1.18	34	-1.10	31
58	-2.38	91	0.00	5	0.65	14	0.51	10	1.62	58	0.79	18	1.75	64	-0.49	10	0.16	6	1.45	48	0.83	19	-1.24	37
59	-1.69	61	-2.71	97	0.20	6	1.39	45	1.20	35	0.54	11	2.32	89	1.57	54	1.35	43	1.24	37	0.91	23.00	0.58	12
60	-1.45	48	-1.37	44	-1.62	58	0.24	6	1.82	68	2.45	91	1.25	38	-1.59	56	-0.62	13	-1.19	35	-1.83	6	-2.99	99
61	-2.17	84	0.25	6	-1.40	45	-0.36	8	1.29	40	1.35	43	1.37	44	-0.58	12	-0.10	5	-1.19	35	-1.29	40	-4.77	100
62	-1.27	39	-2.16	83	-3.35	100	0.46	9	0.94	24	2.51	94	2.62	96	-0.44	9	-0.73	16	0.35	8	-0.60	13	-0.31	7
63	0.15	5	-0.01	5	-0.03	5	1.60	57	2.40	91	2.19	84	2.31	89	1.77	65	0.20	6	0.63	13	0.80	18	0.16	6
64	-2.31	89	-1.28	39	0.38	8	1.50	51	2.32	89	1.56	54	1.41	46	-0.58	12	0.23	6	-2.12	82	-1.31	41	-2.47	93
65	-1.50	51	-1.07	29	-1.78	66	0.25	6	2.51	94	1.41	46	1.49	51	-0.88	21	-0.47	10	-1.68	61	0.00	5	-1.32	41
66	-0.08	5	0.50	10	-4.05	100	0.07	5	2.07	80	2.87	98	1.37	44	-0.31	7	-0.82	19	1.25	38	-0.63	13	-2.39	91
67	-0.58	12	-0.66	14	-1.91	73	0.07	5	1.73	63	1.74	64	1.69	61	-0.48	10	-0.82	19	0.73	16	0.04	5	-1.08	30
68	0.70	15	-2.12	82	-1.35	43	1.83	68	2.56	95	1.73	63	1.46	49	0.20	6	-0.04	5	0.71	16	0.35	8	-1.92	73
69	0.79	18	-0.83	20	-0.71	16	0.57	12	2.71	97	1.77	65	0.74	16	-1.03	27	-0.23	6	1.65	59	-0.47	10	0.23	6
70	-1.27	39	-2.08	80	0.74	17	1.15	33	2.04	79	2.27	87	1.97	76	0.99	26	0.93	23	0.60	13	-0.47	10	-1.81	68
71	0.56	12	0.12	5	-1.44	48	0.54	11	2.45	92	2.65	96	2.42	92	-0.86	20	1.59	56	1.04	28	-0.21	6	0.50	10
72	-1.59	56	-4.47	100	0.59	12	-0.57	12	2.61	95	1.89	71	1.24	37	-0.57	12	-0.41	8	-2.11	81	-2.21	85	-3.34	100
73	-1.97	75	-1.27	39	-0.78	18	0.11	5	2.61	95	2.41	91	1.46	49	-0.30	7	-0.41	8	-1.33	42	-0.35	8	0.19	6
74	0.06	5	-2.33	89	-0.82	19	1.59	56	2.47	93	1.83	69	2.47	93	1.46	49	0.11	5	-0.21	6	-1.77	66	-1.26	38
75	0.81	19	-0.03	5	-0.62	13	-0.52	11	1.91	73	1.36	43	1.42	47	-0.29	7	-0.29	7	-1.65	59	0.66	14	-3.19	100
76	-0.87	21	-2.97	99	-0.88	21	0.26	6	1.66	59	1.14	32	1.01	27	-0.25	6	-0.42	9	0.35	8	-0.04	5	-1.37	44
77	-1.58	55	0.18	6	0.63	13	0.79	18	1.95	75	2.42	92	2.19	84	-0.02	5	1.61	57	1.76	65	0.54	11	0.13	5
78	-2.06	79	0.35	8	0.24	6	1.79	66	1.57	55	2.44	92	1.27	39	1.68	60	-0.47	10	1.42	46	0.56	12	-1.23	37
79	-0.02	5	0.30	7	-0.41	8	0.38	8	2.72	97	2.66	96	1.14	32	0.59	12	1.46	49	1.90	72	1.24	37	0.37	8
80	-3.52	100	-0.58	12	-0.15	5	0.14	5	2.65	96	1.81	68	1.25	38	-1.17	34	1.66	60	-0.07	5	-0.01	5	-3.52	100
81	-2.18	84	-1.27	39	-0.18	6	1.24	37	2.19	85	2.55	94	1.92	73	-0.51	10	0.25	6	1.05	28	-1.15	33	-1.32	41
82	-1.97	75	-2.38	91	-2.06	79	-0.24	6	2.23	86	2.42	92	2.33	89	0.11	5	1.36	43	1.68	61	-0.78	18	-0.97	25

[CBE Thermal Comfort Tool. Center for the Built Environment, University of California Berkeley]

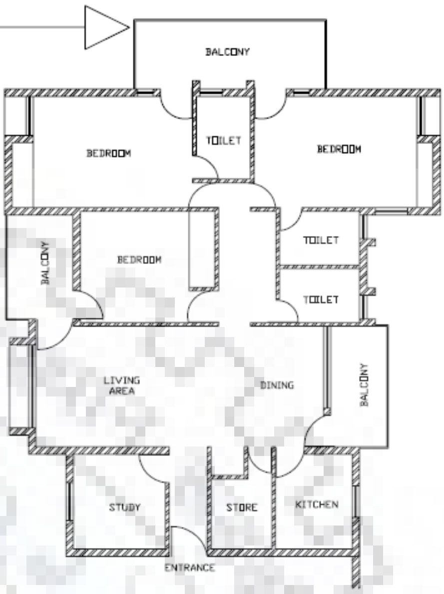
S.No.	Ta	Tg (°C)	Av	RH (%)	Mean	clo	met	TS	TS	PMV	PPD
1	17.9	18.2	0	46.3	18.2	1.6	2	-2	-1	0.89	22
2	15.8	16.3	0	60.9	16.3	1.8	1.6	-3	-1	0.76	17
3	18.3	19.3	0.7	47	21.3	1.8	0.8	-1	-1	-1.42	47
4	17.4	18.7	0.1	50.4	19.5	2.2	0.8	-3	-1	-0.67	14
5	17.4	18.7	0.1	50.4	19.5	0.9	1	-2	-2	-1.57	55
6	17.0	17.8	0	49.7	17.8	1.0	1.6	0	0	-0.13	5
7	16.3	16.9	0	54.8	16.9	1.0	1	0	-2	-1.78	66
8	17.0	17.3	0	51.8	17.3	1.4	0.8	0	-2	-2.10	81
9	15.6	15.7	0	56.9	15.7	1.4	1.6	-1	0	0.10	5
10	17.6	18.0	0	47	18.0	0.9	0.8	0	-3	-3.27	100
11	18.0	18.7	0	45	18.7	1.4	1	-2	-1	-0.61	13
12	18.0	18.7	0	45	18.7	1.0	0.8	-1	-3	-2.71	97
976	15.7	16.2	0	60.3	16.2	1.3	1	-2	-1	-1.26	38
977	15.7	16.2	0	60.3	16.2	1.1	0.8	-3	-3	-3.19	100
978	15.2	15.7	0	63.6	15.7	1.3	1	-2	-1	-1.37	44
979	15.5	16.1	0	62.5	16.1	1.4	1.6	-3	0	0.13	5

980	15.8	16.4	0	60.2	16.4	1.3	1	-3	-1	-1.23	37
981	15.5	15.8	0	63.1	15.8	1.7	1.6	-3	0	0.37	8
982	15.4	16.5	0	63.2	16.5	1.0	0.8	-2	-3	-3.52	100
983	15.5	15.8	0	63.1	15.8	1.3	1	-3	-1	-1.32	41
984	15.5	15.8	0	63.1	15.8	1.5	1	-3	-1	-0.97	25

Fig1.1 a,b,c,d &e: Geometric Representaion Of Baseline Models



Key Plan of Hill View (HV)



Floor Plan of Dwelling Unit (HV)

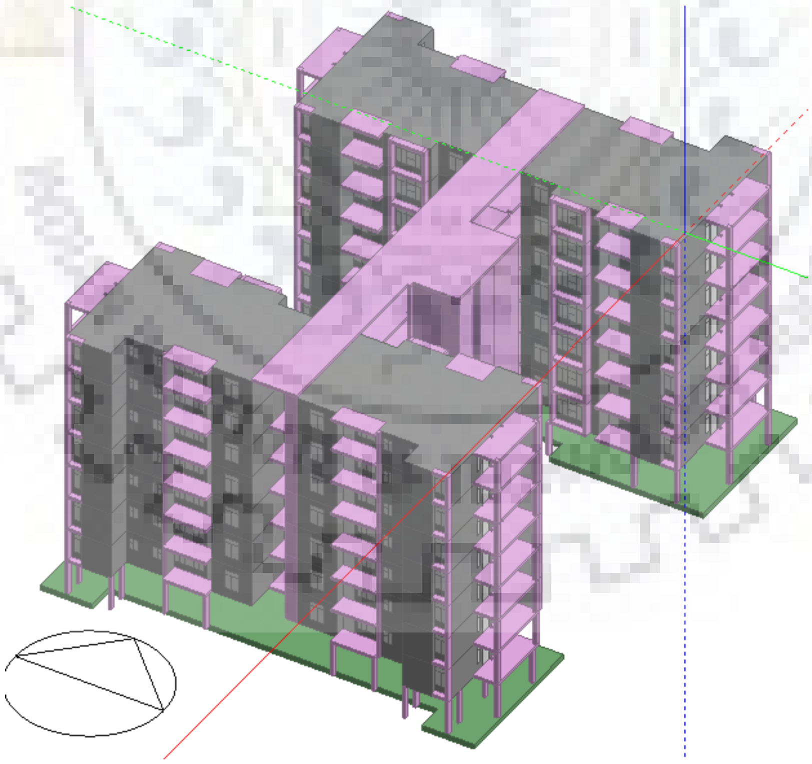
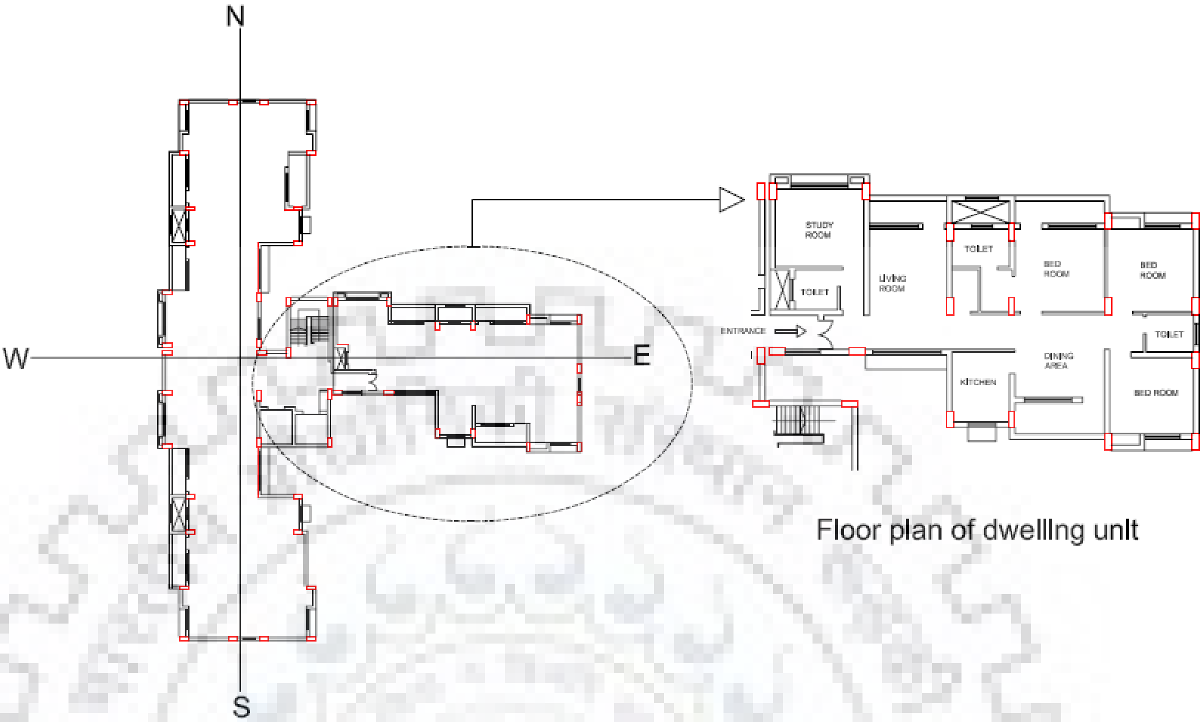


Fig 1.1 a Hill View (HV)



Floor plan of dwelling unit

Key plan of Canal View (CV)

