THERMAL PERFORMANCE OF RESIDENTIAL BUILDINGS IN COLD CLIMATE

A DISSERTATION

Submitted in partial fulfilment of the
requirements for the award of the degree
of

MASTER OF ARCHITECTURE

by

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CANDIDATE'S DECLARATION

I hereby declare that work, which is being presented in the dissertation entitled "**THERMAL PERFORMANCE OF RESIDENTIAL BUILDINGS IN COLD CLIMATE**' in the partial fulfilment of the requirement for the award of degree of Master in Architecture, submitted in the Department of Architecture and Planning, Indian Institute of Technology, Roorkee, is the authentic record of my own work carried out during the period of July 2017 to September 2018 under the guidance of Dr. E. Rajasekar, Assistant Professor, Department of Architecture and Planning, Indian Institute of Technology, Roorkee, India.

The matter embodied in this report has not been submitted by me for the award of any degree of this or any other institute.

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This is to certify that the above statement made by candidate Ms. Thakur Gargi Sanjay Sarla is true to best of my knowledge.

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CERTIFICATE

This is to certify that, this report titled "**THERMAL PERFORMANCE OF RESIDENTIAL BUILDING IN COLD CLIMATE**", which has been submitted by **Ms. Thakur Gargi Sanjay Sarla** in the partial fulfillment of the award of Post Graduate Degree in Master of Architecture, to Department of Architecture and Planning , Indian Institute of Technology, Roorkee is the student owns work as per my knowledge carried out by her, under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree.

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ABSTRACT

India is home to a wide variety of climatic regions and different types of materials, techniques, strategies for the architectural design are needed in each different climatic region. The industrializations and mass production has paved the way to a wide variety of materials and construction techniques which surpassed the traditional ones. These factory made materials started gaining popularity soon since they were cheaper and techniques were faster.

These newly formed materials and techniques has significant impact on the thermal performance of the buildings. In this study, The thermal performance of these materials in context of cold climate are analysed. Residential buildings of Himachal Pradesh are chosen for the study. Thermal performance of AAC blocks, Solid brick masonry and brick cavity walls were evaluated and compared with that of Kathkhuni construction, Rubble stone masonry and Adobe walls. It is found that AAC blocks, Kathkhuni construction and Adobe wall construction were performing better than Solid brick masonry, Brick cavity wall and Rubble stone masonry. But Solid brick masonry and Brick cavity walls performed quite stable in both the seasons. A lower WWR ratio, compactness of the spatial design improved the thermal performance of residential buildings too.

Keywords: Thermal performance, Cold climate, Traditional building materials

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1. INTRODUCTION

India is home to an uncommon variety of climatic regions, ranging from tropical in south to temperate alpine in north, where the elevated regions receive sustained winter snowfall. The nation's climate is strongly influenced by Himalayas and Thar Desert. And to build in every different type of climate we need different types of materials, techniques, strategies for the architectural design to provide the comfortable indoor environment to the respective human activity. But when India started to experience the evolution in industries and mass production, when India started to see dams, railways, and canals, it had started influencing the smaller sectors of society too. In addition to that, India has faced population explosions more than three times till 2011, which has increased the demands in various sectors of society and added into mass production.

Today, India is a developing country. And in developing country like India, economics is the game changer for any decision making in any sector of development. In this rat race, a lot many factors just as important as health, environment, etc. have been and are being ignored intentionally or unintentionally.

If we say only about health, the most important aspect of the indoor climate to consider are these thermal conditions in which the resultant physiological stresses cannot be relieved by reasonable action on the part of occupants, but only means of design. There is a lot to be said for specifying a lower thermal limit for housing, if only purely from the comfort point of view. It is well recognized that the lower income groups suffer considerable amount of discomfort in the cold winter areas through their inability to afford adequate clothing, extra blankets, good food or adequate heating. Somewhere between certain lowest comfortable temperature value and upper comfortable temperature value, body has to take no appreciable physiological action to maintain its heat balance. This point or range may be considered as the point of optimum thermal comfort for any given set of conditions.

It should also be taken into account how different degrees of heat affect the comfort of the individuals. It has been studied that ability of the body to lose heat to its surroundings depends upon air temperature, humidity of air, rate of air movement, mean radiant temperature (MRT) of the surrounding surfaces of the environment. An increase or decline in the temperature of at least one of the surrounding surfaces above or below air temperature will have a tendency to achieve a sense of increased or decreased warmth respectively. Threshold does limit for absolute discomfort beyond which unforeseen effects on health like fatigues, diminished work productivity, reduced mental efficiency, increased possibilities of accidents, and so forth. Extreme limits can be decided upon health or thermal stability of the body.

When it comes to a ‘house’, the primary object of it is to provide protection from severe weather conditions. And across the decades, the industrial revolution, population explosion, increased demands, haphazard and unplanned development has affected the choices of basic materials, and environment due to easiness of availability. In lower income groups it has even been worse. With thin walled or light structures like tents, or galvanized steel huts there is little difference between indoor and outdoor temperature at night in winter. With the low insulation that these structures provide, adequate heating becomes a major and costly matter. It is generally agreed that, greater protection against severe cold weather than is offered by any permanent housing.

Background

The whole world has being seeing and facing the effect of climate change. One of the studies conducted in this dissertation compares the historic weather data (1960-1990) with the current weather data. And the data also shows the warming up of the regions. With the changing weather conditions, we have to change the architectural practices and so the building materials and construction techniques to provide a better shelter against this change. To study about the emerging materials and techniques and how the thermal performance is effected this dissertation is conducted.

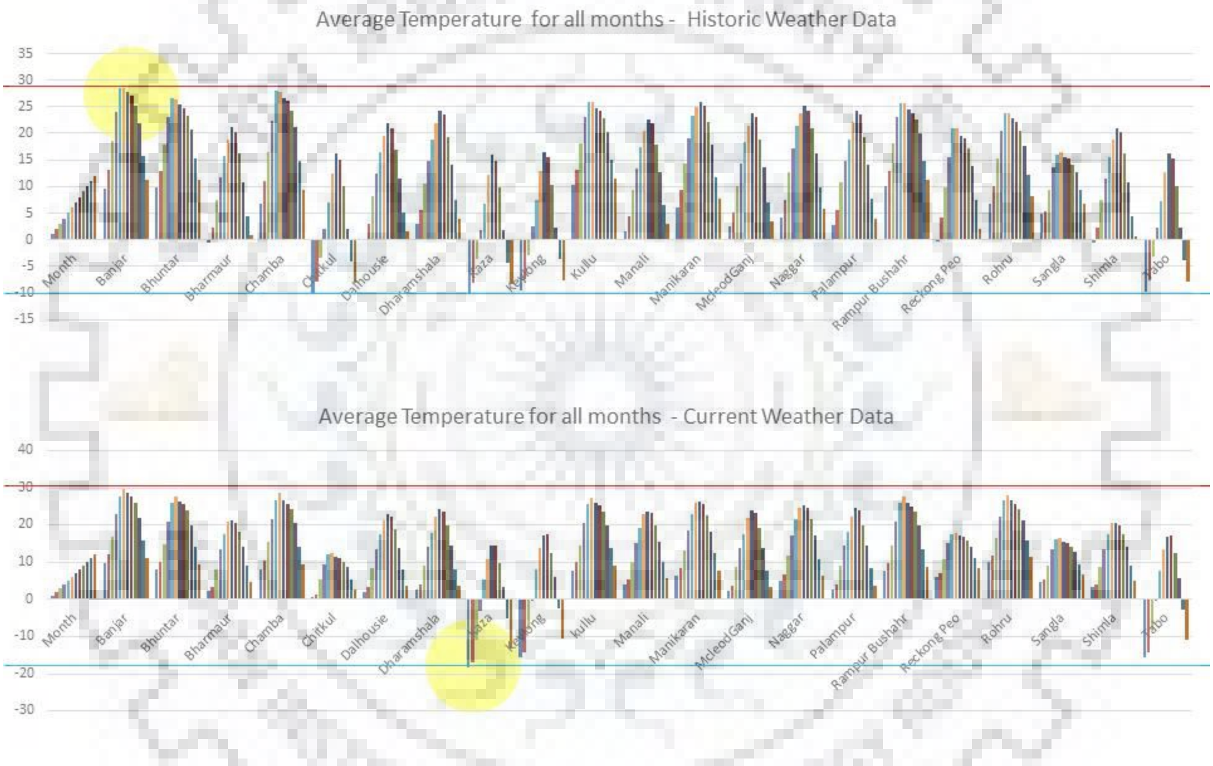


Figure 1 Historic and Current Average Temperatures for locations in Himachal Pradesh

The urban development that India has been seeing after the Independence have been very haphazard and rapid due to which the naturally resourceful areas lie Himachal Pradesh have been seeing the serious urban environmental problems. This development is contributing to economic development of the region but on the other hand it is causing deprivation of basic natural resources also.

Everyone is familiar environmental effect of this haphazard urban development. But there are some effects which are completely unknown or neglected by the society. Primary education covers makes the current generation sensitive about outdoor environment, but the biggest disadvantage is the indoor environment is not given that much weightage in it. Just like that, this problem grows to the next generations too. This has been happening from the independence. And the other (inner) side of the built environment is being neglected unintentionally.

The design procedure does play a significant role in creating built environment respecting all principles of sustainable development. It has to consider various climatic zones (hot-dry, warm-humid, composite, temperate and cold climates), sun path movements, location (prone to tsunami, hurricane, etc.), wind directions and geological conditions in the design of building, its orientations, wall and roof materials combinations, space layout, fenestrations and landscape. A solar passive architecture that places minimum energy demand in maintaining thermal comfort should be explored foremost. This dissertation puts an effort to contribute in that little sensitive but most important area of the developments happening in the country i. e. Thermal Performance of the Building. Now, why it is one of the most important parts of the development considerations is explained further in subsection of Chapter Literature study. The change in temperature of surroundings of human's body affects the health and mind. The positive and negative effects can be both temporary and permanent depending on the duration of exposure to the change and its frequency. Some of the effects found are fatigues, frostbite, heat strokes, trench foot, cardio vascular and respiratory diseases, hypothermia, hyperthermia, drying of mouth, impaired endurance, sleep disturbances, headache, impaired concentration, dizziness, impaired muscular strength, nausea, vomiting, influence on emotional stimuli, etc.

NEED FOR THE STUDY

The transitions in spatial design, material use and construction techniques, resource constraints, lifestyles, costs have has transformed the thermal performance of modern day residential building. Though replicating the traditional building styles in today's context is challenging, there is a strong need to incorporate the wisdom in today's buildings.

2. LITERATURE STUDY

The literature study is conducted into following parts:

- Understanding thermal performance of building
- Understanding the cold climate of India
- Learning about the evaluation of thermal performance of the building
- Learning traditional and modern construction materials and techniques used in the selected site, (i.e. Dharamshala, Himachal Pradesh.)

THERMAL PERFORMANCE

Function of any building is to provide a desired spatial environment (maybe controlled or uncontrolled) within if continuously, for a given human activity. Building must provide for safe and comfortable indoor environment against existing external and unwanted/obstructing conditions for the given human activity. Safe here means it should provide shelter against the forces of nature, rainfall, snowfall, earthquake, human actions, etc. And the external factors which affect the comfort inside the building are the humidity, air motion, noise, lightning, pollution, noise, solar radiation, air temperature, etc. Some of these factors are desirable and a building must act like a filter. Building should allow some of these allowable aspects of the environment to come in and some of them to cut off. For example, It is said, where the sunlight comes, doctors don’t. Sunlight becomes the important aspect to be allowed in the building as well as the ventilation. Whereas the aspect like excess temperature in tropics will make the building uncomfortable. This discomfort can be caused by the excess values of temperature, humidity, relative humidity, solar radiation, air movement, lux levels on the both negative and positive sides of the scale, depending upon the location and human activity for that building.

It is important to evaluate the thermal performance to ensure the quality and overall performance of the building.

The thermal performance of a building refers to the process of modelling the energy transfer between a building and its surroundings. For a conditioned building, it estimates the heating and cooling load and hence, the sizing and selection of HVAC equipment can be correctly made. For a non-conditioned building, it calculates temperature variation inside the building over a specified time and helps one to estimate the duration of uncomfortable periods. These quantifications enable one to determine the effectiveness of the design of a building and help in evolving improved designs for realising energy efficient buildings with comfortable indoor conditions. The lack of proper quantification is one of the reasons why passive solar architecture is not popular among architects. Clients would like to know how much energy might be saved, or the temperature reduced to justify any additional expense or design change. Architects too need to know the relative performance of buildings to choose a suitable alternative. Thus, knowledge of the methods of estimating the performance of buildings is essential to the design of passive solar buildings.

The thermal performance of a building depends on a large number of factors. They can be summarised as (i) design variables (geometrical dimensions of building elements such as walls, roof and windows, orientation, shading devices, etc.); (ii) material properties (density, specific heat, thermal conductivity, transmissivity, etc.); (iii) weather data (solar radiation, ambient temperature, wind speed, humidity, etc.); and (iv) a building's usage data (internal gains due to occupants, lighting and equipment, air exchanges, etc.). A block diagram showing various factors affecting the heat balance of a building is presented in Fig. 4.3. The influence of these factors on the performance of a building can be studied using appropriate analytical tools. Several techniques are available for estimating the performance of buildings. They can be classified under Steady State methods, Dynamic methods and Correlation methods. Some of the techniques are simple and provide information on the average load or temperature, on a monthly or annual basis. Others are complex and require more detailed input information. However, the latter perform a more accurate analysis and provide results on an hourly or daily basis. In this chapter, we discuss a simple method that is easy to understand and amenable to hand calculations.