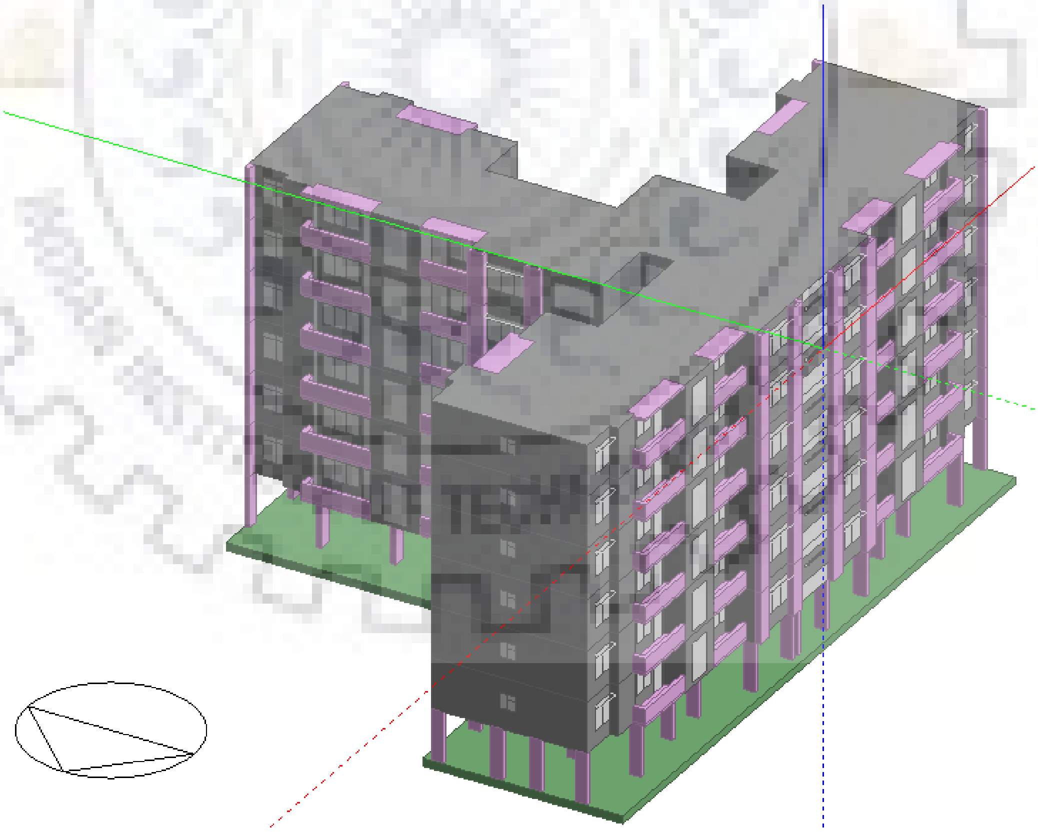
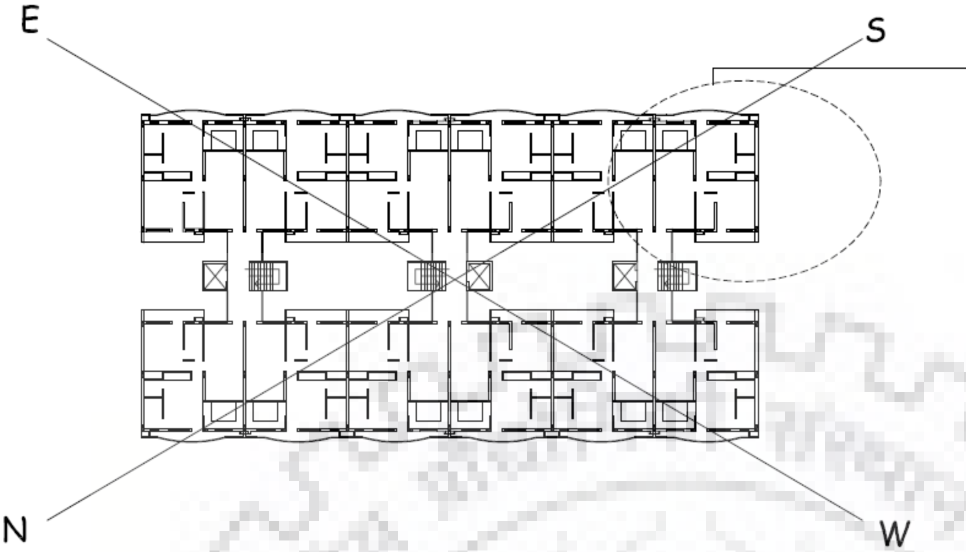


Fig 1.1b Canal View (CV)



Floor Plan of Single Unit (TR)

Key Plan of Trishla (TR)

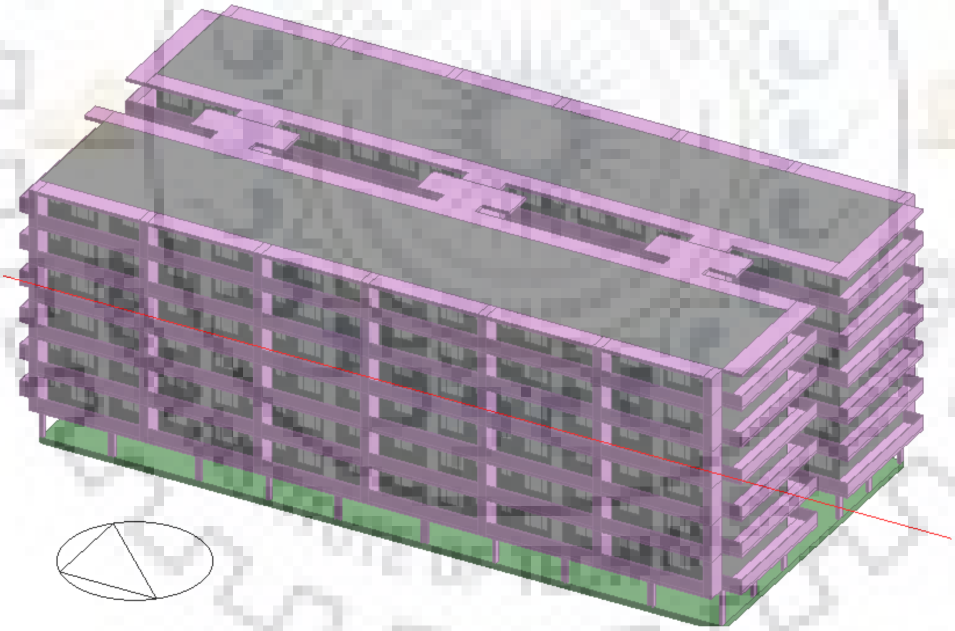
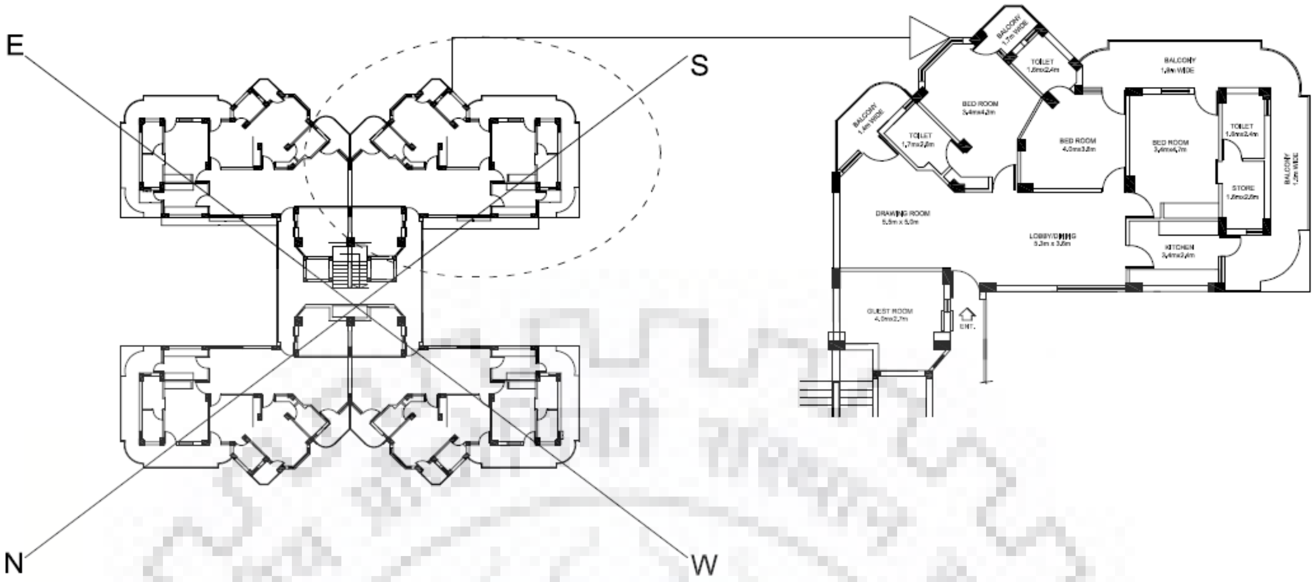


Fig 1.1c Trishla (TR)



Key Plan of BhaiMata Das (BMD)

Floor Plan of BhaiMata Das (BMD)

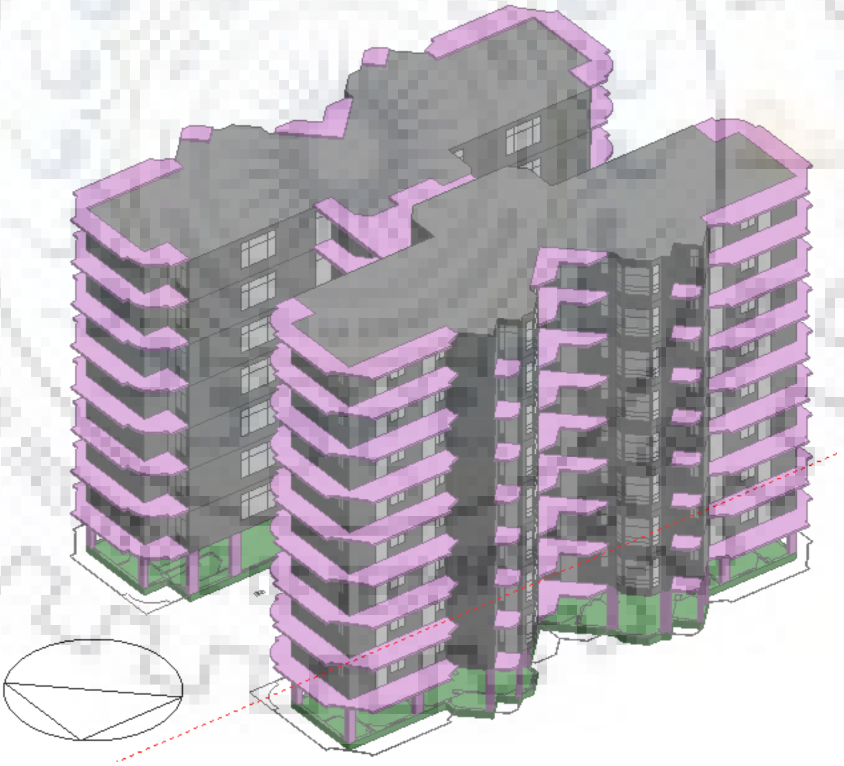
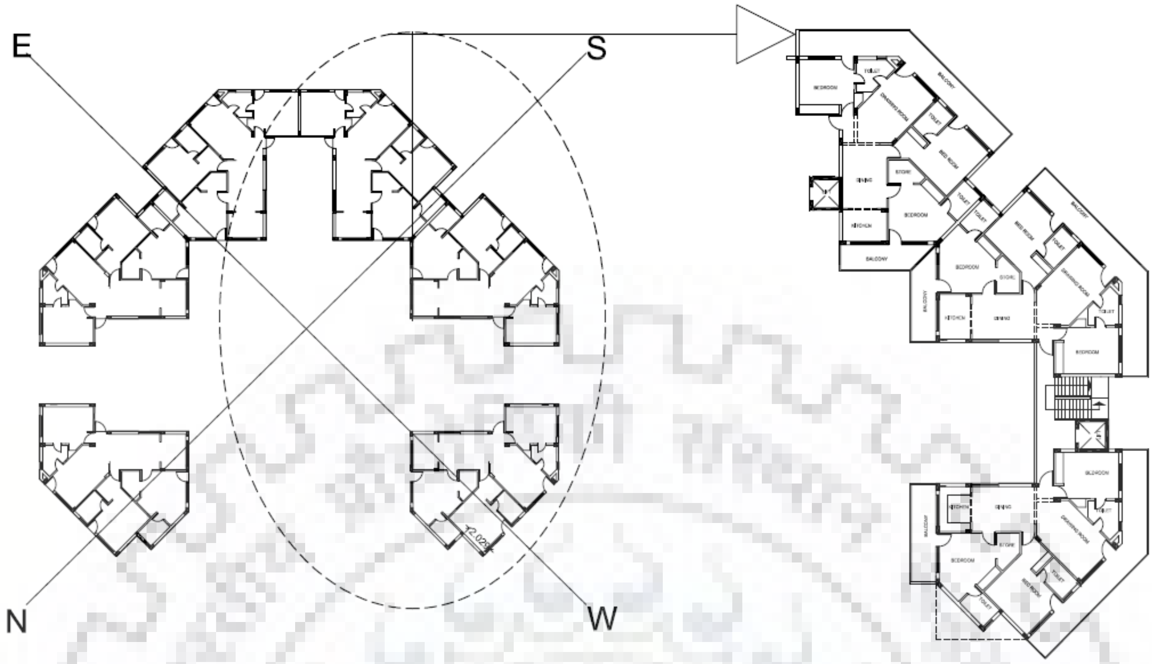