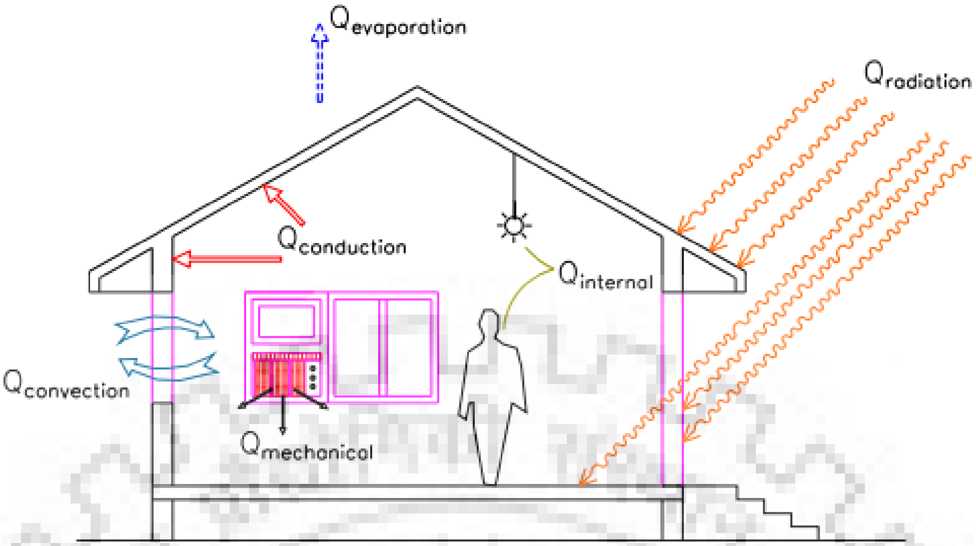


Figure 2 Heat exchange processes between a building and external environment

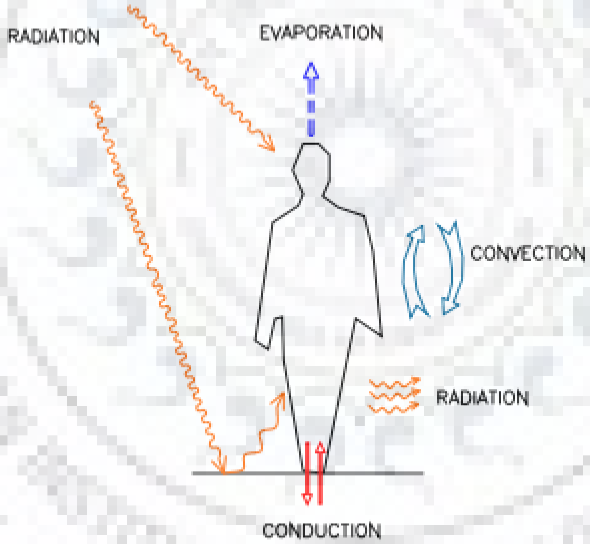


Figure 3 Heat exchange processes between a human body and indoor environment

A chapter published by CBRI talks about Thermal performance of building envelop considering Building envelops and spatial planning. It also discusses about the regional geographic and building level considerations like material choices, surface treatment, passive design strategies, and overall spatial layout. Emergence of new building materials, construction techniques, cost, resource constraints have resulted transformation in the buildings, which has caused modularity and standardization in design solutions and consequently the shift from responsive design to compliant design.

The document talks about the thermal performance indicators. The Statistical Cluster Analysis carried out in order to classify the annual climate data results in 5 distinct seasonal clusters. Thermal response of building envelop depends on two aspects – thermo-physical properties of **opaque** assembly and thermo-physical property of **fenestration** assembly. It discusses about three ways in which heat is transferred to the building

-Conduction
-Convection
-Radiation
It also talks about how indoor thermal environment can be improved by judicious selection of

-Building components
-insulating materials
-fenestration components
-shading systems
-minimizing the flow of heat gains in summer and heat loss during winter. It discusses about the mediums/ways of heat transfer which are

CONDUCTIVE:

1. Exterior wall conduction: transient heat transfer responding to climatic effects such as temperature fluctuation solar radiation, etc.
2. Interior wall conduction: heat storage in partition walls, floor/ceiling It tells about the principle factors affecting conductive heat transfer through building fabric are Density, Porosity, Moisture content on the fabric

CONVECTIVE:

1. Heat transfer at external surface considering both wind and surface roughness characteristics
2. Heat transfer through leakage from exterior walls
3. Heat transfer from different enclosing surfaces to indoor air.

RADIATIVE:

1. Short-wave radiation which includes solar heat absorption on opaque exterior surfaces solar heat transmission through transparent surfaces, absorption and reflection of solar heat by window glass
2. Long wave radiation which includes the heat exchange between external surfaces and sky, surrounding buildings, ground and heat exchange among interior surfaces

   To carry out Real Time Assessment of Envelop Thermal Performance following parameters were considered,

   - Heat flux (W/m2) through building envelop
   - Inside/outside surface temperature
   - Indoor radiant temperature asymmetry between two planes
   - Indoor dry bulb temperature,
   - Indoor Globe temperature
   - Indoor thermal comfort in terms of indices such as Fanger's PMV (Fanger, 1970)
   - Tropical Summer Index (TSI)

Also it says thermal performance of building envelop can be described in terms of its-

- Thermal resistance
- Reflectance
- Capacitance
- Air to air thermal transmittance = U-value
- Reciprocal of U value = R-value

It is factor of material layers, thickness and the external and internal heat transfer coefficients It is said that Thermal conductivity of a material is directly proportional to its density. U value only represents the conductive mode of heat transfer through envelop assembly. The important values which are to be considered are Thermal time constant (TTC), Diurnal heat capacity (DHC), Thermal mass/Kappa value (k). Transient heat transfer phenomenon of a building envelop assembly can be represented in terms of time lag and decrement factor. Time lag describes the temporal delay in peak external and internal surface temperature of building envelop. Decrement factor is the ratio which describes the ability of envelop in reducing its peak inside surface temperatures.

Reflective properties of building envelop are represented in terms of solar absorptivity, emissivity.

Then the document discussed about the critical properties of glass assembly i.e. U value - Thermal transmittance, SHGC -Solar heat gain coefficient, VLT -Visible light transmittance. To improve U-value, we can increase number of glass layers, increase spacing width of glass layers, replace the air cavity with vacuum or inert glass. And to improve SHGC, fraction of solar radiation admitted through a glass through direct transmission as well as reradiated after absorption; darker tints can be used. But it has negative impact on daylight availability and reduced VLT.

The document talks about **Parametric assessment of Envelop Thermal Performance** as follows -

Influence of orientation (orientation of exposed wall has a significant impact on its thermal performance and the resultant indoor thermal conditions as represented by TPI), Influence of wall thickness, Influence of Density, Influence of surface characteristics, Multicriteria assessment of Thermo-physical variables.

Heat Transfer

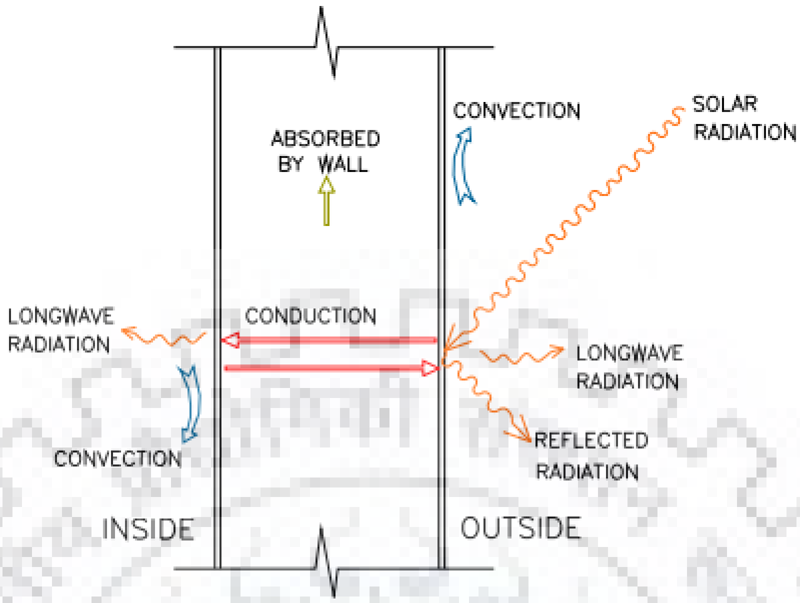


Figure 4 Heat transfer through wall

Conduction

Thermal conduction is the procedure of warmth exchange from one a player in a body at a higher temperature to another (or between bodies in coordinate contact) at a lower temperature. This occurs with unimportant development of the particles in the body, in light of the fact that the heat is exchanged starting with one atom then onto the next in contact with it. Heat can be exchanged through solids, fluids and gases. A few materials direct more quickly than others. The essential condition of heat transfer is or a given temperature difference, the higher the thermal conductivity of a material of fixed thickness and cross-sectional area, the greater is the quantity of heat transferred.

Factors affecting thermal conductivity:

a. Moisture content

b. Temperature

c. Density and Porosity

Convection

The convection is the transfer of heat from one a player in a liquid (gas or fluid) to another part at a lower temperature by blending of liquid particles. Heat transfer by convection happens at the surfaces of walls, floors and roofs. Because of the temperature difference between the fluid and the contact surface, there is a density variation in the fluid, resulting in buoyancy. This result in heat exchange between the fluid and the surface and is known as free convection. However, if the motion of the fluid is due to external forces (such as wind), it is known as forced convection. These two processes could occur simultaneously. The rate of heat transfer ($Qc_{onvection}$) by convection from a surface of area A, can be written as –

$$Q_{convection} = h\,A\,(T_s - T_f)$$

where, h = heat transfer coefficient (W/m^2-K)

T_s = temperature of the surface (K)

T_f = temperature of the fluid (K)

The numerical value of the heat transfer coefficient depends on the nature of heat flow, velocity of the fluid, physical properties of the fluid, and the surface orientation.

Radiation

Radiation is the heat transfer from a body by virtue of its temperature; it increases as temperature of the body increases. It does not require any material medium for propagation. When two or more bodies at different temperatures exchange heat by radiation, heat will be emitted, absorbed and reflected by each body. The radiation exchange between two large parallel plane surfaces (of equal

$$Q_{12} = \varepsilon_{eff}\ A\ \sigma\,(T_1^4 - T_2^4)$$

with $\varepsilon_{eff} = [\,1/\varepsilon_1 + 1/\varepsilon_2 - 1]^{-1}$

where Q_{12} = net radiative exchange between surfaces (W)

σ = Stefan-Boltzmann constant (5.67×10^{-8} W/m^2-K^4)

A = area of surface (m^2)

T_1 = temperature of surface 1 (K)

T_2 = temperature of surface 2 (K)

ε_1 and ε_2 = emissivities of surfaces 1 and 2 respectively

area A) at uniform temperatures T1 and T2 respectively, can be written as

In case of buildings, external surfaces such as walls and roofs are always exposed to the atmosphere. So the radiation exchange ($Q_{radiation}$) between the exposed parts of the building and the atmosphere is an important factor and is given by

$$Q_{radiation} = A \varepsilon \sigma (T_s^4 - T_{sky}^4)$$

where A = area of the building exposed surface (m^2)
ε = emissivity of the building exposed surface
T_s = temperature of the building exposed surface (K)
T_{sky} = sky temperature (K)

Equation can be written as:

$$\frac{Q_{radiation}}{A} = h_r (T_s - T_a) + \varepsilon \Delta R$$

where T_a = ambient temperature (K)

$$h_r = \varepsilon \sigma (T_s^4 - T_a^4)/(T_s - T_a)$$

h_r is the radiative heat transfer coefficient, and ΔR is the difference between the long wavelength radiation incident on the surface from the sky and the surroundings, and the radiation emitted by a black body at ambient temperature. For horizontal surface, ΔR can be taken as 63 W/m2 and for a vertical surface, it is zero. For building applications, usually convective and radiative heat transfer coefficients are combined to define surface heat transfer coefficient. Table 4.1 presents values of the surface heat transfer coefficient for a few cases.

Some of the following researches were studied in detail which helped more in forming the methodology and deciding parameters:

Table 1 Literature study

Sr.no	Author	Year	Title	Research	Studied Parameters
1	S. S. Chandel & R. K. Aggarwal	2012	Thermal Comfort Temperature Standards for Cold Regions & to reduces the base temperature	The new base temperature of 13.5 °C results in reducing the heating degree-days by 58% in comparison to the heating degree-days obtained using 18.3 °C as base temperature. The lower base temperature has also reduced the heating Innovative Energy Policies 5 requirements of solar passive building by 44%, thus resultant to lower cost reduction on building with the help OF ISHARE55 STANDARD.	Heating degree days
2	Liu, K. Baskaran, B.	2003	Thermal performance of green roofs through field evaluation	Observation from the Field Roofing Facility showed that a generic extensive green roof with 150 mm (6 in.) of growing medium could reduce the temperature of the roof membrane significantly in the summer..	U value, R-value and k-value
3	Kamel H. Haddad, Ph.D.	1998	Comparison of the monthly thermal performance of a conventional window and a supply-air window.	The supply-air window has a lower conductive loss than the conventional triple-glazed window. This difference is the largest during the coldest months of the year when the conductive losses are the highest.	Solar heat gain

4	Sami A.Al-Sanea	2002	Thermal performance of building roof elements	The study focusses on the comparison of six variants of typical roof structure. The study shows the details of the temperature and heat flux variations with time.	R value
5	A. Gagliano ∗,F. Patania, F. Nocera, C. Signorello	2013	Assessment of the dynamic thermal performance of massive buildings	The paper shows the thermal behavior of the massive building. The paper characterizes the thermal performance of the walls in dynamic condition.	Time lag (ϕ) and decrement factor (f)
6	H. Asan	1998	Effects of Wall' s insulation thickness and position on time lag and decrement factor	The study investigates the effect of wall insulation and position on time lag and decrement factor numerically. Different configuration of insulation in the wall is studied.	Time lag (ϕ) and decrement factor (f)
7	Xing Jin ∗, Xiaosong Zhang, Yiran Cao, Geng Wang	2011	Thermal performance evaluation of the wall using heat flux time lag and decrement factor	The paper discusses about the two parameters heat flux time lag and the heat flux decrement factor to evaluate performance of wall.	Time lag (ϕ) and decrement factor (f)
8	RongDan Diao, Linzhu Sun, Fang Yang	2018	Thermal performance of building wall materials in villages and towns in hot summer and cold winter zone in China	This paper investigates the wall material of rural buildings in China. The methodology used was theoretical calculation test detection of thermal performance of seven different materials.	heat transfer coefficient

There is a study conducted to evaluate and compare thermal performance of roof elements. It was carried out by observing the periodic changes in ambient temperature, solar radiation and non-linear radiation exchange. A numerical model based on finite volume method and using implied formulation was developed and it was applied to 6 different roof structures .The study gives detail temperature and heat flux variation with time and relative importance of heat transfer components and daily averaged roof head-load transfer, dynamic-values and radiative heat transfer dynamic R-values and radiative heat transfer coefficient .In result, 5cm of modelled polyesterene layer helped in reducing roof heat transfer to $1/3^{rd}$ of its value in an identical roof section without insulation. Another study conducted for new thermal performance index for dwelling roofs in warm and humid tropics worked with the U-values and R-values. TPI is studied base on thermal comfort and actual thermal performance of roof design options. The Handbook of Functional Requirements of Buildings suggests the use of parameters like U-value, and Damping for assessment of thermal performance. And these parameters are only applicable under steady state method since it helps in realistic comparisons between different types of building elements. It suggests considering peak degree hours above 30°C and peak heat gain factor to justify thermal rating of the building sections.

Parameters/Indicators

ECBC has recommended values (code 2009) For WWR, SHGC, U values; For roof, wall and fenestrations. Whereas NBC recommended values – U-factor. Some other parameters are discussed further

TPI

Thermal performance index of a non-air- conditioned building element is given by:

$$TPI = [(Tin - 30) X 100]/8$$

Thermal Resistance -

It is reciprocal of thermal conductance. For a structure having plane parallel faces, thermal resistance is equal to thickness (L) divided by thermal conductivity (K) as given below:

$$R = L/K$$

The unit of thermal resistance is $(m^2K)/W$

The usefulness of this quantity is that when heat passes in succession through two or more components of the building unit, the resistance may be added together to get the total resistance of the structure.

Thermal Resistivity -

It is the reciprocal of thermal conductivity. It is expresses in (mK)/W

Thermal Time Constant -

It is the ratio of heat stored (Q) to thermal transmittance (v) of the structure. It is expressed in hour (h).

a) For homogeneous wall of roof, thermal time constant may ,e calculated from the following formula :

$$T = Q/V = [(1/fo) + (1/2K)] Lpc$$

Where,

Q = quantity of heat stored,

U= thermal transmittance,

$f0$ = surface coefficient of the outside surface,

K= thermal conductivity of the material,

L= thickness of the component,

p = density of the material,

c = specific heat of the material.