Fig 1.1d BhaiMata Das(BMD)



Key plan of Growmore (GMR)

Floor plan of Growmore (GMR)

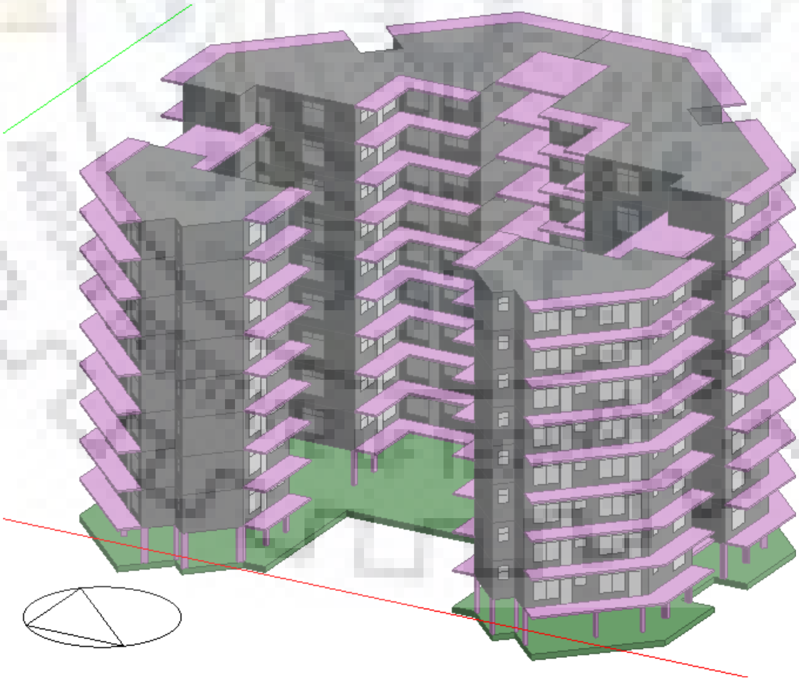


Fig 1.1e Growmore(GMR)

Fig 1.2a-i Construction Details of Baseline Model

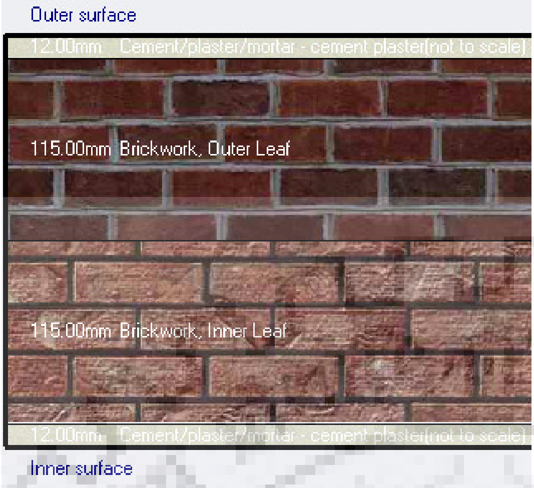


Fig 1.2a External Wall

Fig 1.2b Internal Brick Wall Partition

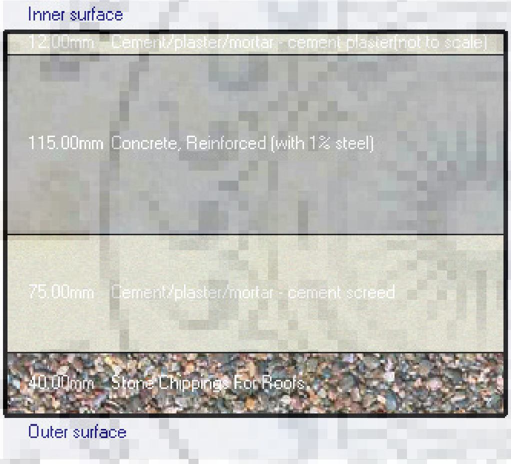


Fig 1.2c Stone Chipping Suspended Semi Exposed Floors

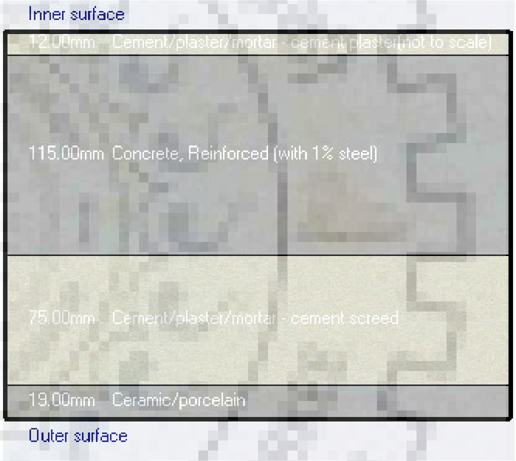


Fig 1.2d Ceramic Porcelain Suspended Floors

Fig 1.2e Kota Semi Exposed Floor Slab

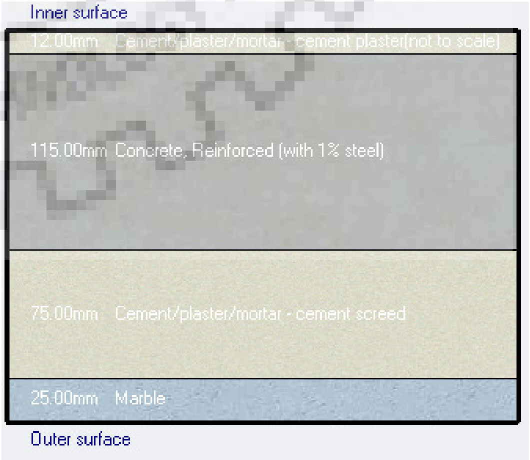
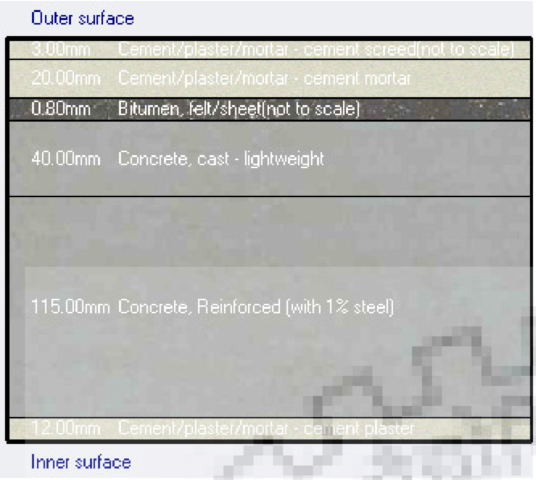


Fig 1.2f Marbles Suspended Floors



Outer surface

3.00mm Cement/plaster/mortar - cement screed(not to scale)

20.00mm Cement/plaster/mortar - cement mortar

0.80mm Bitumen, felt/sheet(not to scale)

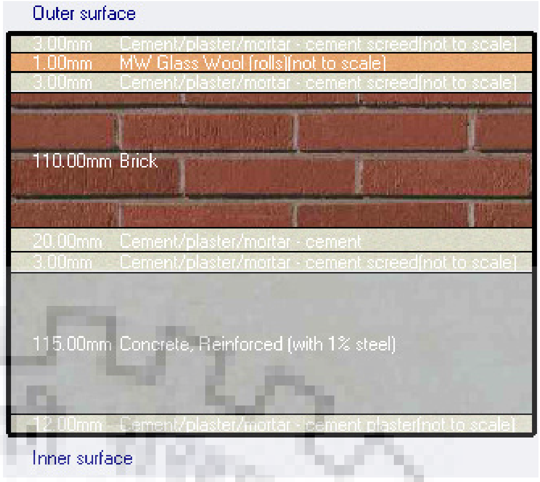
40.00mm Concrete, cast - lightweight

115.00mm Concrete, Reinforced (with 1% steel)

12.00mm Cement/plaster/mortar - cement plaster

Inner surface

Fig 1.2g Bitumen Felt Roof



Outer surface

3.00mm Cement/plaster/mortar - cement screed(not to scale)

1.00mm MW Glass Wool (rolls)(not to scale)

3.00mm Cement/plaster/mortar - cement screed(not to scale)

110.00mm Brick

20.00mm Cement/plaster/mortar - cement

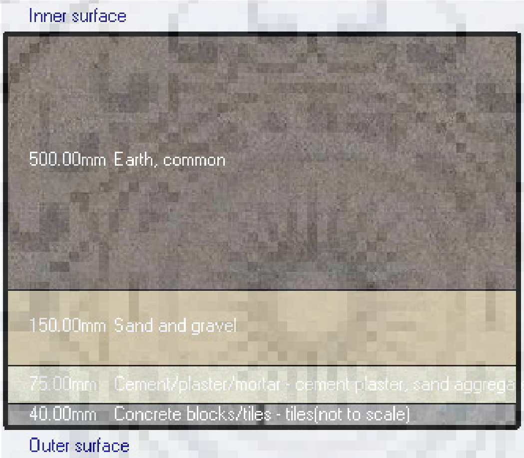
3.00mm Cement/plaster/mortar - cement screed(not to scale)

115.00mm Concrete, Reinforced (with 1% steel)

12.00mm Cement/plaster/mortar - cement plaster(not to scale)

Inner surface

Fig 1.2h Coba Waterproof Roofing



Inner surface

500.00mm Earth, common

150.00mm Sand and gravel

75.00mm Cement/plaster/mortar - cement plaster, sand aggrega

40.00mm Concrete blocks/tiles - tiles(not to scale)