Thermal Transmission or Rate of Heat Flow (q) -

It is the quantity of heat flowing in unit time under the conditions prevailing at that time. The unit of q is taken as W.

Thermal Transmittance (U) -

It is the thermal transmission through unit area of the given building unit divided by the temperature difference between the air or other fluid on either side of the building unit in 'steady state' conditions. It is reciprocal of total thermal resistance. Its unit is W/(m^2K).

Thermal transmittance differs from 'Thermal conductance' in so far as temperatures are measured on the two surfaces of material or structure in the latter case and in the surrounding air or other fluid in the former. The conductance is a characteristic of the structure whereas the transmittance depends on conductance and surface coefficients of the structure under the conditions of use.

Thermal mass is particularly effective in hot dry climate with larger diurnal range. The building mass stores heat during daytime when outside temperature is high, and releases it to the inside space during night when outdoor temperature is cooler. Thermal mass is also used in storing heat during daytime in cold climates, to release it into the space during night, to warm it up when outdoor conditions are colder. Materials such as concrete, brick and water have high thermal storage capacity and can be used for such application. Storage mass exposed to direct sunlight should be dark in colour to allow larger absorption. It is generally more efficient to have thicker rather than thinner storage mass. The optimum thickness varies between 100 mm and 200mm.

Climate Severity Index for Cold Climates

Q=aT-bR +cW where Q is the annual heat loss (kW h/m3), T a selected value of outdoor air temperature (°C), R a selected value of total radiation (W/m2), W a selected value of wind velocity (m/s), and a, b and c are appropriate coefficients for specific types of construction. CSI =KX Q, where K = a constant. If the three individual relationships are non-linear, then a non-linear multiple relationships will apply.

Time Lag -

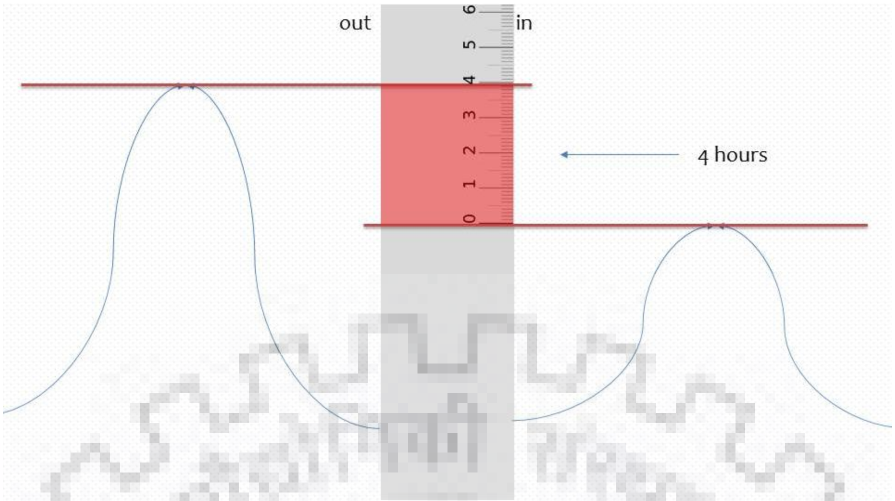


Figure 5 Time Lag

It is the time difference between the occurrences of the temperature maximum at the outside and inside when subjected to periodic conditions of heat flow. It is expressed in hour (h).

Thermal Damping -

The mechanism responsible for thermo-elastic **damping** is the resulting lack of **thermal** equilibrium between various parts of the vibrating structure. Energy is dissipated when irreversible heat flow driven by the temperature gradient occurs.

Thermal Damping = $[(T_{out}-T_{in})/T_{out}] \times 100$

Heating degree days –

It is the number of how many hours in that particular season/year requires heating. And Degree hours is a cumulative value of how many degrees and hours are exceeding the comfort temperatures calculated according to Adaptive thermal comfort formula for that regions.

Regional Practices – Building materials and Construction techniques

Mud Construction

Kath Khuni Technique

Dry Stone Construction

Dhajji Dewari Technique

Figure 6 Regional Practices

Before delving into existing regional practices in Himachal Pradesh, it is imperative to understand the natural occurrence of materials in the area. One of the most robust conifers, Deodar wood is abundantly found here. The material imparts stability to tall structures and is hence used in making posts, beams, windows, doorframes, shutters, roofs etc. The soft wood is easy to work with in absence of high tech tools and is resistant to insects and termites even when untreated. Mud and stone, one of the most easily available construction materials is not only a good insulator but also a good binder. Its usage, however, is intricate. Either mud is filled into the wooden frames and rammed into the place slowly building up the wall or sundried mud-blocks are used in the wall construction. Foundations and walls are often constructed with locally found quarries of hard stone, while roofs of building are made of slate tiles – a metamorphic rock with high quartz content, frost resistance, heat and moisture barrier. Often traditional artisans are employed in the process. Oral transfer of knowledge from master artisan to apprentice reflects in traditional building techniques. (Adaptive Climate responsive Vernacular Construction in High Altitude – Amitava Sarkar)

There is a variation in the architecture of different components of the state. Even so, in a relatively minute area several types of house are found which have different betokens of construction. The houses are orchestrated in a compact manner on a square ground facing the south sun to sanction the maximum sun perforation. Traditional houses are laid along the contours to evade much perturbance to the topography. Stepped/ terraced orchestrating is prevalent in the areas if steep slope or very hard rock strata. The substratum is of several feet and is generally of stone. The stones are symmetrically arranged and are filled with a little the roofs are flat as well as sloping depending upon the precipitation in the region. Roofs are tiled with deep grey slates which are additionally native to the region.

The superstructure is withal built with locally available materials, generally stone and wood or mud, with the sagacity of the local workmanship. The walls are generally left unplastered but at times surkhi (cumulation of lime, brick powder, sand and jaggery, etc.) is utilized to plaster the outer walls. The climatic conditions of the region determine the type of construction which may use one of these materials or at times an amalgamation of two or more. Depending on the materials used and the type of construction, traditional techniques are categorised into five categories Kath-kunni, Dhajji construction, wooden construction, Stone construction and Mud construction.

Kath Khuni Technique:

This type of construction is mainly found in the higher ranges of Kinnaur and Kullu districts of Himachal. The walls are constructed of alternate layers of wood and stone. The wood battens 4"-6" thick elongate beyond the wall length and interlock with the wood on perpendicular wall. The wooden planks are interlocked by lap joint. Floors are composed of wood not more than 7-8 ft high for better insulation. The upper floors project out of the stone wall with wooden balconies engendering a sun space for sitting. Thus maximizes the heat gain. This type of construction is earthquake resistant as the wooden battens form a framework which is well bonded and gives ductility to the otherwise rigid stone wall.

Dhajji Dewari Technique:

Dhajji-Dewari is derived from Persian meaning "patch quilt wall." Such construction is prevalent in the Kaihmir valley and the hills of Shimla. It is characterised by walls of wooden bracing with in-fills of immensely colossal mud bricks or stone proximately packaged. The astronomically immense timber members rest along the load bearing masonry walls with the floor beams and the runners for the cross walls lapping over them. The wood accommodates to tie the walls of the structure together with the floors. It is lighter in weight, sanctioning for its use on walls that are cantilevered over the street. The surface is plastered with a coat of mud and lime at some places. This type of construction is economical and structurally stable. The fame of wood distributes the lateral loads in case of an earthquake.

Wood Construction:

Wooden construction is very prevalent in hilly areas for facile availability of construction wood and its thermal properties provide mitigation from the cool winters. In Himachal this construction is mundane in most of the areas except cold and dry Lahaul-Spiti, in cumulation with other techniques at times. Houses are built 2-3 storeys high where the vertical wooden posts are denoted to carry the load. Horizontal members are placed at different calibers with an in-fill of wooden battens. The upper flowers are cantilevered thus providing living space all around. In some cases, the ground floor is built in stone masonry with the upper floor of wood.

Dry Stone Construction:

Dry stone construction is prevalent in Kangra region where slate is in abundance. However, this type of construction is additionally prevalent in Kinnaur district where good quality stone can be quarried. Different sized stones are placed over each other and compacted without the mortar. Through stones are utilized at conventional intervals. A more vigorous bond is achieved by interlocking the stone rather than integrating more minuscule stones in gaps. !interior surface may be mud plastered. The stone masonry structural walls take main lateral and gravity load. The walls uniformly distribute the load in both orthogonal directions.

Mud Construction:

Mud construction is prevalent in Himachal in two types, rammed earth conduction and sun dried mud construction. Rammed earth construction is prevalent in the areas where construction materials like stone and wood like the cold desert of Lahaul-Spiti. Thick walls upto 2 feet wide are built with by pouring wet mud mortar and ramming it to make it compact afore pouring another layer. Monolithic walls thus constructed keep the interiors cold in the chilling winters but earthquake resistance of this construction sundry with the form of and the building the type of loading on the walls. Sun dried mud bricks are utilized in the Kangra region where good quality of mud is available from the river beds. The walls are composed of sun dried bricks about 2-3 ft. thick plastered with mud phuska. These walls are susceptible to erosion due to rain thus the buildings are raised over stone or plastered to evade it. The floors are composed of wood plastered with mud enabling insulation. Thick flat mud roofs are utilized for insulation in Lahaul while in places with rainfall slate roofs are adopted. The roof is built over wooden frame reposing on the mud walls.

We can have a look at an example of ongoing regional practice in Himachal Pradesh.

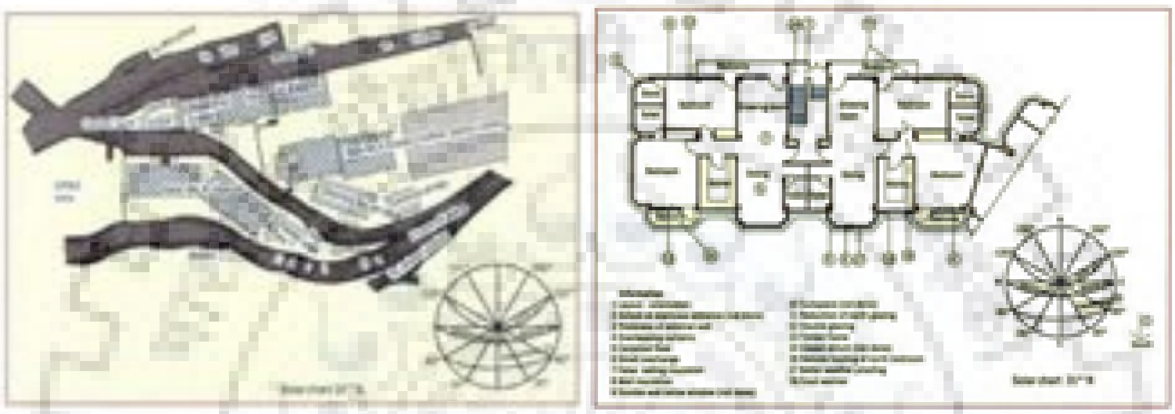


Figure 7 MLA Hostel, Shimla

It is a MLA Hostel constructed in Shimla. It has used techniques like Retrofitting (e.g. Using 9” thick external wall instead of 4.5” thick wall), Passive Solar Design Considerations with cost benefit analysis, Energy Efficient Appliances with cost-benefit ratio. One of the main objectives while designing this building was to ensure the minimum use of conventional energy being used in the building. The hostel buildings have been designed to make full utilization of the heat from the sun. Building integrated south facing food warmers.

Another example can be Himurja Office Building from Shimla which has used insulation maintained throughout (5cm thick glass wool), South orientation, Solar Water heater radiates the heat to north facing room, Double glazed windows, RCC diaphragm walls on north, Solar Chimney, Solarium on South side, Light shelves.

According to Housing Encyclopaedia, the most used traditional material and construction practices in Dharamshala were found are given.

Stone Masonry	Rubble Stone in mud/lime mortar or without mortar (usually with timber roof)
	Dressed Stone Masonry
Adobe/Earthen Walls	Mud Walls
	Mud walls with horizontal wood elements
	Adobe block walls
	Rammed earth/ Pile construction
Unreinforced masonry walls	Brick Masonry in mud or lime mortar
	Brick Masonry in mud or lime mortar with post
	Concrete block masonry in cement mortar
Confined masonry	Clay brick/tile masonry, with wooden posts/ tie columns and beams
	Clay brick/tile masonry, with concrete posts/ tie columns and beams
	Concrete blocks tie columns and beams
Reinforced masonry	Stone masonry with cement mortar
	Clay brick masonry with cement mortar
	Concrete block masonry with cement mortar
Moment resisting frame	Flat slab structure
	Designed for gravity loads only
	Designed for seismic effects
	Designed for seismic effects with structural infill
	Dual system – Frame with shear wall
Structural wall	Moment frame with shear in situ walls
	Moment frame with shear precast walls
Precast	Moment frame

concrete	Pre-stressed moment frame with shear walls
	Large panel precast walls
	Shear wall structure with walls cast in situ
	Shear wall structure with precast wall panel structure
Moment resisting frame	With block masonry partitions
	With cast in situ concrete walls
	With lightweight partitions
Braced frame	Concentric connections in all panels
	Eccentric connections in few panels
Structural wall	Bolted plate
	Welded plate
Load bearing timber frame	Thatch
	Walls with Bamboo/reed mesh and post
	Masonry with horizontal beams/planks at intermediate levels
	Post and beam frame (without any special connections)
	Wood frame (with special connections)
	Stud wall frame with plywood/gypsum board sheathing
	Wooden panel walls
Seismic Protections systems	Building protected with base isolation system
	Building protected with seismic dampers

There are traditional materials used according to the purpose in building. Which are -

Building Material Name	Usage
Wooden Logs of Poplar	In ceiling
Stems of Willow & Sea buckthorn	Used as void fillers
Branches of Willow	
Mud	Plaster
Clayey Soil	External plaster
Wooden logs of Eucalyptus	Central supporting member for ceiling
Scrub	Edges of Roof
Red soil	Painting
Limestone	White wash from outside

The materials and construction techniques selected for the study are -

1. Autoclaved aerated concrete
2. Adobe wall
3. Solid brick wall
4. Brick cavity wall
5. Kath khuni Construction
6. Rubble stone masonry

The framework for this dissertation was formed with the help of the literature study as follows:

Aim

Identify means of improving thermal performance of new residential buildings by comparing them with thermal performance of traditional buildings.

Objectives

1. Evaluate the thermal performance of residential buildings in cold climate
2. Compare the thermal performance with, that of regional practices adapted in such buildings
3. Identify means and materials for improving thermal performance of residential buildings considering current day building practices

Scope and Limitations

- The study will limit to the low and mid income multi storied residential building.
- The study does not cover extreme cold locations

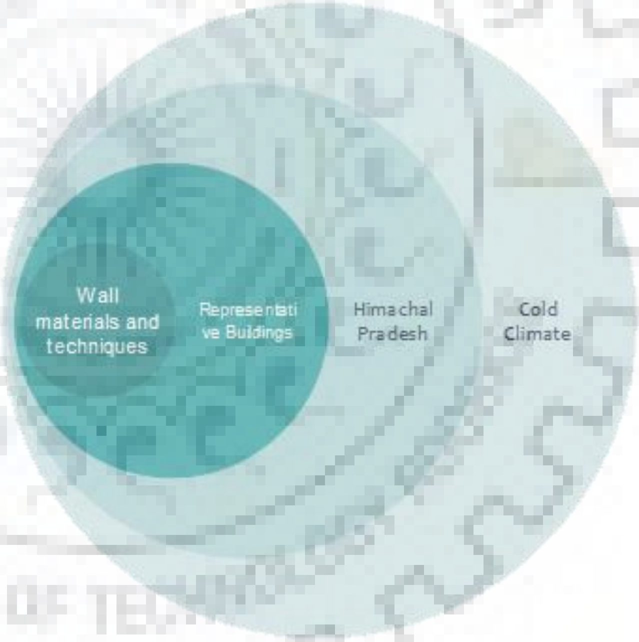


Figure 8 Scope and Limitations

Research Methodology And Analytical Framework

The research problem is born through thought process described in the background of the study. It is strongly supported and directed by the Literature study done in the dissertation.

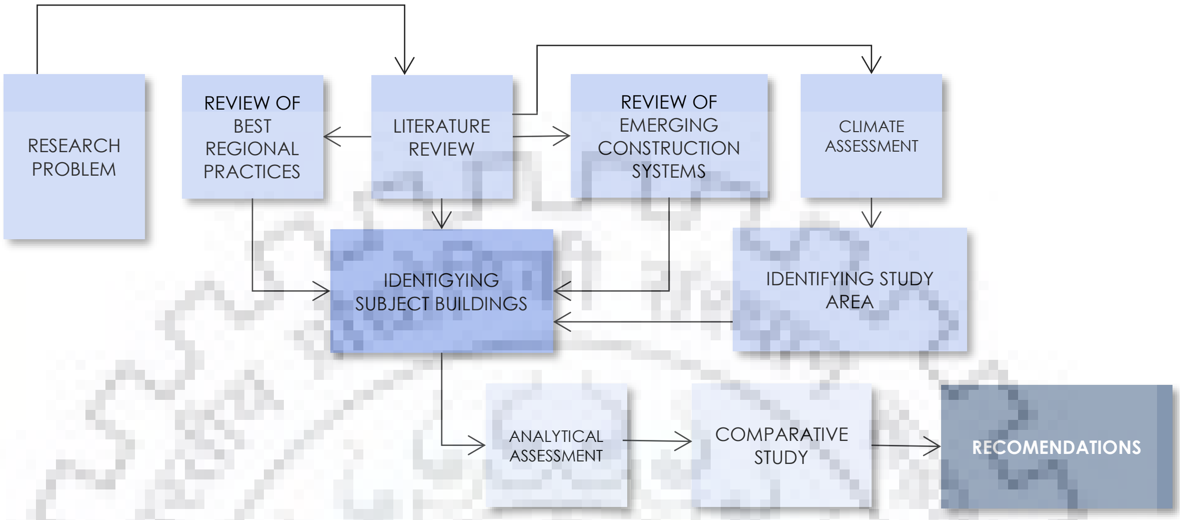


Figure 9 Research Methodology

Initially, Literature study has 3 independent parts covering regional practices, construction, location of the study. And representative traditional building and a modern day building from the location s selected are processed through the analytical assessment. This comparative study has developed the final output of the dissertation in the form of recommendations.

Analytical Framework

The analysis is carried out in the particular hierarchies and sequence. The initial part of analysis is carried out to finalize the representative location for the study. The next part for analysis is focusing on building level which also includes material and construction techniques. The values of temperatures in representative summer and winter week are for carrying out the analyses and evaluation of thermal performance.

This analytical framework moves along with the objectives of the dissertation. The framework is based upon objective, tasks under that respective objective, the expected out come and the tool to carry it out.

Table 2 Tasks for the study & their output

Tasks	Output
Climate Analysis	Thermal Performance Assessment & Identification of Study Area
Analytical Assessment (Modern)	
Review of regional best practices	Identification of Practices for further study
Analytical Assessment (Traditional)	
Comparative Study (Traditional Vs. Modern)	
Review of emerging construction systems	Recommendations to improve thermal performance
Thermal performance analysis	
Comparative analysis of emerging technologies	

If we look at first objective i.e. to evaluate the thermal performance of residential buildings in cold climate has the following tasks under it. Climate analysis was conducted to finalizing the representative location of cold climate for the study. A representative modern apartment building was chosen and the assessment was carried out to evaluate the thermal performance of that particular building. A base case for prepared for the same. The expected outcome of this objective is supposed to be the Thermal performance assessment and the identification of the study area for further work. In Second objective – Compare the thermal performance with that of regional best practices adapted in such buildings. To achieve the expected outcome to identify the best practices, the review of regional best practices and analytical assessment by the comparative study (Traditional vs. Modern) will be carried out with the help of literature studies and surveys. And lastly for the final objective of dissertation – To identify methods and materials to improve thermal performance of residential buildings considering the current day best practices; the review of emerging construction system in the selected study area will be conducted. Also thermal performance of selected building will be analysed and then compared with each to other which will lead to expected outcome of providing recommendations for the better thermal performance of residential buildings in cold climate which will be the final output of this dissertation.

Tools and Techniques

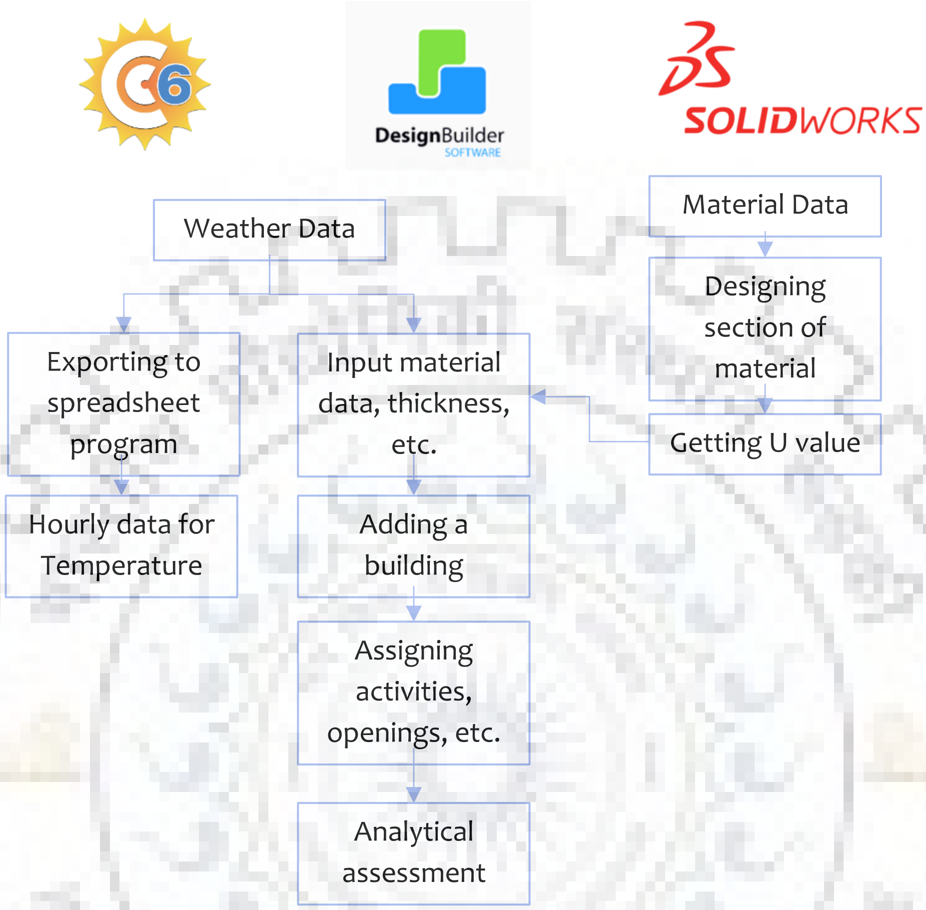


Figure 10 Tools and Techniques

Climate consultant

This tool is the graphic based program to conduct the study about climate by uploading the weather data of particular location. It has helped in finalizing the study location for this dissertation.

Solidworks

This tool covers up a very small yet innovative part of the study i. e. calculating a composite wall system/assembly used in traditional building. This technique with help of this tool can be applied for any location and any composite wall system.

Energy plus - Design Builder

This tool helps in achieving the results at building level.

Context for simulation:

Occupant level–

- Air quality
- Acoustical quality
- Ergonomic factors
- Spatial design

Owner level –

- Optimal Investment
- Lower operational costs

Environmental –

- Low energy consumption
- Lesser environmental impact

This tool can simulate Heat load received inside, Temperature inside building, Wind speed inside building, Daylight inside building, etc. To simulate, the inputs given are Building geometry, Co-orientation, Arrangement of openings, Wall type and thickness, Chajjas, Weather (solar radiation, wind, humidity), Material data (Density, Specific heat, conductivity, etc.), Occupants' behaviour, etc. and the techniques that can be used to conduct the analytical assessment are steady state method (assume some parameter steady), Dynamic methods, Correlation methods. This study is using the steady state method majorly. A pilot study was conducted to validate and expertise this tool.

Pilot Study

In this study, a shoebox model has been simulated for the given combinations.

- 4X4 meter brick building with single pane glazed windows at two opposite walls.
- Roof and floor is adiabatic.
- Orientation of 0 and 90 degrees.
- Two different locations used that are, Manali and Shimla.
- Naturally ventilated and a Heating equipment used.

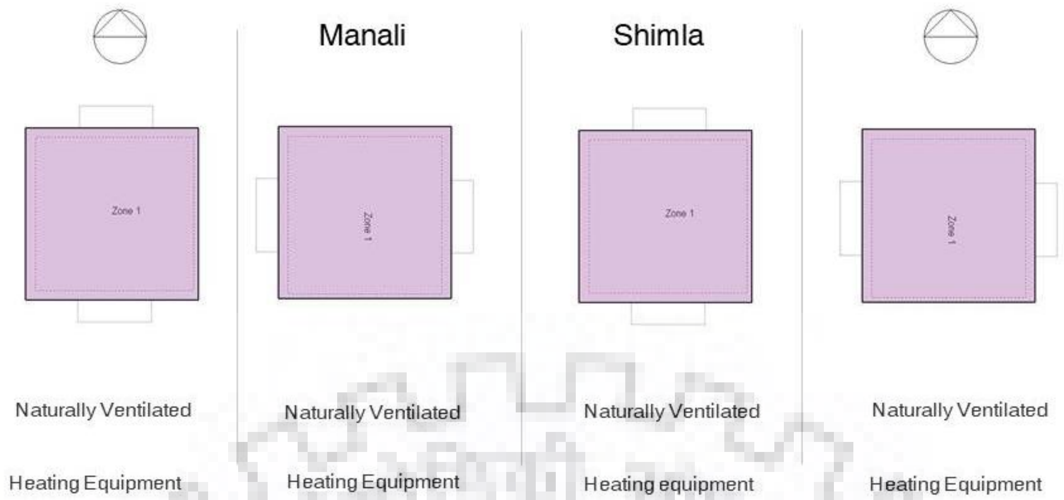


Figure 11 Combinations for Pilot Study

Some results like were taken out. Windows facing north south with WWR of 20% is letting the heat in the block. So the indoor temperature is higher than outdoor temperature during most of the day time. But also the Heating equipment (In this case, Packaged direct expansion - chosen for this case according to CoP and cost) system is even more helping to keep the block warm inside in regular.

Manali **Shimla**

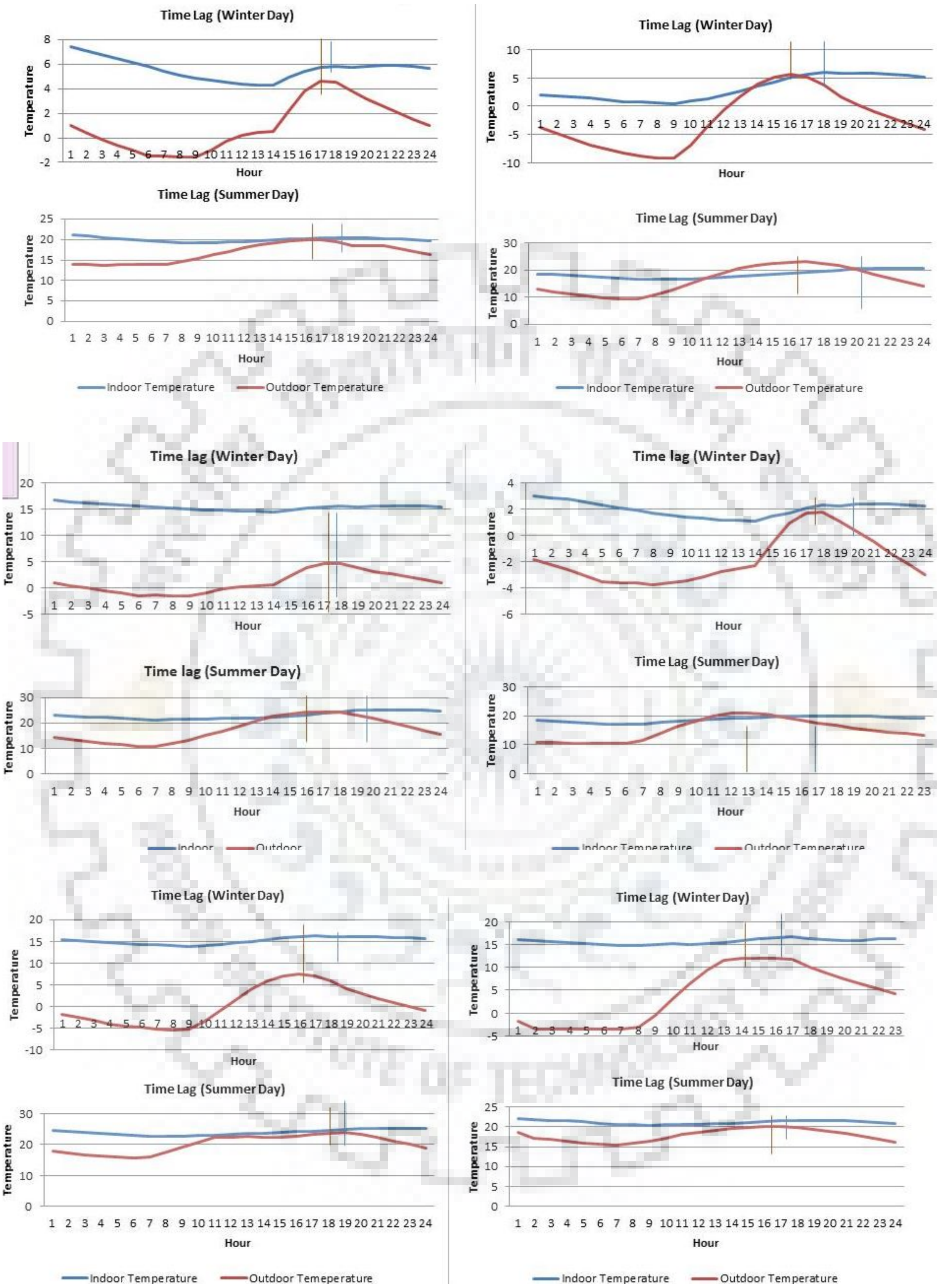


Figure 12 Pilot study - Time lag for Shimla and Manali

3. DETAILS OF THE STUDY

CLIMATE

Climate plays a major role in day-to-day and overall life of human beings. Their life patterns, activities and behaviour are greatly influenced by the elements of climate. The basic elements, namely, air temperature, solar radiation, humidity, rainfall and Wind form the general climate of a place. And all these basic elements affect the energy and thermal performance of the building. Variations in the levels of these elements occur throughout the country. Climate is an overall output of weather over long periods of time. It is measured by evaluating the patterns of variables in given region and over long periods of time. Some of the climate variables can be given are Dry bulb Temperature, Relative Humidity, Solar Radiation, Air Movement, Precipitation, Cloud Cover, Sunshine duration, etc.