Outer surface

Fig 1.2i Ground Floor

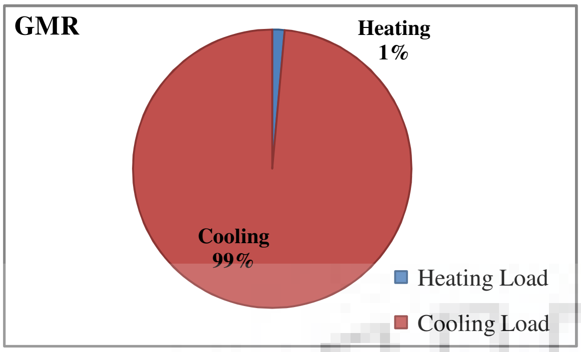


Fig 1.3a

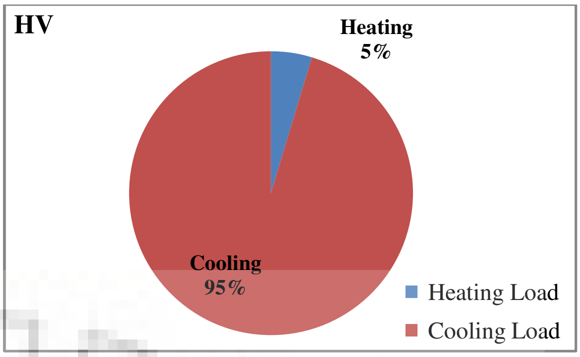


Fig 1.3b

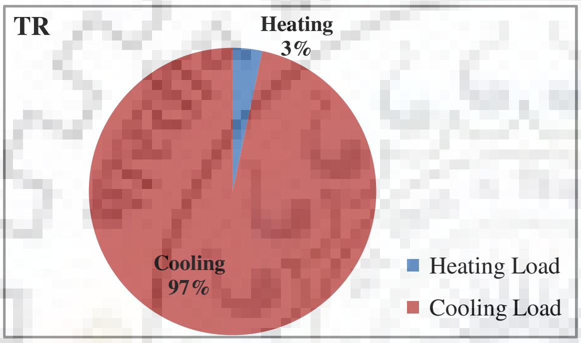


Fig 1.3c

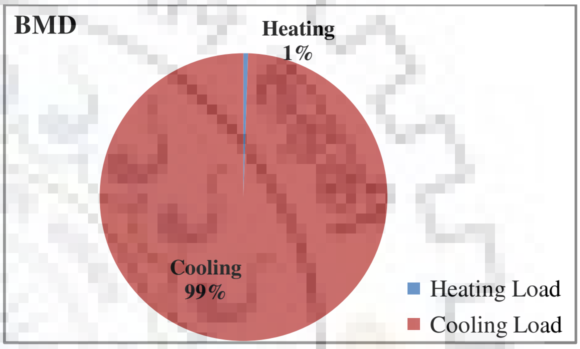


Fig 1.3d

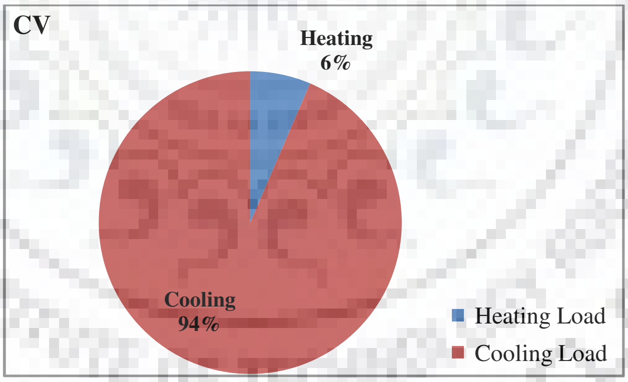


Fig 1.3e

Fig 1.3a-e Annual Heating/Cooling Load

Fig 1.5 (a,b,c,d &e) Percentage Distribution of Internal Gains

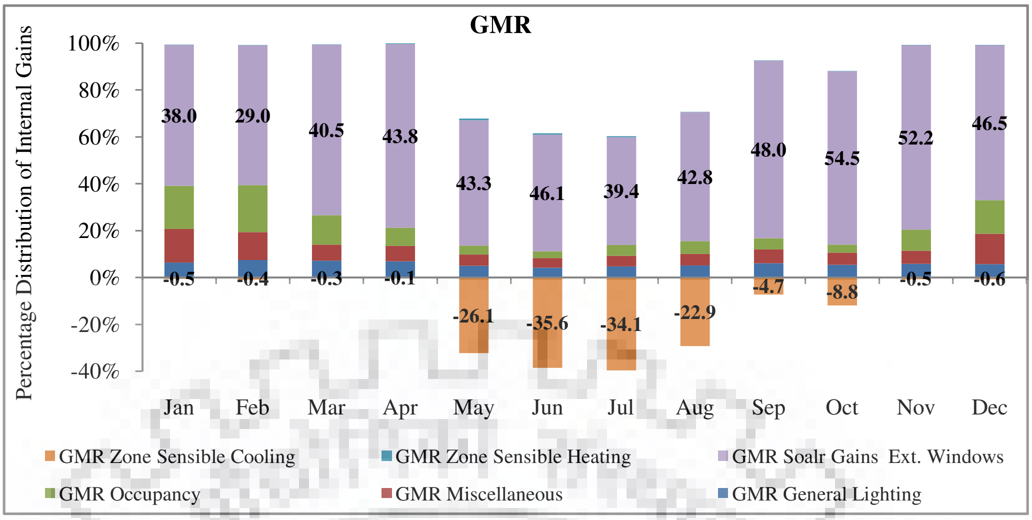


Fig 1.5a

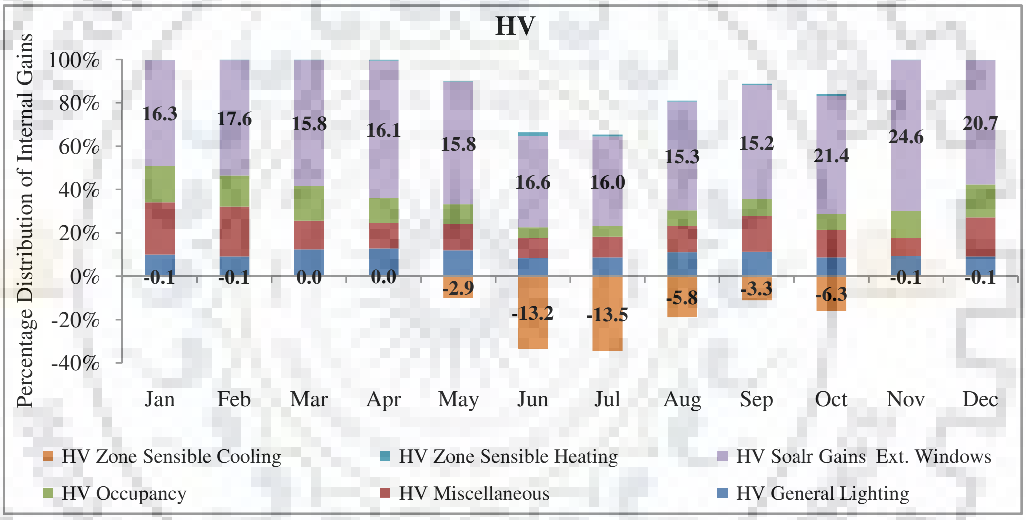


Fig 1.5b

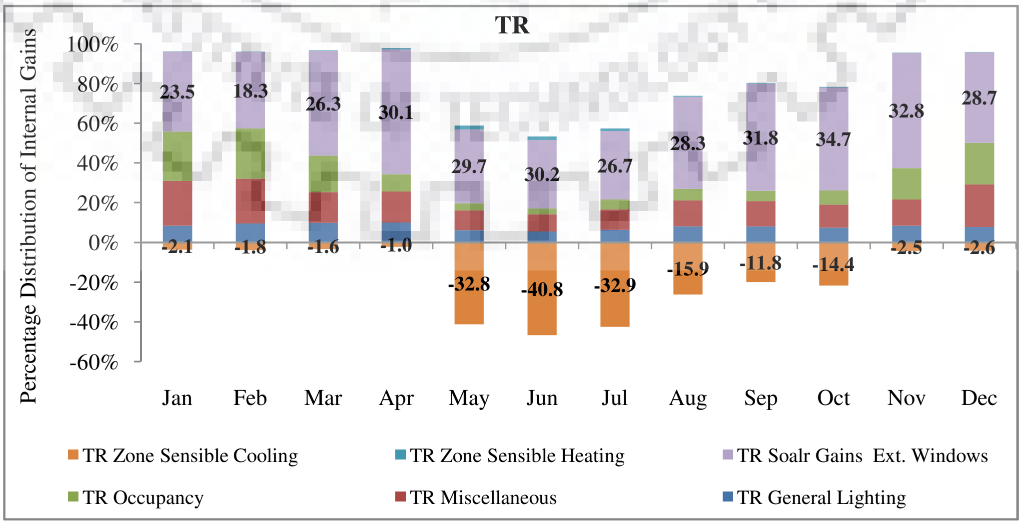


Fig 1.5c

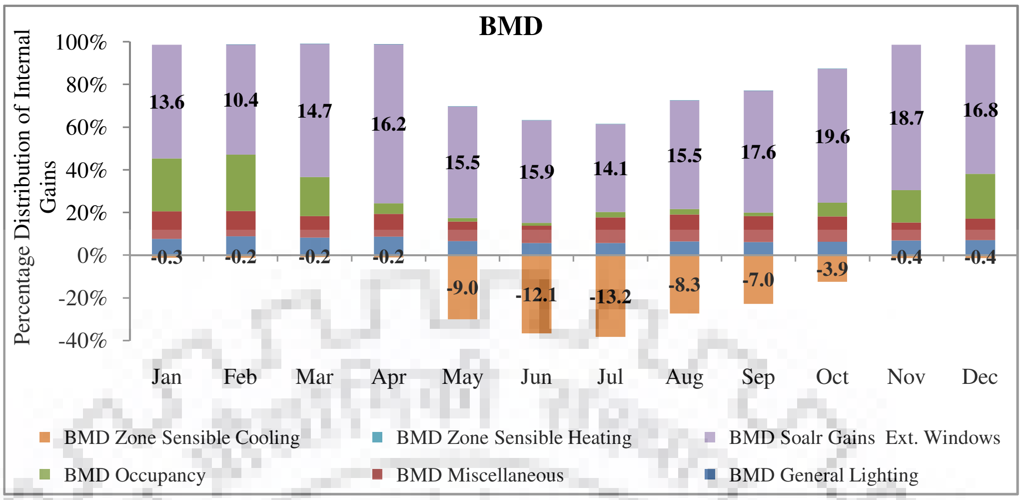


Fig 1.5d

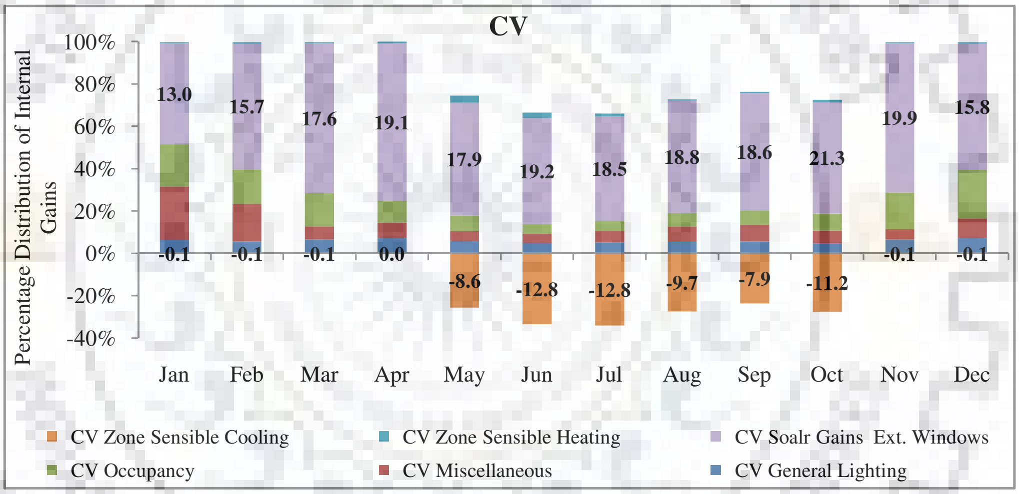


Fig 1.5e

Fig 1.6 (a,b,c,d &e) Percentage Distribution of Fuel Breakdown (all Buildings)

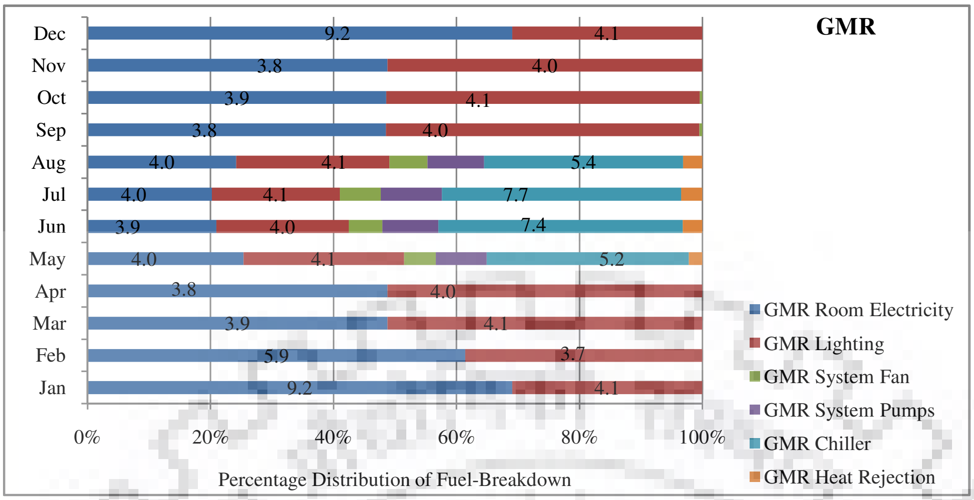


Fig 1.6a

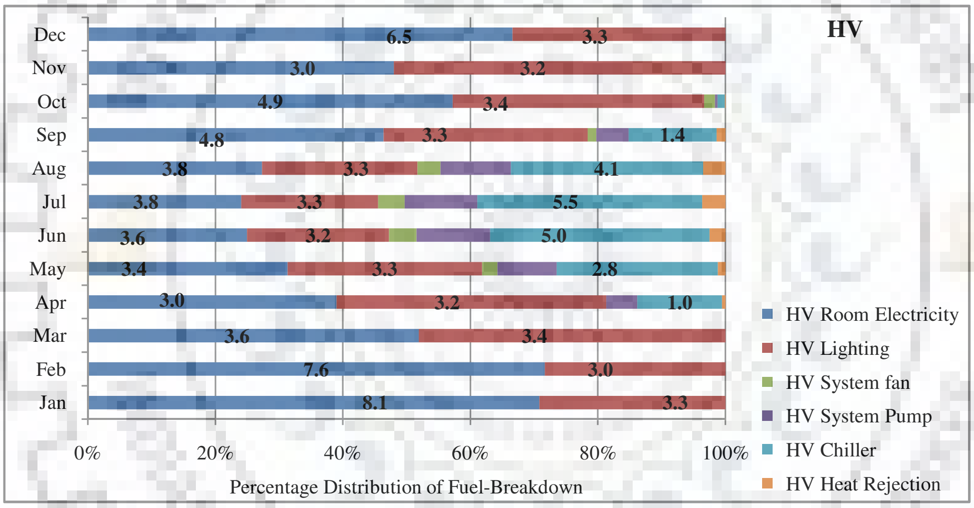


Fig 1.6b

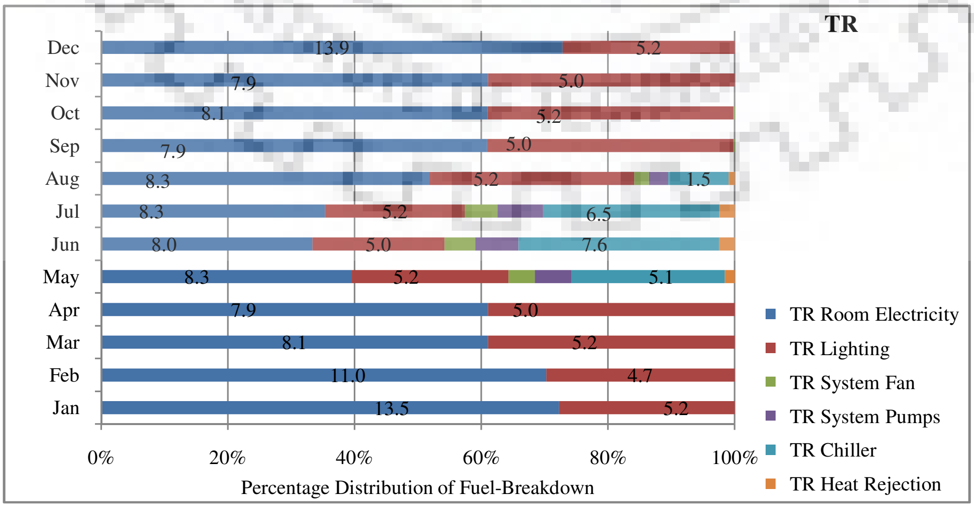


Fig 1.6c

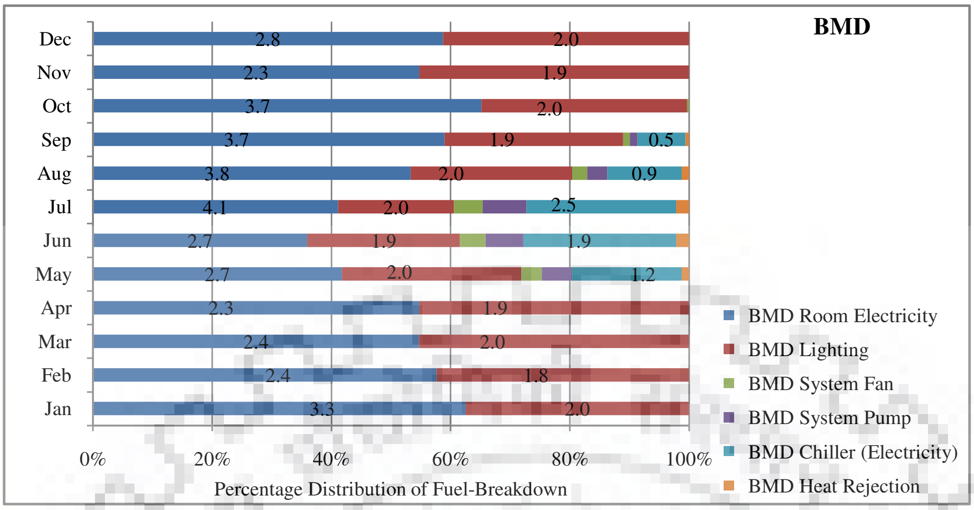


Fig 1.6d

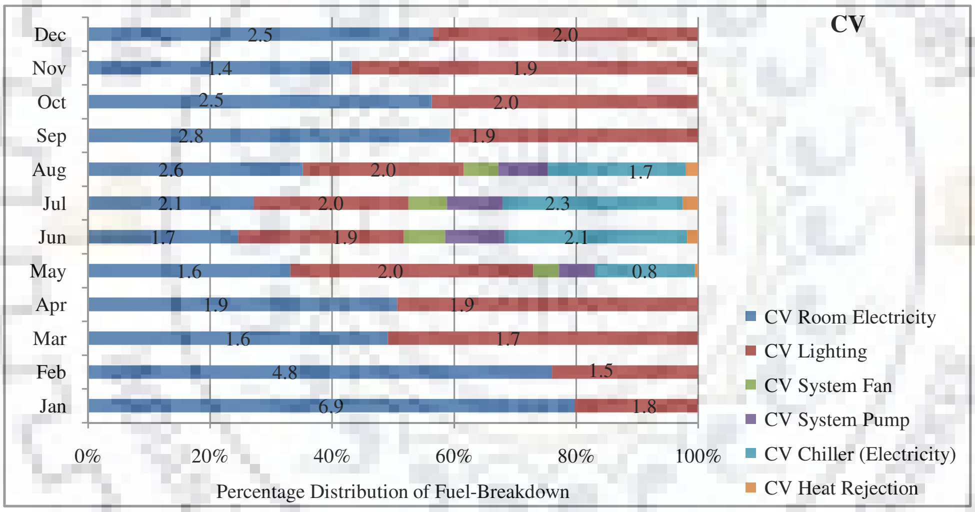
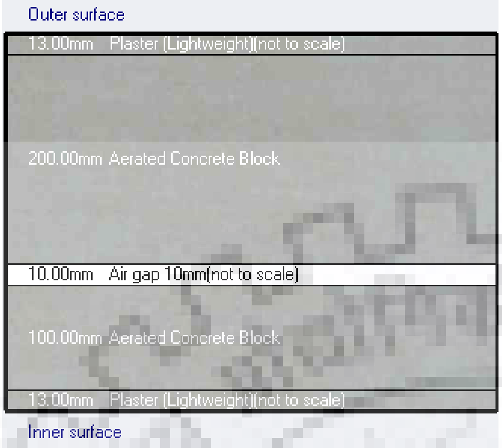


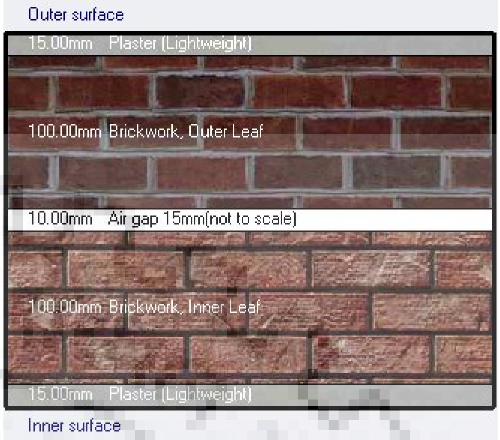
Fig 1.6e

Fig 1.7 Construction Details of Retrofit Models: Wall & Roof

WALL RETROFIT – CONSTRUCTION DETAIL

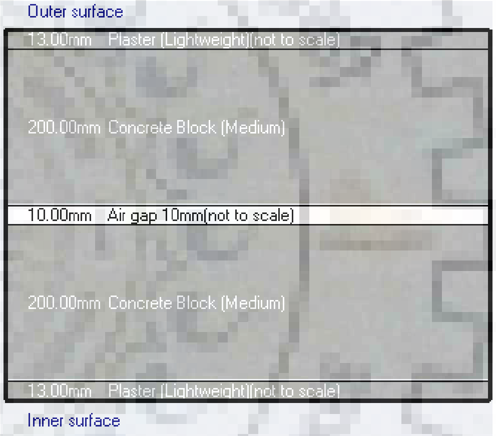


1.7a AAC Wall



1.7bBrick Air Gap Brick

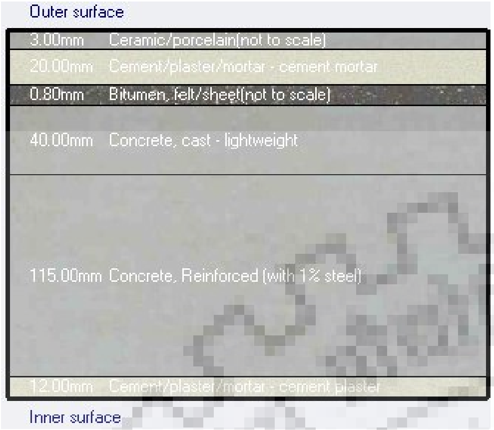
1.7c Concrete Air Gap Brick



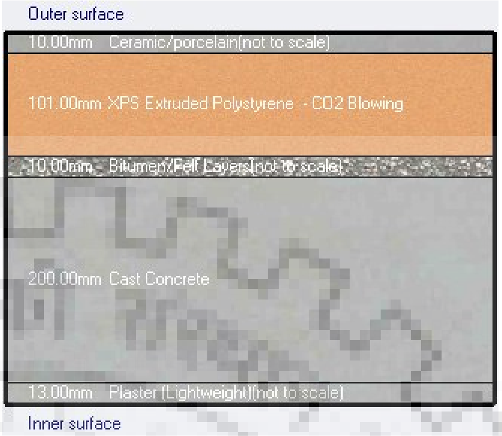
1.7d Concrete Air Gap Concrete

1.7e XPS Wall

ROOF RETROFIT –CONSTRUCTION DETAIL



1.7f Ceramic Porcelain



1.7g XPS Insulated Roof

THERMAL RESISTANCE OF BUILDING ENVELOPE: ALL MODELS

Wall Retrofit	U-value	R-value
Concrete air gap Brick	.965	1.03
Brick air gap Brick	1.24	.81
AAC Wall	.577	1.73
Concrete air gap Concrete	.78	1.27
XPS wall	.35	2.8

Roof Retrofit	U-value	R-value
Ceramic Porcelain	2.1	.48
XPS Extruded Polystyrene insulation	.29	3.4

Surface Treatment	Solar Absorptance
White Colour	.25
Light Colour	.45
Dark Colour	.75

Glaze Retrofit	SHGC	Direct Solar Transmission	Light Transmission	U-value (ISO 10292/EN 673	U-value (W/m2-K)
Single Clr 6mm	.819	.775	.881	5.718	5.778
Single LoE; Clr 6mm	.72	.68	.81	3.772	3.779
Double Clr 6mm/6mm air	.7	.60	.78	3.2	3.09
Double LoE Clr 6mm/6mm Air	.569	.474	.745	2.519	2.429
Triple Clr 3mm/6mm Air	.682	.595	.738	2.311	2.178

Fig 1.8a,b,c,d,&e Percentage reductions in heat flow through other building component: Wall Retrofit

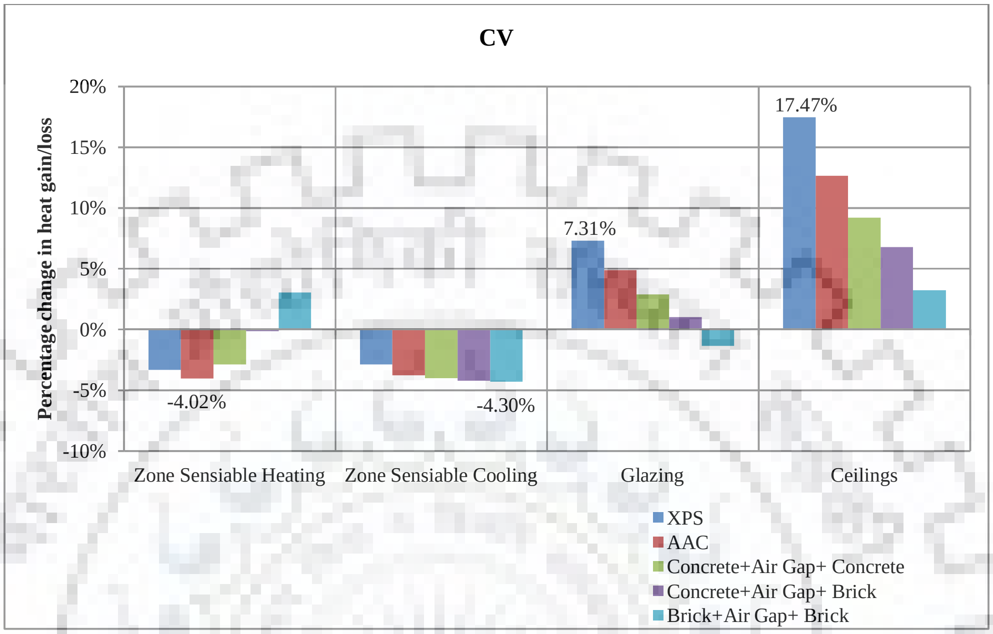


Fig 1.8 a Percentage reductions in heat flow through other building component: Wall Retrofit- CV

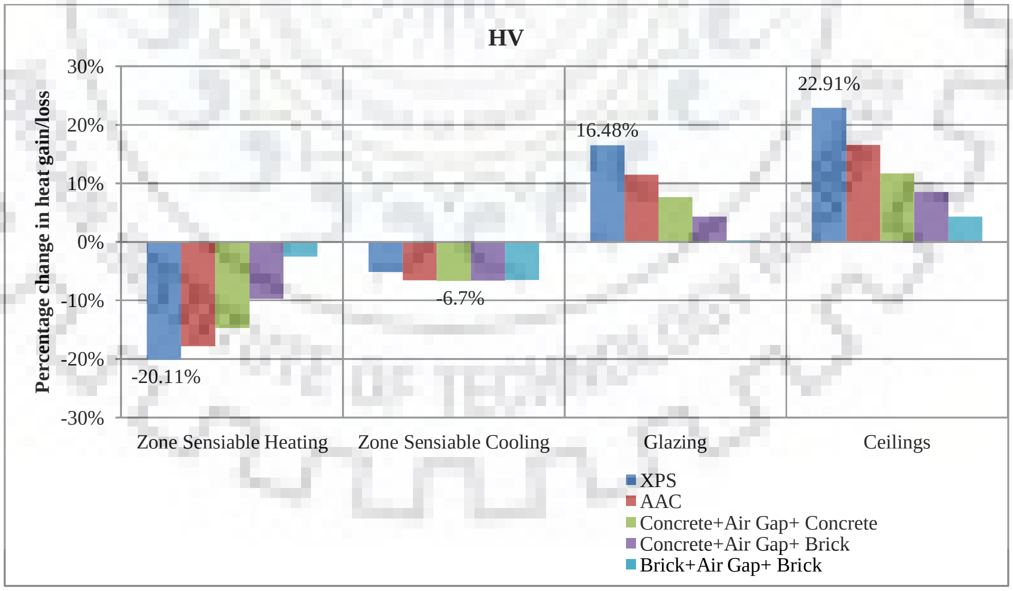


Fig 1.8 b Percentage reductions in heat flow through other building component: Wall Retrofit - HV