Elements of Climate data for climate classification –

Temperature –

- Monthly mean of daily maxima (°C)
- Monthly mean of daily minima (°C)
- Standard deviation of their distributions

Humidity –

- Early morning relative humidity (%)
- Early afternoon relative humidity (%)

Solar Radiation –

- Monthly mean daily total (in MJ/m^2 or Wh/m^2)

Wind –

- Prevailing wind speed (m/s) and direction

Rainfall –

- Monthly total (mm)

Basically, there are five types of climate relevant to building design according to National Building Code of India,

- Hot and dry
- Warm and humid
- Composite
- Temperate
- Cold

COLD CLIMATE

Cold Climate are the regions, where the mean day by day dry bulb temperature of 6°C or less win amid the periods of December and January, and height is in excess of 1200 m above mean ocean level (MSL), are the zones of cold climate according to National Building Code, India. IT is spread over Jammu and Kashmir, Himachal Pradesh and Pratts of Uttarakhand, Sikkim and Arunachal Pradesh. There are other small areas of cold climate across the India too. Primary criterion in this locale is heating in winter season. Partitions and rooftop should to be secured against the precipitation and snowfall. Artificial heating is required in the winter months in these areas for survival.

DATA

The core of this study is the weather data for the locations which has helped for the selection of study area and has helped in studying the effect on thermal performance on the representative residential buildings.

Weather data is the measured weather. Collecting data every day can show you patterns and trends, and helps figure out how our atmosphere works. Weather data comprises of the facts or readings about the state of the atmosphere, including temperature, wind speed, rain or snow, humidity, and pressure of that particular location. Nowadays, high-tech equipments help take reading of above variables with a very good accuracy. And it can be measured from the ground, the air, and from the help of satellites. Data Collection Devices like thermometers to measure temperature, radar systems to create maps of rain and snow and measure motion of rain clouds by bouncing waves off the clouds and measuring how long it takes to return, barometers to measure pressure in atmosphere, i.e. how much air is present in the particular volume, rain gauges to measure the rainfall, wind vanes and anemometers to measure speed and direction of the wind, , transmission meters to measure visibility, and hygrometers to measure humidity help in taking readings and then prepare the weather data files.

Global climate database can generates accurate and representative typical years for any place on earth and one can choose from more than 30 different weather parameters. The database consists of more than 8 000 weather stations, 5 geostationary satellites and globally calibrated aerosol climatology.

SELECTING LOCATION FOR THE STUDY

To arrive at a representative location for the study, weather for a bunch of locations is compared with the help of Monthly average temperature, Maximum and Minimum Temperatures of those locations, Heating degree days and hours, Diurnal variation were considered. The weather data was processed to compare these values. And HIMUDA demand survey and other literature studies helped in identifying the criticality of the location and finalizing the location.

Monthly average temperature

Monthly average values help us define the difference between the hottest and coldest months. Thus it has helped in selecting the representative summer and winter weeks for the study.

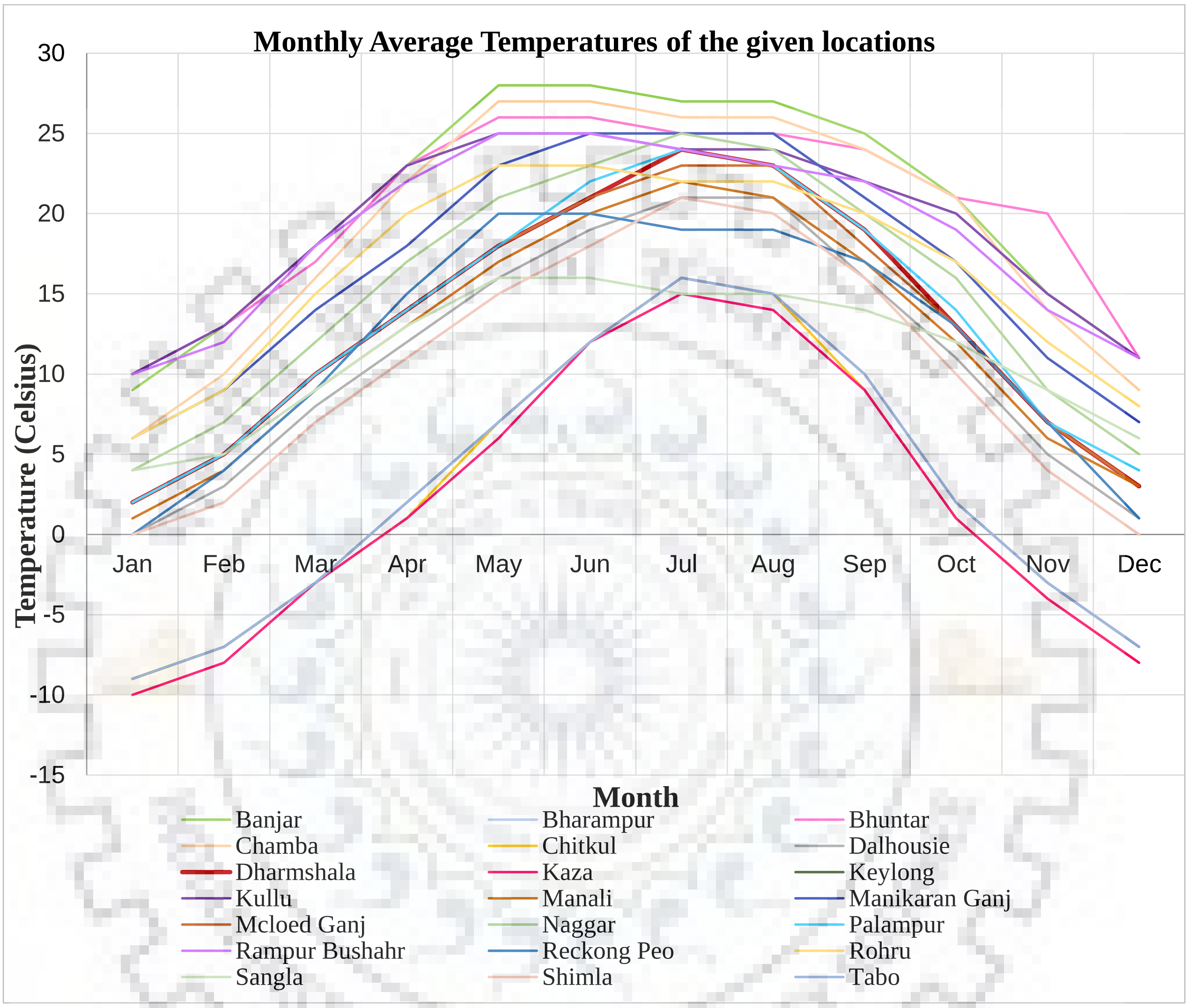


Figure 13 Monthly Average Temperatures of Given Locations

Himachal Pradesh is chosen to conduct the research on the dissertation topic and funnel down representative study area according to data availability and time constraints. If we look at the monthly average values of temperatures of certain locations of Himachal Pradesh, we find that Kaza and Tabo are showing the extremities of cold climate. And most of the other locations are falling in the ribbon of 10°C difference. But only monthly averages are not enough to decide the location for the study which will represent the cold climate in Himachal Pradesh. Because average values are made from all the values in the month, including the rare extremes, which can cause misinterpretation about the weather of that particular location. But in case of Tabo and Kaza, even the monthly average values are going near the extremes and are out of the bunch of locations. So they are excluded for the further funnelling down for deciding the location for the study. Assessment of climate conditions are further carried out for the other given locations above are carried out as this discussion goes further with the help of other types of analyses.

Maximum and Minimum Temperatures

The maximum and minimum temperature readings give an idea about the extremities of hot and cold period of those particular months.

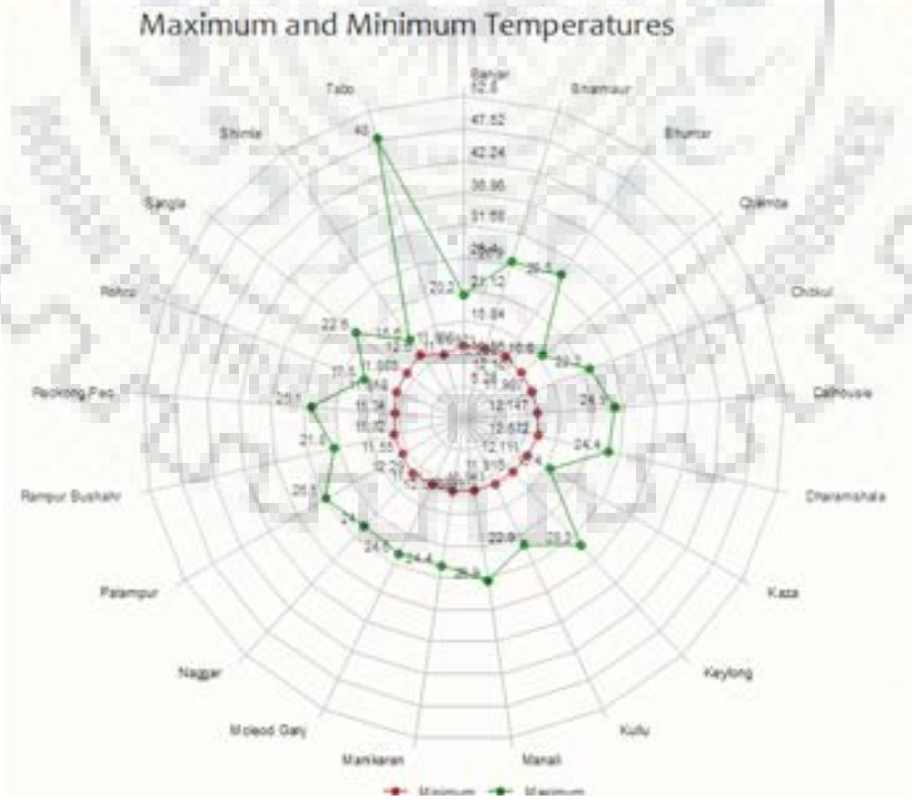


Figure 14 Maximum and Minimum Temperatures for given locations

In this case, Kaza, Rohru, Shimla, Chamba, Banjar, Rampur Bushahr are relatively colder locations in the given list, Also Kaza and Tabo are having extreme climates. Bharmaur, Bhuntar, Keylong, Manali are relatively warm regions. Chitkul, Dalhousie, Dharamshala, Kullu, Manikaran, Mcleod Ganj, Naggar, Palampur, Reckong Peo and Sangla are in the similar range. Amongst these, **Dharmashala** stands on 6th place, having most demand in houses followed by **Palampur** on 10th place and D**alhousie** on 20th.

Diurnal Variation

The difference between maximum of the day and minimum of the night temperatures or the temperature difference range between minimum and maximum of the day (24 hours) is known as Diurnal Variation of that day. This value also gives the idea about thermal mass capacity needed for that particular location.

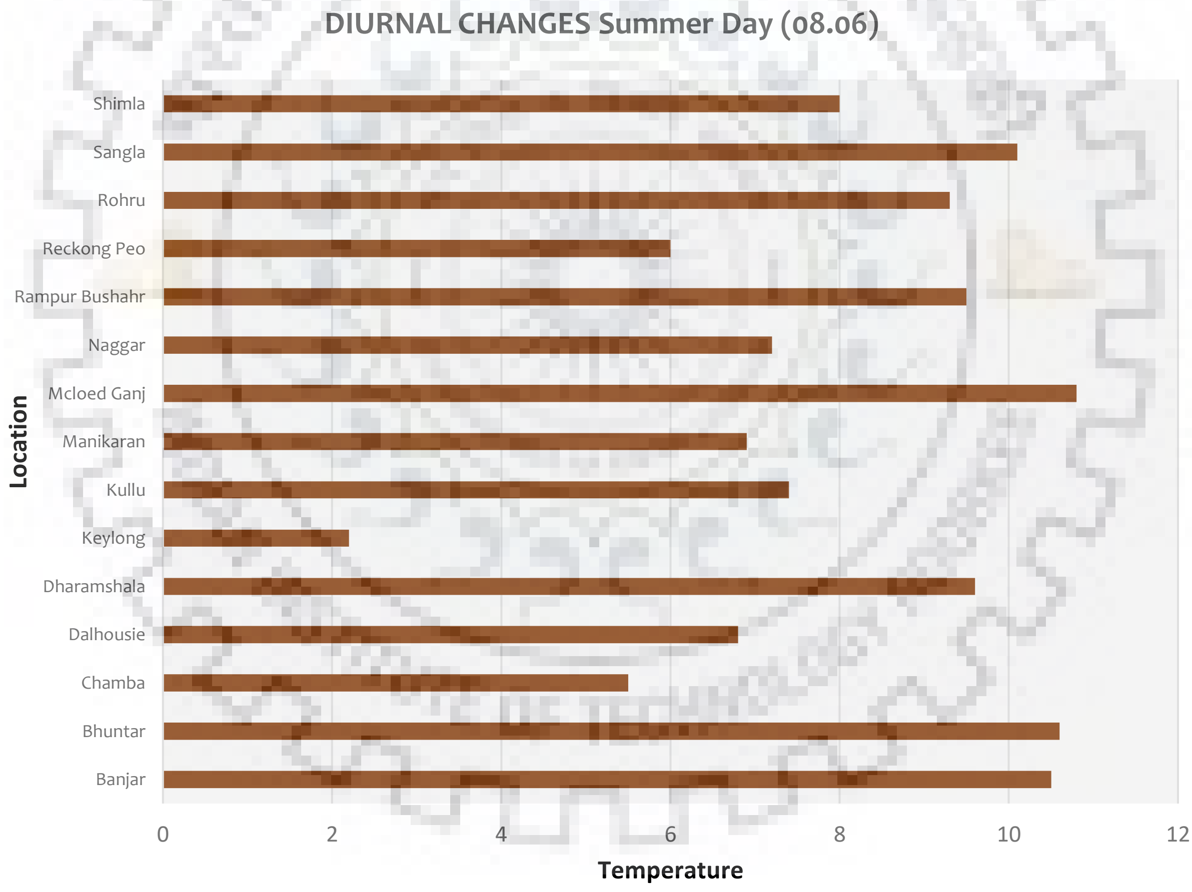


Figure 15 Diurnal Changes for given locations on summer day

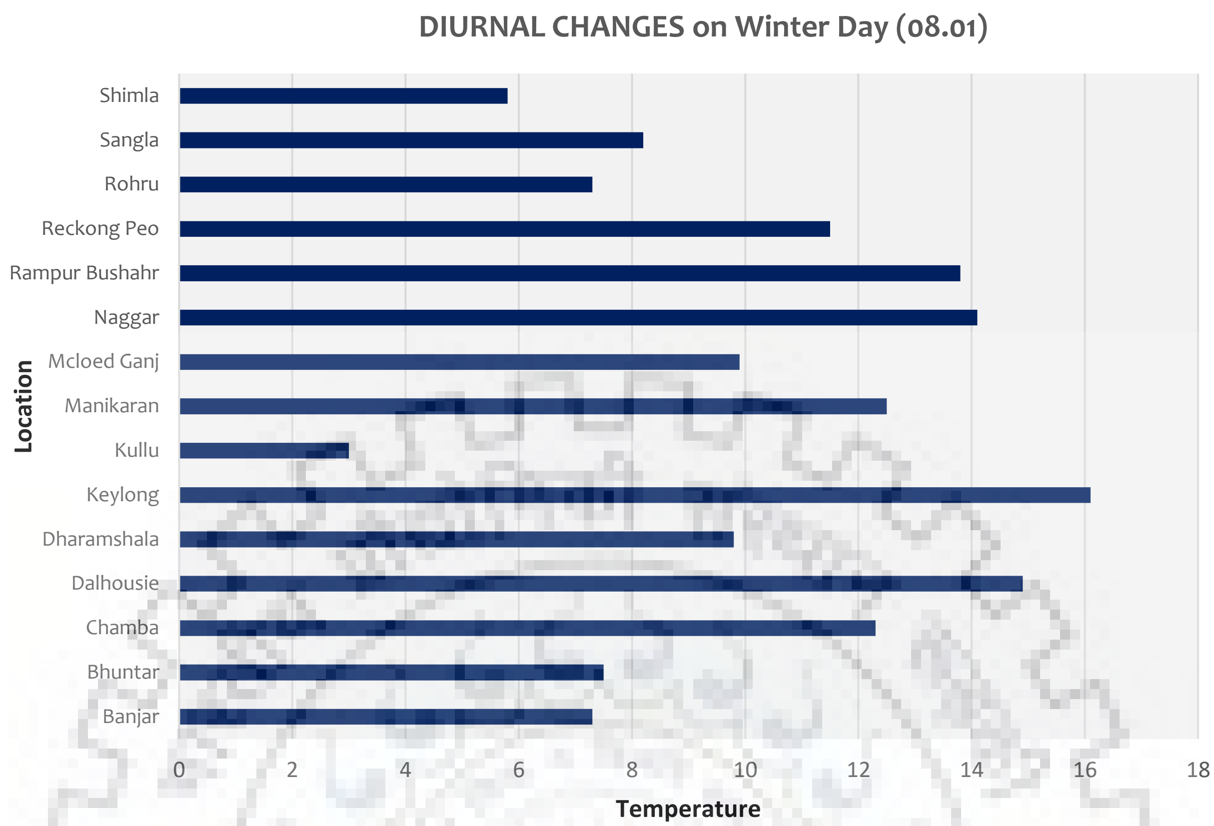


Figure 16 Diurnal Changes for given locations on Winter Day

According the monthly average temperatures and minimum and maximum values of temperature in every month it is found that January represents the winter month and June represents the summer month of the year. The representative summer week decided is 08.06-15.06 and the representative winter week decided is 08.01-15.01, again according to the daily average values. To learn about diurnal changes one representative day has been selected.

Heating Degree Days

These are the days on which the building is needed to heat to maintain the thermal comfort. In this case, heating degree days are calculated according to adaptive thermal comfort formula of ASHRAE and not by the set comfort temperature levels.

$$Adaptive\ Comfort\ Temperature = 13.5 + 0.54\ (To)$$

If Outdoor temperature is 34 degree Celsius, Then,

$$Adaptive\ Comfort\ Temperature\ =\ 13.5\ +\ 0.54\ (34)$$

$$Adaptive\ Comfort\ Temperature\ =\ 31.86$$

So, the comfortable temperature indoors at outdoor temperature 34°C is 31.86°C

Heating degree hours

Similarly, The hours which are in need to heat the building to maintain the thermal comfort inside according to given human activity are the heating degree hours. Here, they are calculated for the whole year.

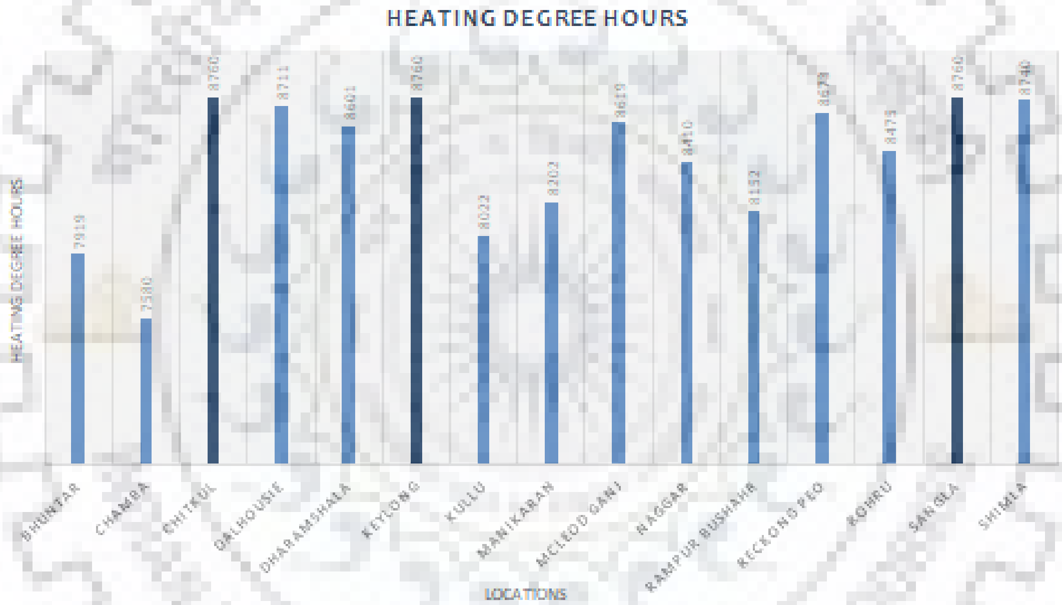


Figure 17 Heating Degree hours for year for given locations

Here, after calculating the heating degree hours for the given locations according to the adaptive thermal comfort formula given by ASHRAE, Chitkul, Keylong and aSnagla are the mostly cold locations, since they are in need of heating almost over the year. Dlahousie, Dharamshala, Reckong Peo, Mcleod Ganj, Rohru and Shimla are the locations in which more than 85% of tbe year is in need of heating. And the least heating needed is in the Chamba, Bhuntar, Kullu,Rampur Bushahr and Manikaran.

HIMUDA Demand Survey

India's cold climate is spread over quite a number of states. The cold climate is spread major over Jammu and Kashmir, Himachal Pradesh, Parts of Uttarakhand and parts of Sikkim and Arunachal Pradesh. There are other small areas of cold climate across the India. Some parts of Himachal Pradesh are chosen for the dissertation. The study area is further funnelled for the detailed study for this dissertation according to the Climate analyses carried out in Chapter – 'Analyses and Results' along with the support of HIMUDA (Himachal Pradesh Housing and Urban Development Authority) demand survey.

HIMUDA demand survey was conducted in 77 cities in Himachal Pradesh to fullfill the purpose to assess the demand of residential houses, plots and flats in respective cities prior starting the development. 69,618 applications were received for both the phases under this survey. The applicants prioritized the location according to the cleanliness in the city, type of the city (agricultural city, industrial city or tourist hotspots), connectivity and access during winter season.

Sr. No.	District	Applications Received	Amount Collected
1	Shimla	14,673	Rs. 7,33,65,000
2	Solan	18,260	Rs. 9,13,00,000
3	Sirmour	2,044	Rs. 1,02,20,000
4	Una	6,505	Rs. 3,25,25,000
5	Hamirpur	5,840	Rs. 2,92,00,000
6	Kangra	9,589	Rs. 4,79,45,000
7	Mandi	5,053	Rs. 2,52,65,000
8	Bilaspur	1,788	Rs. 89,40,000
9	Chamba	1,343	Rs. 67,15,000
10	Kullu	4,523	Rs. 2,26,15,000
11	Kinnour	-	-
12	Lahoul Spiti	-	-
		69,618	Rs. 34,80,90,000

Figure 18 HIMUDA Demand Survey

Most of the applications received were from Solan, Shimla, Kangra, Una and Mandi. Also, if we look at the ten cities which are in highest demands, they are, Shimla, Una, Hamirpur, Solan, Kasauli, Dharamshala, Mandi, Parwanoo, Baddi and Palampur.

	Number Of House	Districts	Flat	House	Plot	Total
1	Shimla	Shimla	1427	592	9357	11376
2	Una	Una	142	98	4932	5172
3	Hamirpur	Hamirpur	128	133	4614	4875
4	Solan	Solan	624	326	3859	4809
5	Kasauli	Solan	956	309	3088	4353
6	Dharamshala	Kangra	206	219	3828	4253
7	Mandi	Mandi	156	166	3366	3688
8	Parwanoo	Solan	318	148	2914	3380
9	Baddi	Solan	208	98	2631	2937
10	Palampur	Kangra	143	127	2132	2402
11	Manali	Kullu	321	140	1476	1937
12	Kullu	Kullu	126	84	1291	1501
13	Dharampur	Solan	165	60	1148	1373
14	Kangra	Kangra	84	70	1042	1196
15	Mehatpur	Una	34	20	1111	1165
16	Chail	Shimla	196	65	756	1017
17	Nahan	Sirmour	23	24	940	987
18	Kandaghat	Solan	239	69	643	951
19	Bilaspur	Bilaspur	22	15	883	920
20	Dalhousie	Chamba	170	69	631	870

Figure 19 HIMUDA Demand Survey

HIMUDA has also acquired the land according to the demand in various places including Shimla, Kasauli, Parwanoo, Dharmshala, Kangra, Palampur, Una, Kullu, Manali, Chamba, etc.

After analysing the weather for a bunch of locations is compared with the help of Monthly average temperature, Maximum and Minimum Temperatures of those locations, heating degree days and hours, Diurnal variation were considered. The processed weather data and the HIMUDA demand survey has filtered out the locations and the study arrived at selecting Dharamshala as a location for study.

SELECTING REPRESENTATIVE BUILDINGS

Modern day buildings are appearing in large numbers. People are choosing cheaper materials and easier and cheaper construction techniques to construct the building. The economical factor has become the important factor in taking any decision about the design of the building; instead it should be users' preference and comfort (Thermal, Acoustical, and Visual Comfort), aesthetics, etc. The generations have been experiencing and talking about the difference between older day buildings and modern day building according to their comfort but there has been no valid research happened in this type of climate for Thermal Performance of building. So there is a immense need to compare, observe and learn from traditional buildings to improve our modern day buildings. Representative buildings are selected according to data availability and limitations of tools.

Modern day building was selected according to popular construction materials and practices that have been incorporated in the building which affect the thermal performance of the building. When HIMUDA came into existence in 2004 to fulfil the objective to create infrastructure to meet with the Housing needs of different income groups and to provide for development schemes for mobilizing public and private resources for the promotion of housing colonies and related infrastructure and to provide mechanism for planned development of housing colonies. It aims to develop housing colonies at various places of the State under different housing schemes like Social Housing Schemes, Self-Financing Schemes, and Rental Housing Schemes for HP Govt. employees, Police Personnel etc. So the following plan for housing is also developed for Dharamshala by the same organization and chosen for further analytical assessment.

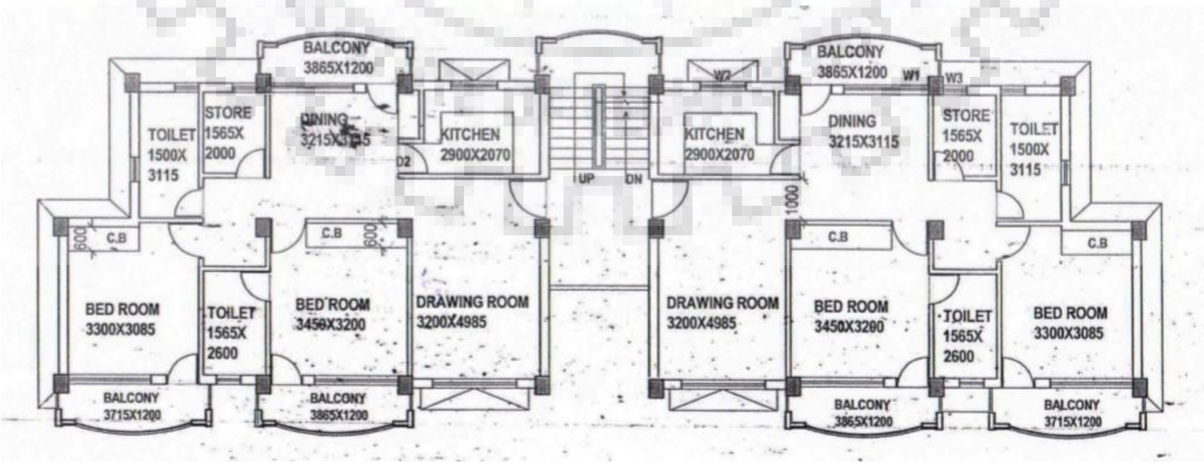


Figure 20 Plan for residential project in Dharamshala by HIMUDA

A traditional building here means a typical building style with common building material and technique used in earlier days. It is chosen according to the literature study (Regional Practices – Building Materials and Construction techniques) done in previous chapter from the same locality.

Figure 21 Traditional representative building

4. THERMAL PERFORMANCE ANALYSIS

Analytical Assessment of Modern Representative Building

The chose buildings are further taken into Energy Plus – Design Builder for analysing and evaluating the thermal performance. It is a three storeyed residential building having total 6 numbers of 1BHK flats in it. A base case was prepared for the same. The building is designed with 230 mm brick walls, 20 mm external wall plaster and 10 mm internal wall plaster. The windows are single layer glazed windows. And the basic activities are provided to each room as per the design. Whereas, A traditional building is smaller and compact in size with comparatively smaller windows and with mud walls and sloping slate roof.