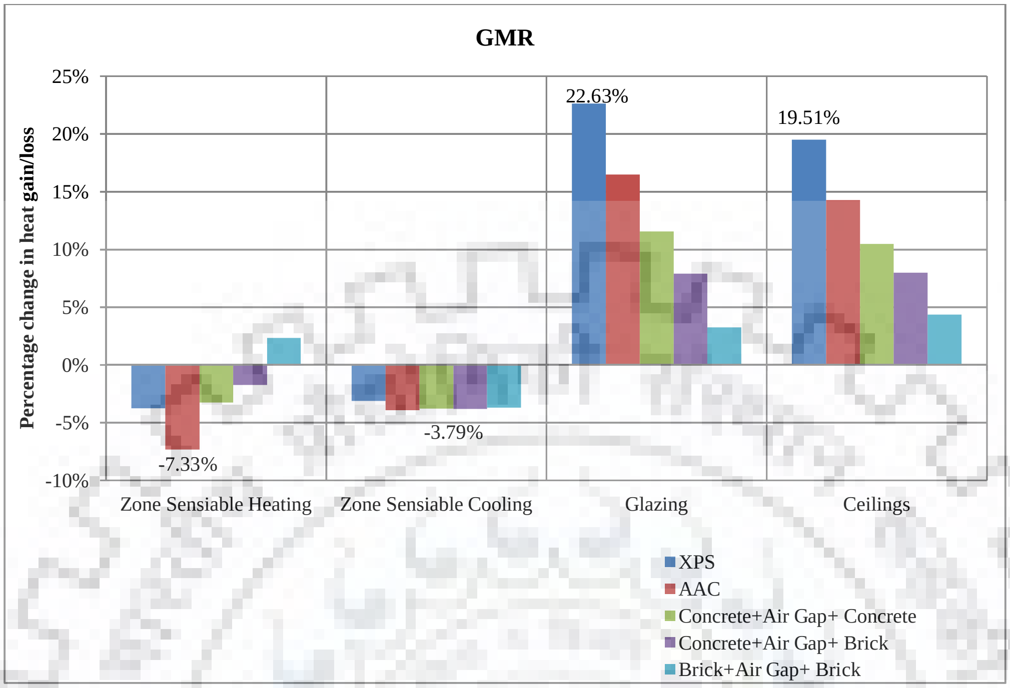


Fig 1.8 c Percentage reductions in heat flow through other building component: Wall Retrofit- GMR

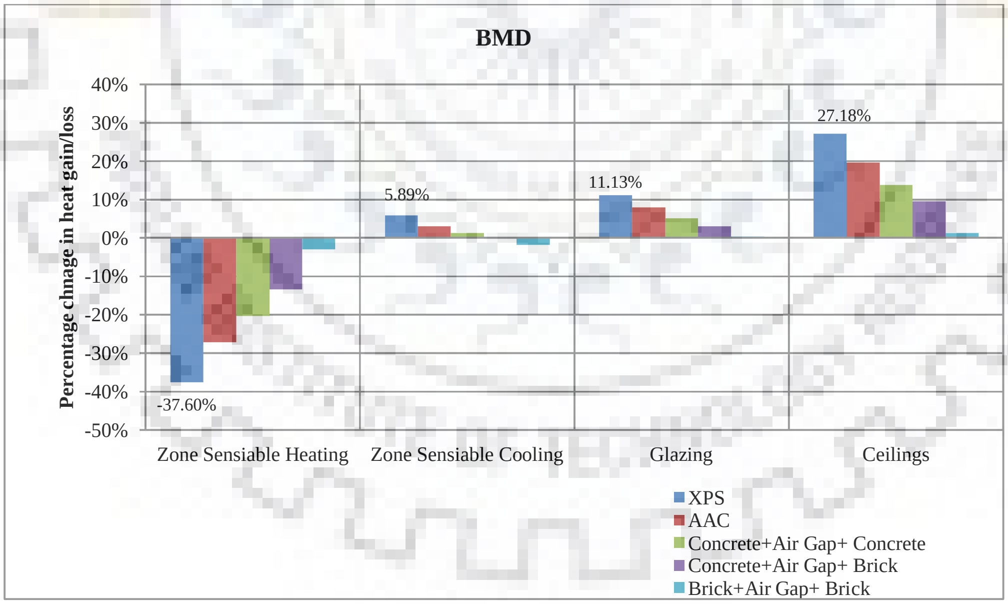


Fig 1.8 d   Percentage reductions in heat flow through other building component: Wall Retrofit -BMD

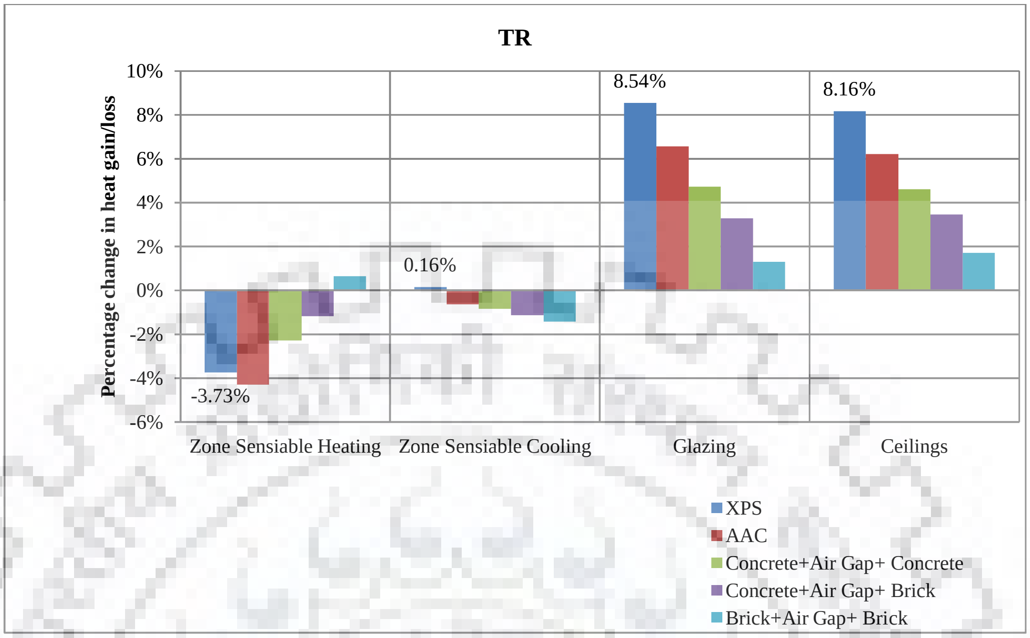


Fig 1.8 e Percentage reductions in heat flow through other building component: Wall Retrofit -TR

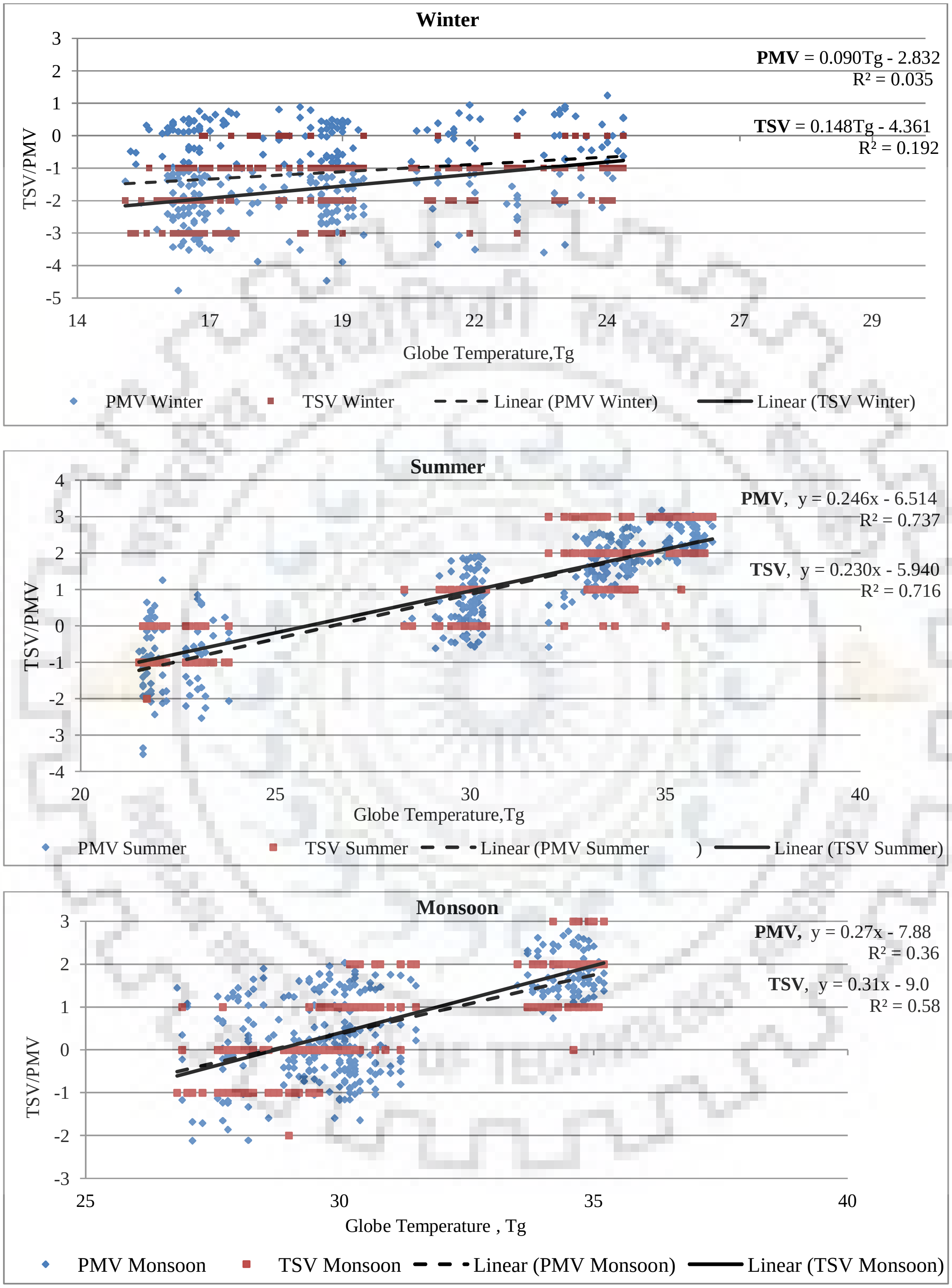


Fig1.9 a,b& c Variation of TSV and PMV with Tg : Winter, Summer & Monsoon

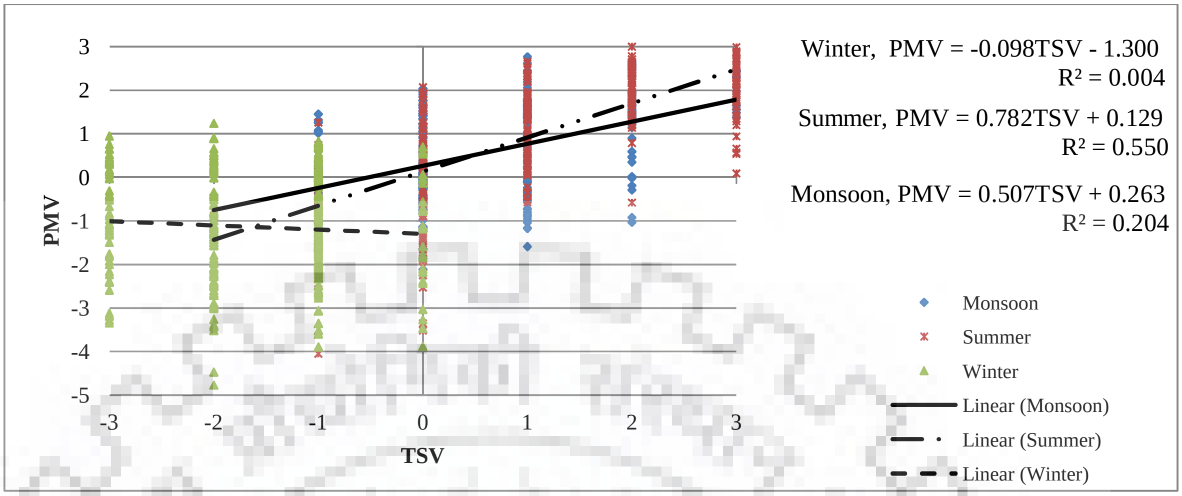


Fig1.10 PMV as a function of TSV: PMV residual : Winter, Summer & Monsoon

APPENDIX II

ENERGY ASSESSMENT OF APARTMENT BUILDINGS IN COMPOSITE CLIMATIC REGIONS OF NORTH INDIA
Shailza Singh, Research Scholar, I.I.T Roorkee
QUESTIONNAIRE SURVEY