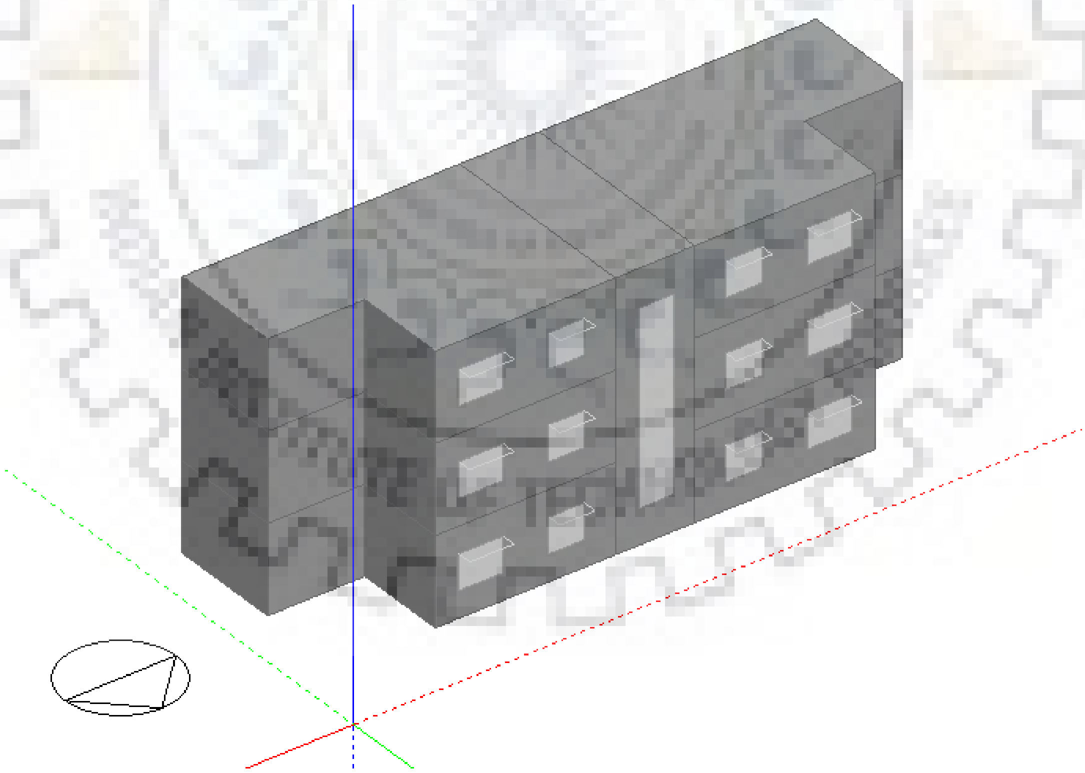


Figure 22 Modern day building modelled in DesignBuilder

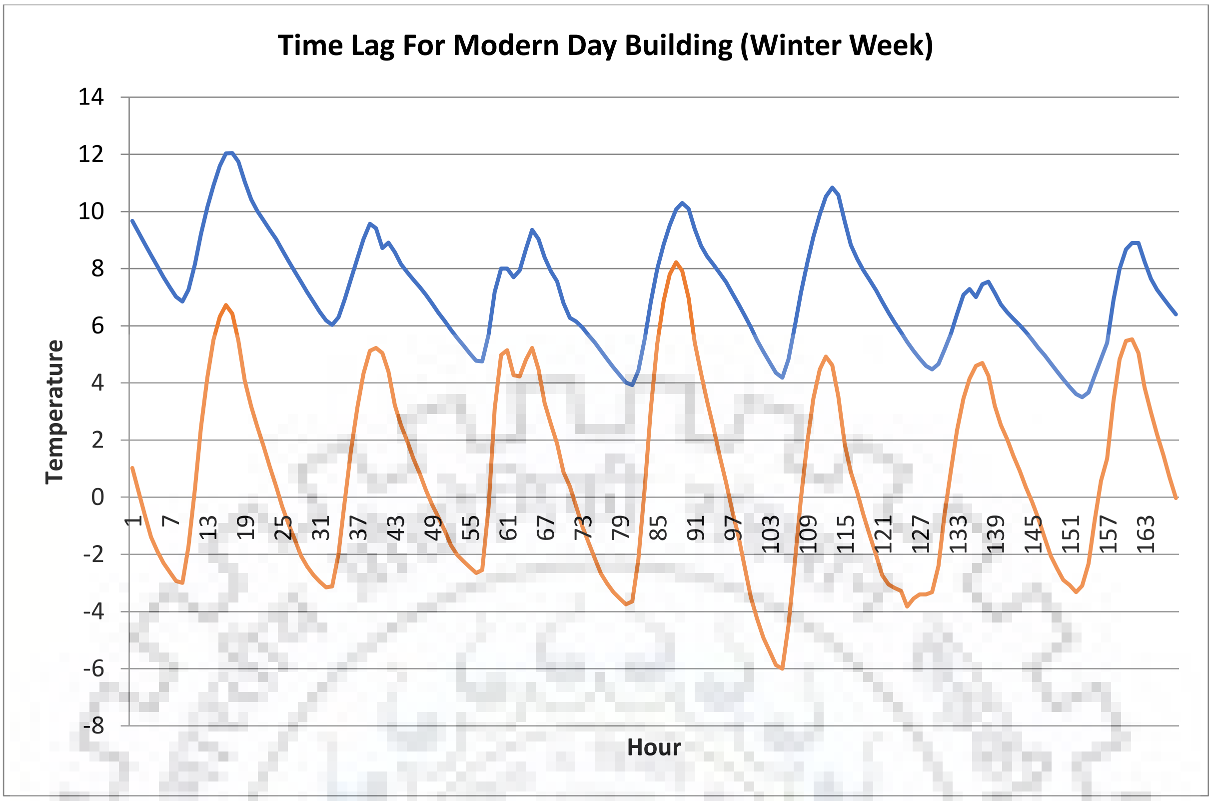


Figure 23 Time lag of Modern Day Building (Winter Week)

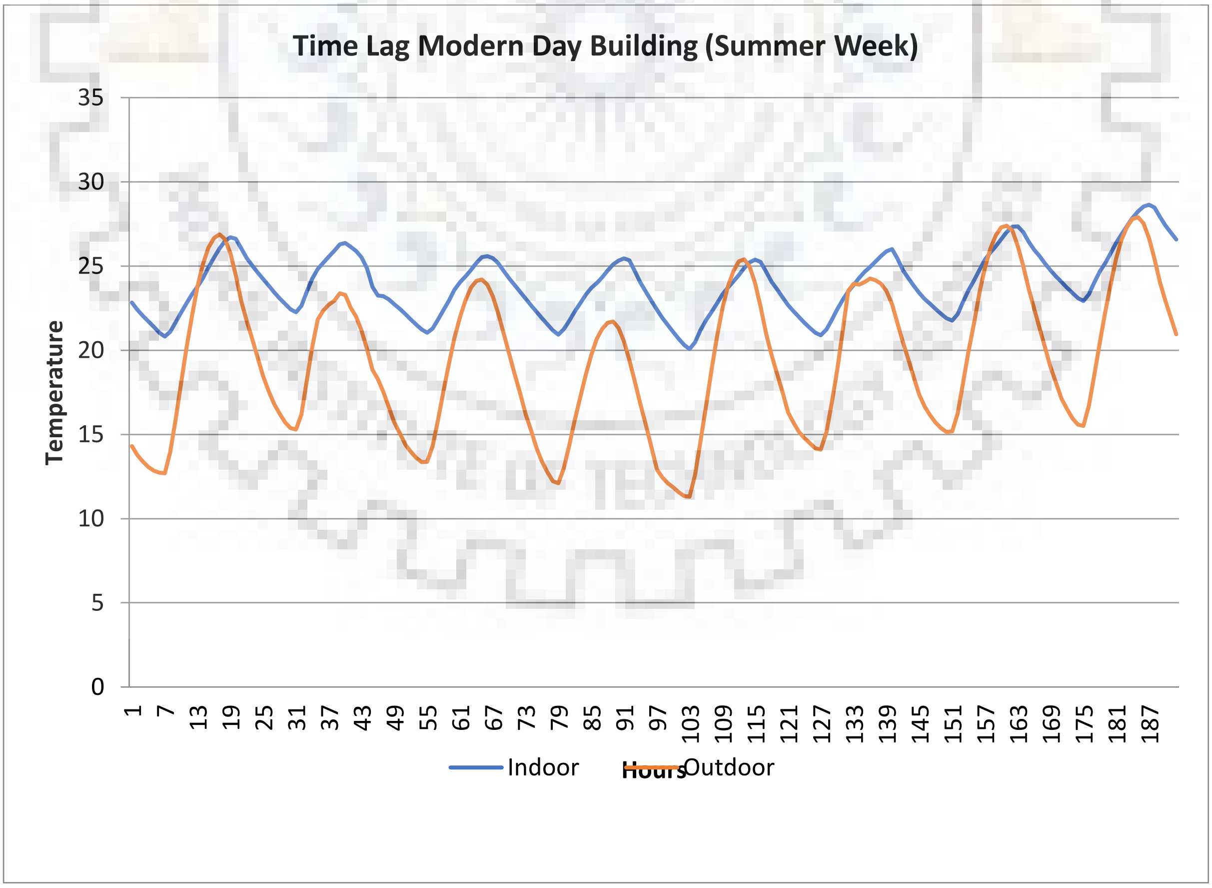


Figure 24Time lag for Modern Day building (Summer Week)

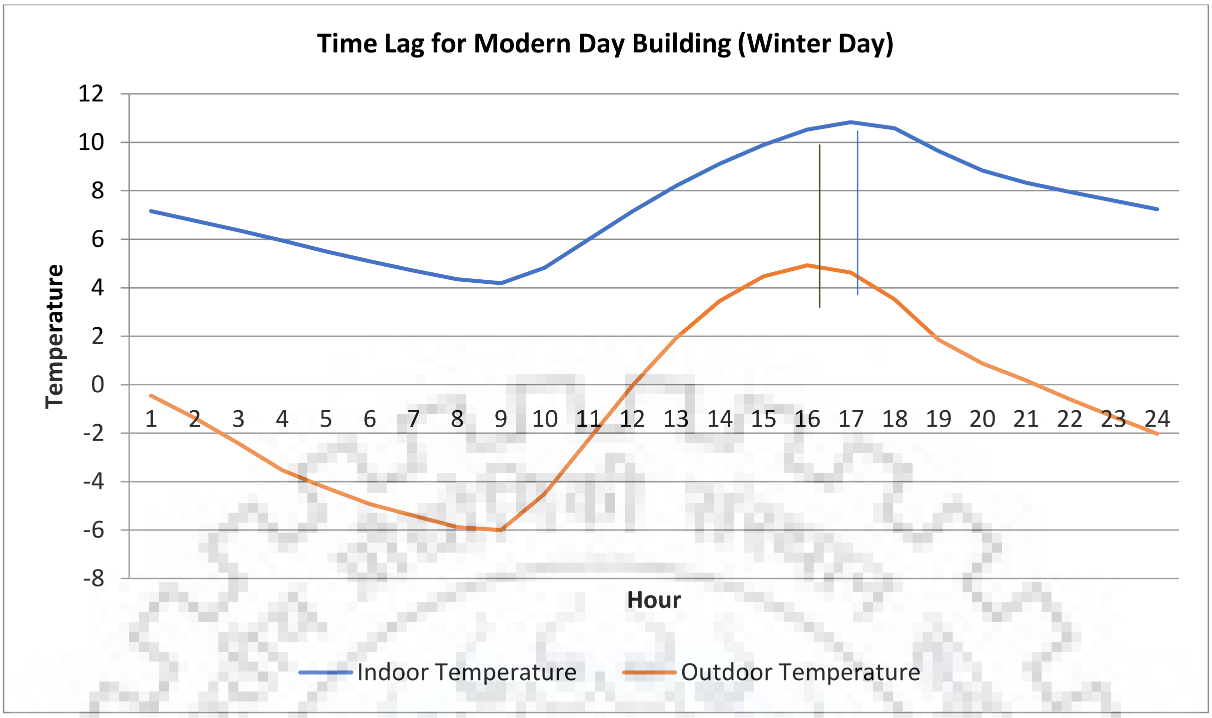


Figure 25 Time lag for modern day building - representative Winter Day

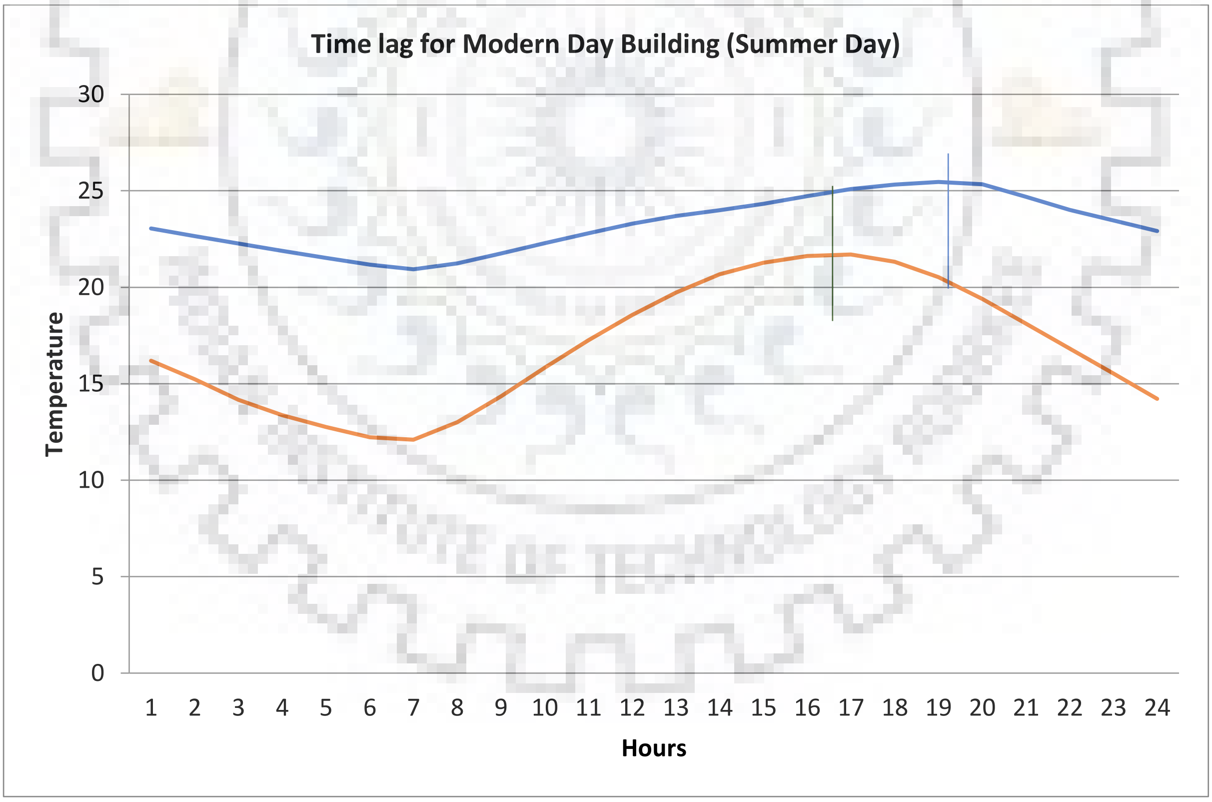


Figure 26 Time lag for Modern Day Building - representative summer Day

The parameter of Time lag was observed for the existing building with existing orientation i.e. Solid brick wall construction. It was observed for representative winter week, representative winter day, representative summer week and representative summer day. It was observed that in the winter when time lag was 1 hour it was extending till 2 to 2½ hours in representative summer week and day. Similar study was conducted for the existing traditional building too.