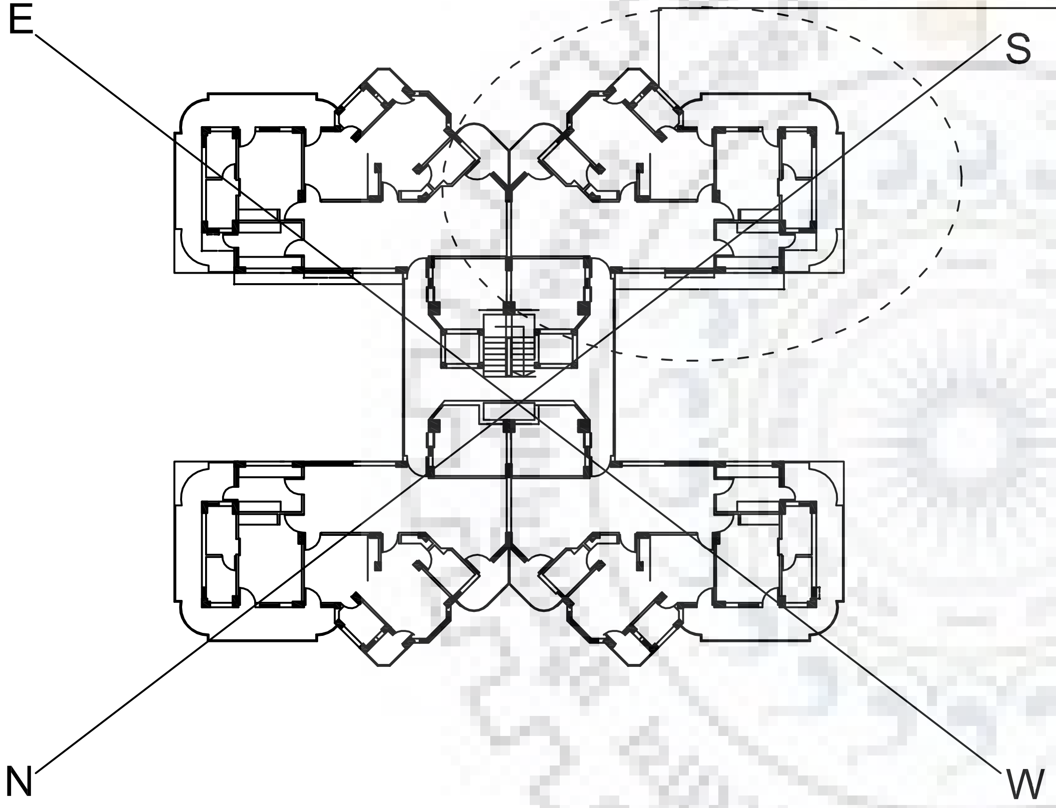
LONGITUDNAL SURVEY	Time:	Building Name :		No. of DU /Floor :
	Date:	Flat no.:		
Name:	Age:	Weight:	Height:	Sex:
What is your approximate monthly electricity bill?				
CLOTHING: Tick as appropriate:				

Summer		Winter	
Undergarments	☐	Cotton salwar kameez	☐
Upholestry	☐	Woolen Salwar Kameez	☐
Cotton Sari + petticoat+blouse	☐	Jacket	☐
Sari (polyester) + petticoat+ blouse	☐	Sweater	☐
Cotton Salwar Suit	☐	Long gown	☐
Trouser (thin)	☐	Trousers/Long skirt	☐
Walking Shorts	☐	Long sleeves shirt	☐
Long sleeves shirt	☐	Short sleeves shirt	☐
Short sleeves shirt	☐	Hand Glubs	☐
Sleeveless/scoop neck top	☐	Shoes	☐
T-shirt	☐	Sandals	☐
Skirt (thin)	☐	Socks	☐
Light Dress, short sleeves	☐	Shawl	☐
Short sleeves pajamas (thin)	☐	Warmer	☐
Shoes	☐	Cotton sari	☐
Sandals	☐	Blouse	☐
Socks (calf length)	☐	Others (specify)	☐

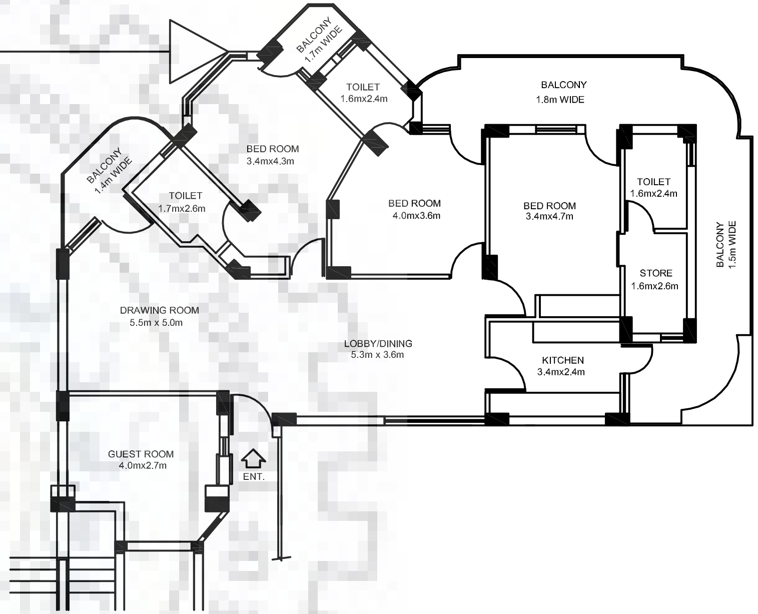
FEELING: At present I feel:	
Hot	☐
Warm	☐
Slightly warm	☐
Neutral	☐
Slightly cool	☐
Cool	☐
Cold	☐
PREFERNCE: I would prefer to be:	
Much warmer	☐
A bit warmer	☐
No change	☐
A bit cooler	☐
Much cooler	☐
ACTIVITY in the last 15 mins:	
Sleeping	☐
Sitting (Passive work)	☐
Sitting (active work)	☐
Standing relaxed	☐
Standing working	☐
Walking indoors	☐
Walking outdoors	☐

Is this Environment acceptable to you now?	Y / N				
Are you sweating/ shivering now?					
No	☐				
Slightly	☐				
Moderate	☐				
Profusely	☐				
CONTROLS (Tick as appropriate)					
External door (ED)	Open / Close				
Balcony door (BD)	Open / Close				
Window (W)	Open / Close				
Blinds/curtains (BL)	Drawn /Undrawn				
How often do you use the above controls?					
Open mostly	☐ ED	☐ BD	☐ W		☐ BL
Closed Mostly	☐ ED	☐ BD	☐ W		☐ BL
Half Open/Half Close	☐ ED	☐ BD	☐ W		☐ BL
Open in Morning & Evening	☐ ED	☐ BD	☐ W		☐ BL
Open in Daytime	☐ ED	☐ BD	☐ W		☐ BL
Reason : not using/using above controls					
Dust	☐				
Too hot outside ('Loo')	☐				
Too cold in winter (especially when fog)	☐				
No sunlight	☐				
Windy outside	☐				
Noise	☐				
Glare	☐				
Privacy	☐				
Lighting on/off	O / F	If On,specify running hours=			
Fan On/Off	O / F	If On,specify running hours=			
Air Cooler On/Off	O / F	If On, specify running hours=			
Air Conditioner On /Off	O / F	If On, specify running hours=			
Heater On /Off	O / F	If On, specify running hours=			
Wetted Khus Mats	Y / N				
Extended shades to windows	Y / N				
Comments:			**Signature :**		

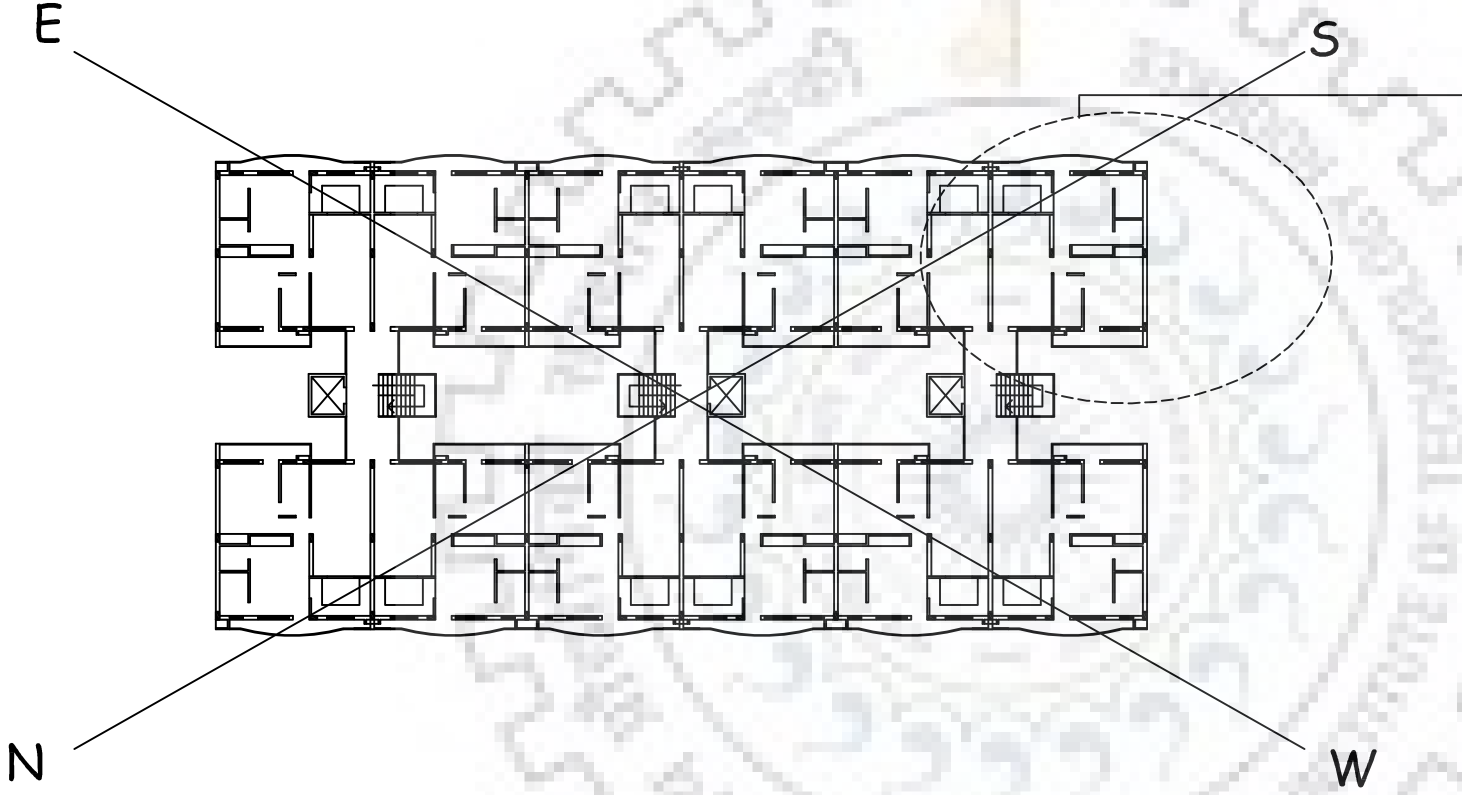
APPENDIX III



Key Plan of BhaiMata Das (BMD)

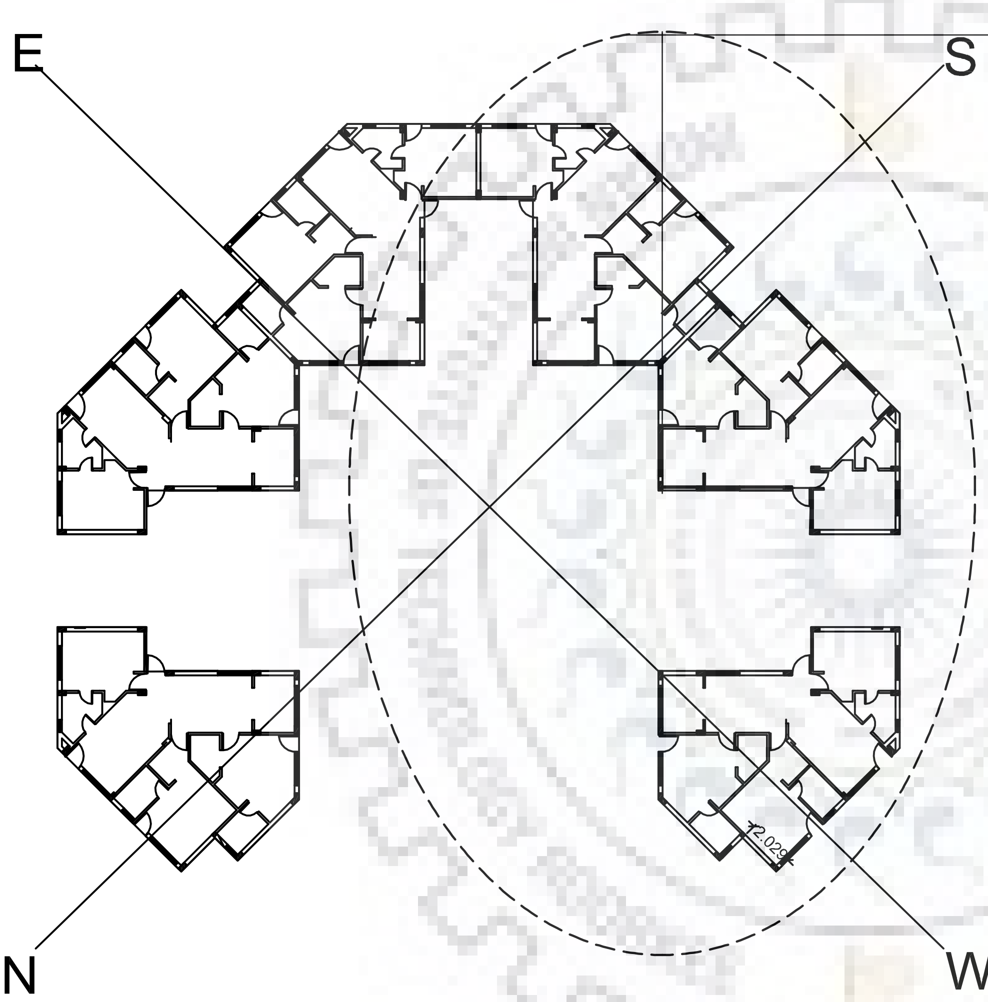


Floor Plan of BhaiMata Das (BMD)

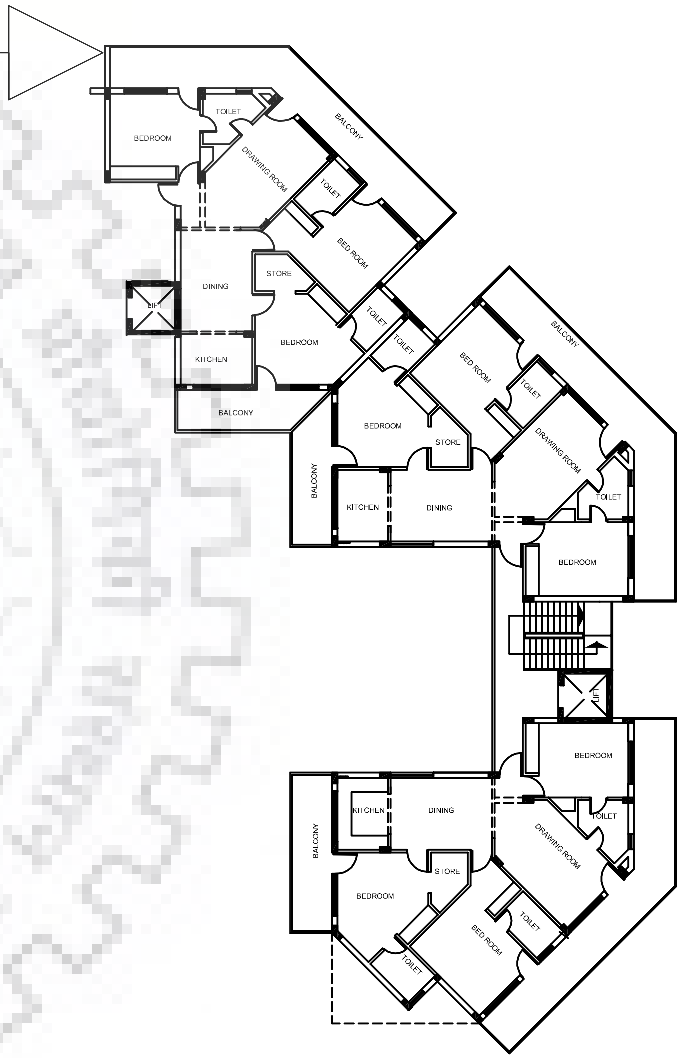


Key Plan of Trishla (TR)

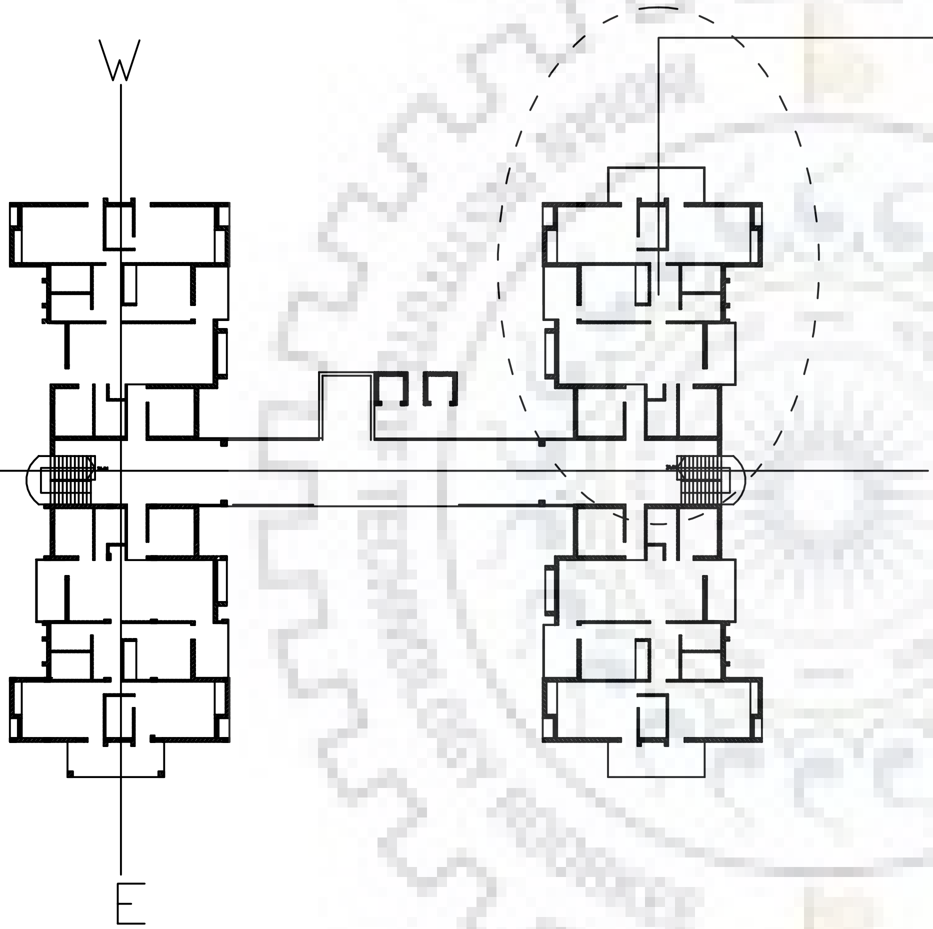
Floor Plan of Single Unit (TR)



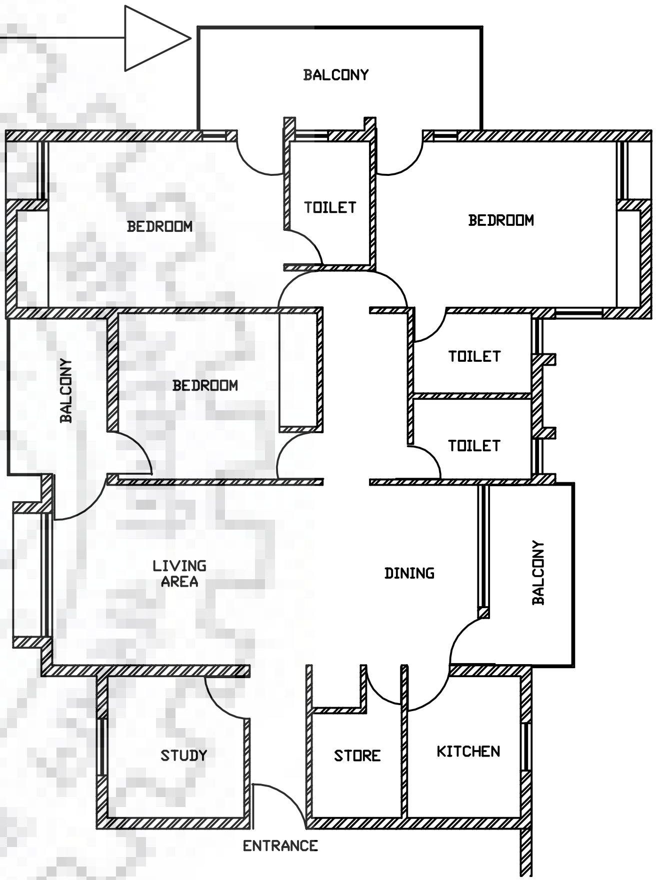
Key plan of Growmore (GMR)



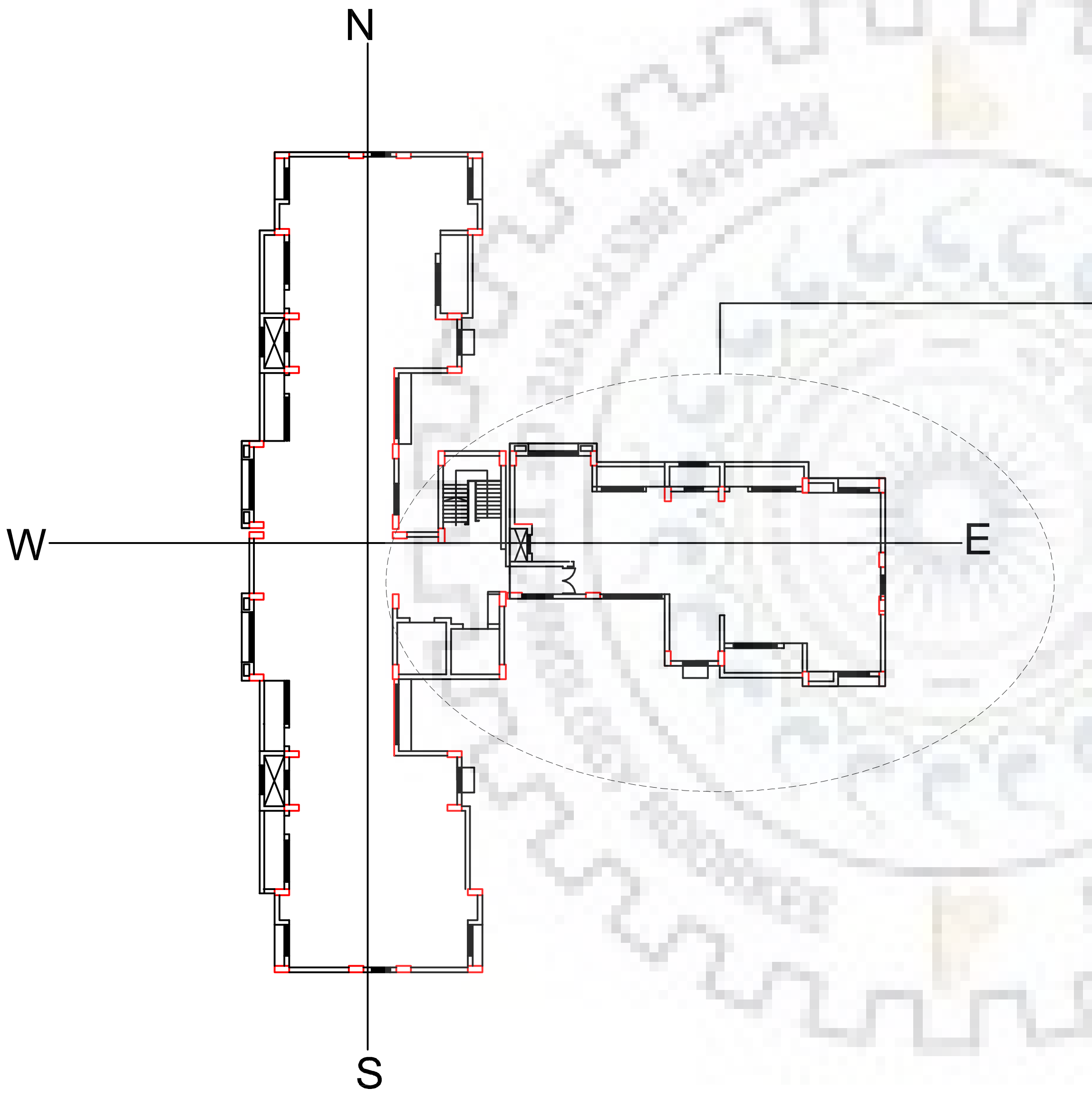
Floor plan of Growmore (GMR)



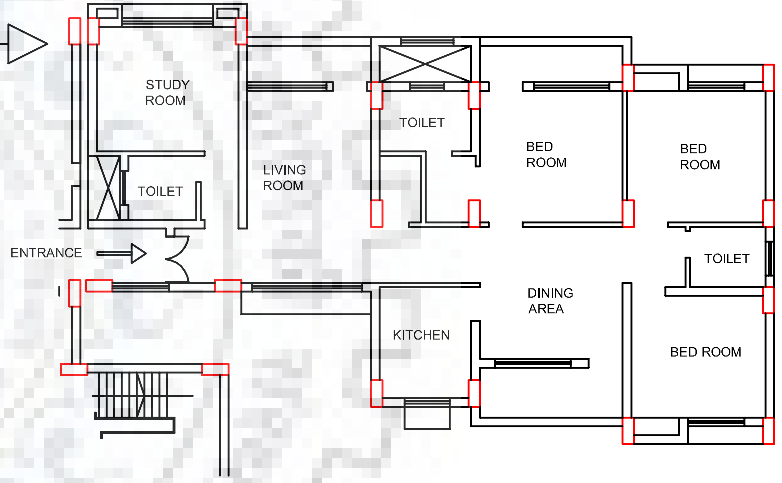
Key Plan of Hill-View Apt. (HV)



Floor Plan of Single Dwelling Unit (HV)



Key plan of Canal View (CV)



Floor plan of dwelling unit

List of Publications

- A research paper entitled ***"Energy Assessment of Multi-Storied Apartments in Roorkee"*** has been published in International Journal of Engineering and Technology (IACSIT), Vol. 4, No. 6, December 2012
- Paper entitled ***"Implication of building energy modeling (BEM) and adaptive model to assess the efficiency of multi storied apartments in composite climate of North India"*** has been published in the proceedings of Proceedings of 8th Windsor Conference: ***Counting the Cost of Comfort in a changing world,*** Cumberland Lodge, Windsor, UK, 10-13 April 2014. London
- Communicated Paper: ***"Effect of age, gender, exposure to roof and season on thermal evaluation of Indian subjects in composite climate: an adaptive approach".***
- Communicated Paper: ***"Seasonal evaluation of adaptive use of controls in multi-storied apartments: a field study in composite climate of north India"***
- Communicated Paper: ***"Evaluation of Thermal Performance of Multi-Storied Apartments: a case study in Indian composite climate"***