Analytical Assessment of Traditional Building

This type of house is chosen as a representative traditional house for the study. It is a two storeyed mud house with small windows and slate sloping roof with comparatively smaller volumes. This building is comparatively smaller and compact than the modern day building chosen. It has small WWR and Verandah.

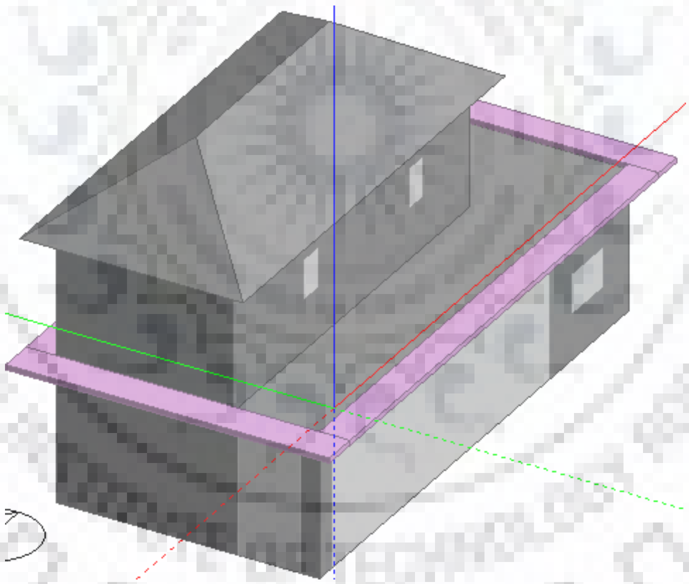


Figure 27 Traditional Building modelled in DesignBuilder

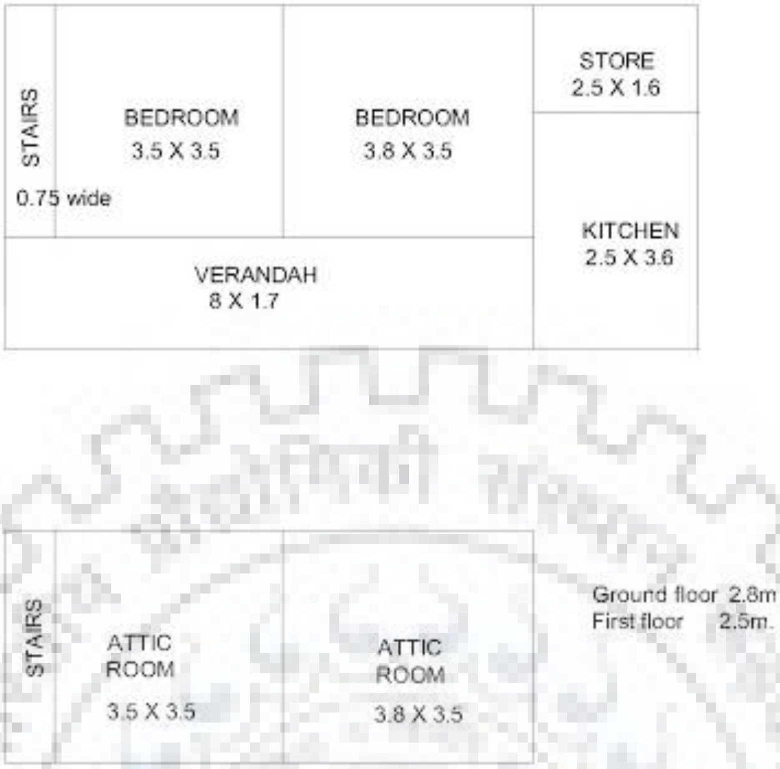


Figure 28 Spatial Layout of Traditional representative building

The representative traditional building is is providing enough shelter against the outdoor air cold temperature that is indoor air temperature is staying around 23-25 degree Celsius.

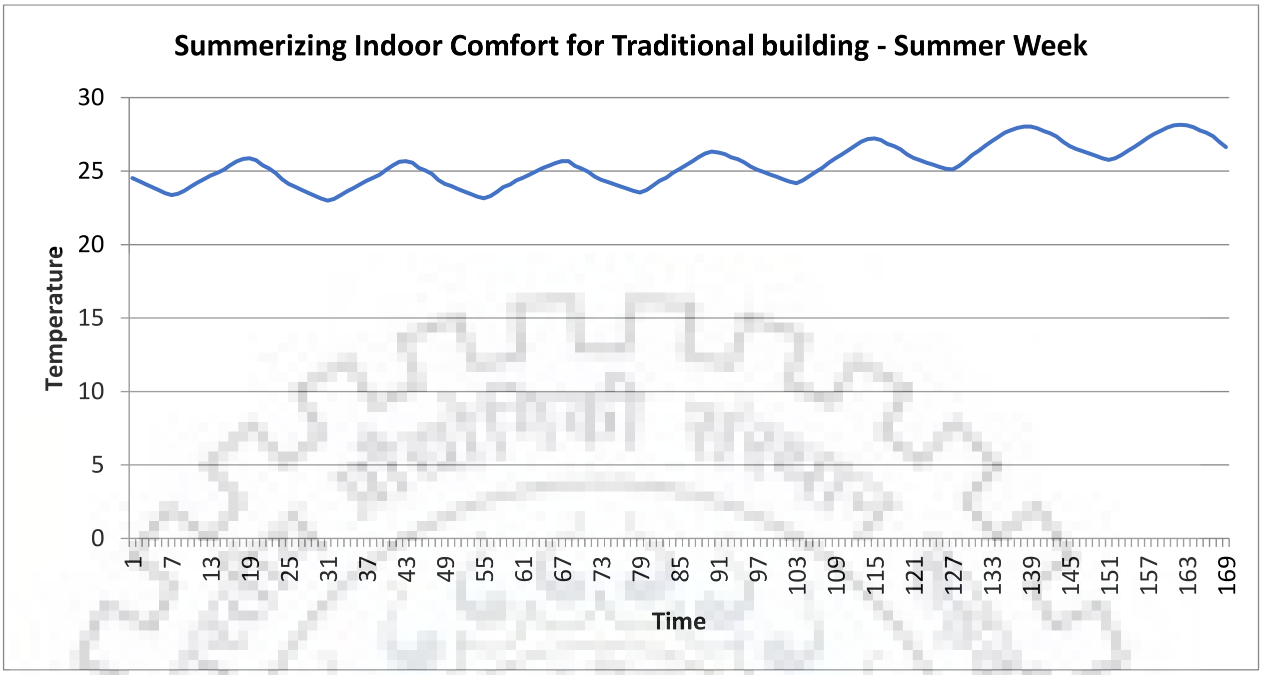


Figure 29 Summerizing indoor comfprt for Summer week - traditional building

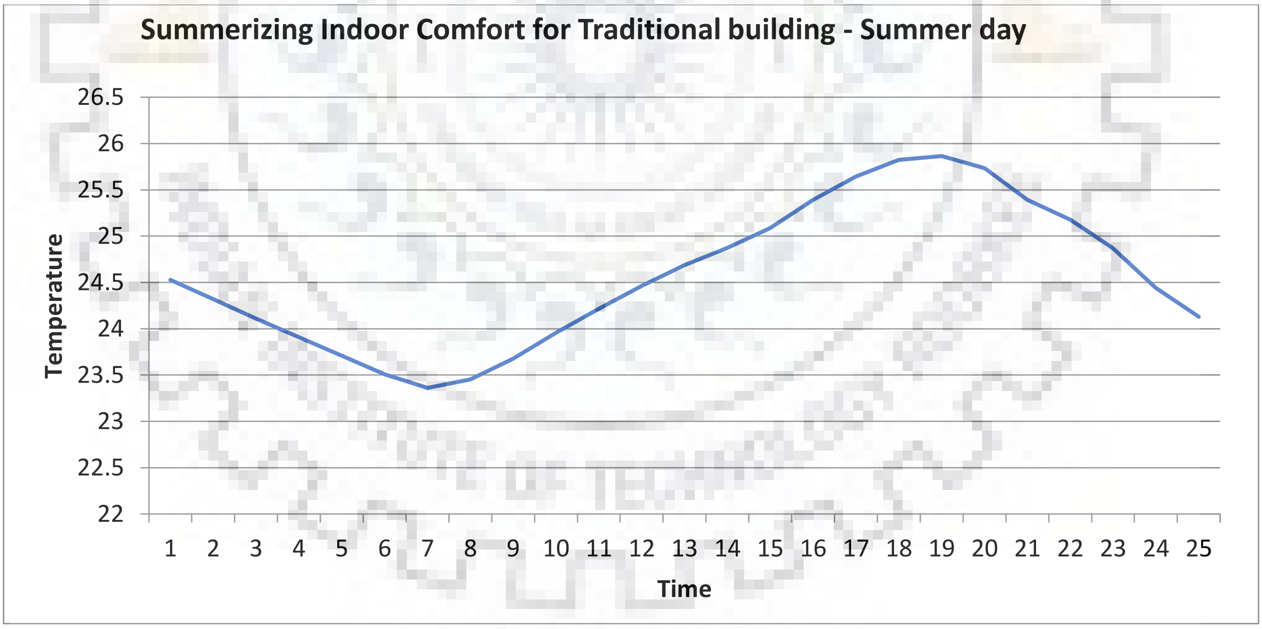


Figure 30 Summerizing Indoor comfort for traditional building summer day

5. COMPARISON OF THERMAL PERFORMANCE

COMPARATIVE STUDY

The shortlisted materials from the literature study were applied and the analytical assessment was carried out evaluate the effect on thermal performance of the materials in representative modern and traditional residential building.

Amongst the shortlisted building material and techniques, Kathkhuni is the one which did not have the basic data to input for the analytical assessment to be done on the Design Builder. The disadvantage of design builder is that only the longitudinal section of the wall can be designed in it. There was a need to design the wall section both vertically and horizontally in this type of wall system. The typical wall section i.e. assembly is designed for the Kathkhuni construction and then a square meter of the wall is prepared to get the Overall U- value for square meter of the wall area according to the following conditions and the material properties.

Figure 31 Typical section of Kathkhuni construction

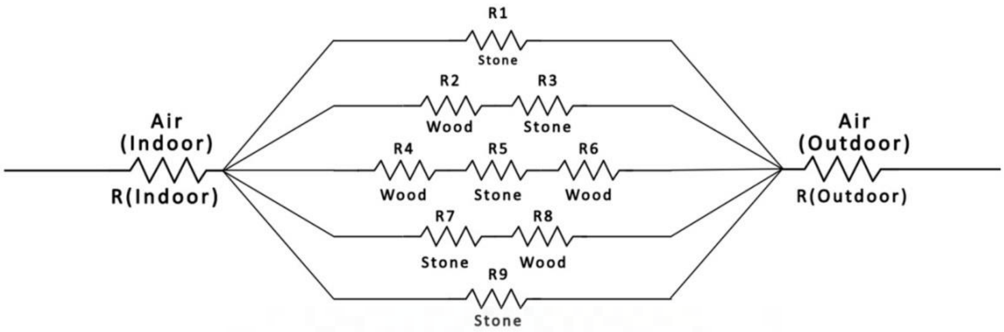


Figure 32 Circuit diagram for typical section of Kathkhuni construction

Figure 33 Heat flow from the typical ssection of Kathkhuni Construction

Outdoor Air Temperature	Indoor Air Temperature		Average resultant heat flux	Delta T	U value = Avg. resultant heat flux/Delta T
39	19	Max	59.3	20	**2.965**
-6	19	Min	74.2	25	**2.968**
39	24	Max	44.5	15	**2.966666667**
-6	24	Min	89	30	**2.966666667**
39	30	Max	26.7	9	**2.966666667**
-6	30	Min	89	36	**2.472222222**
					2.88420370

The average resultant heat flux is generated in the simulation run for the given wall section and given outdoor and indoor temperature conditions. And the averaged values of all combinations are then averaged to do the assessment further in Design Builder for the whole building.

To calculate the U-value, above method is also backed up with the mathematical calculation.

Conduction	k (Thermal Conductivity)	Length	Width	Height	Area	R=(L/k)	Resistance		Resistance *Area
	W/m.K	Meter			m2				
Stone	1.10	0.350	3.000	0.050	0.150	0.318	R1	0.318	0.0477273
Wood	0.13	0.075	3.000	0.050	0.150	0.577	R2	0.827	0.1240385
Stone	1.10	0.275	3.000	0.050	0.150	0.250	R3		
Wood	0.13	0.075	3.000	0.050	0.150	0.577	R4		0.2003497
Stone	1.10	0.200	3.000	0.050	0.150	0.182	R5	1.336	
Wood	0.13	0.075	3.000	0.050	0.150	0.577	R6		
Stone	1.10	0.275	3.000	0.050	0.150	0.250	R7	0.827	0.1240385
Wood	0.13	0.075	3.000	0.050	0.150	0.577	R8		
Stone	1.10	0.350	3.000	0.050	0.150	0.318	R9	0.318	0.0477273
Convection	**h**		**Width**	**Height**	**Area**	**R=(1/h)**			
Air	30.00		3.000	0.250	0.750	0.033	R_{Indoor}	0.033	0.025
Air	30.00		3.000	0.250	0.750	0.033	$R_{Outdoor}$	0.033	0.025

$$R = \left(\left(\frac{1}{\left(\frac{1}{R1}\right)+\left(\frac{1}{R2}\right)+\left(\frac{1}{R3}\right)+\left(\frac{1}{R4}\right)+\left(\frac{1}{R5}\right)}\right)+\frac{1}{Rindoor}+\frac{1}{Routdoor}\right)$$

The U value according to the Fourier’s law of conduction

$$R = L/KA$$

$$U = 1/R$$

U value for Kath khuni construction in **2.27**

The U-value 2.8 was put in the building wall properties for analytical assessment. And the readings for Indoor Air Temperature, Outside Surface Temperature, Surface Heat Gains, etc. were collected. And these readings were processed for the analyses and comparative study.

The representative summer week (08.06 to 15.06) and winter week (08.01 to 15.01) were chosen according to the peak summer and winter days observed for the given location based on historic and current weather data. Furthermore, the representative summer day (08.06) and winter day (08.01) were chosen to conduct the study in detail.

To carry out this comparative study, the shortlisted building materials and techniques were applied to the representative traditional and modern day building with constant WWR (Window Wall Ratio), Wall Thickness, Spatial Layout, Activities, Occupation, Natural Ventilation, Air change rate, minimum artificial lighting, etc.

In the initial part of Comparative study the effect of the wall materials and techniques was studied by looking at the amount of protection provided by the wall material against outdoor air temperature i. e. indoor vs. outdoor temperature. It was observed that Solid Brick Masonry, Kathkhuni Construction and Brick Cavity wall has given maximum warmth, whereas, Rubble stone masonry and AAC blocks used for the wall has caused comparatively least protection from the outdoor air temperature, n the traditional building on the summer day. In reverse, AAC is providing maximum warmth in the winter day, along with Solid Brick Masonry wall and Brick Cavity wall, but Rubble stone masonry could not in traditional building. Similarly in Modern Day building, AAC blocks wall performed comparatively better in summer days along with Solid brick wall and Brick Cavity wall. And In winter day again, AAC block wall managed to keep the significant difference between outdoor air temperatures while maintaining comfortable temperature almost throughout the day (i.e. 24°C) followed by Brick Masonry wall.

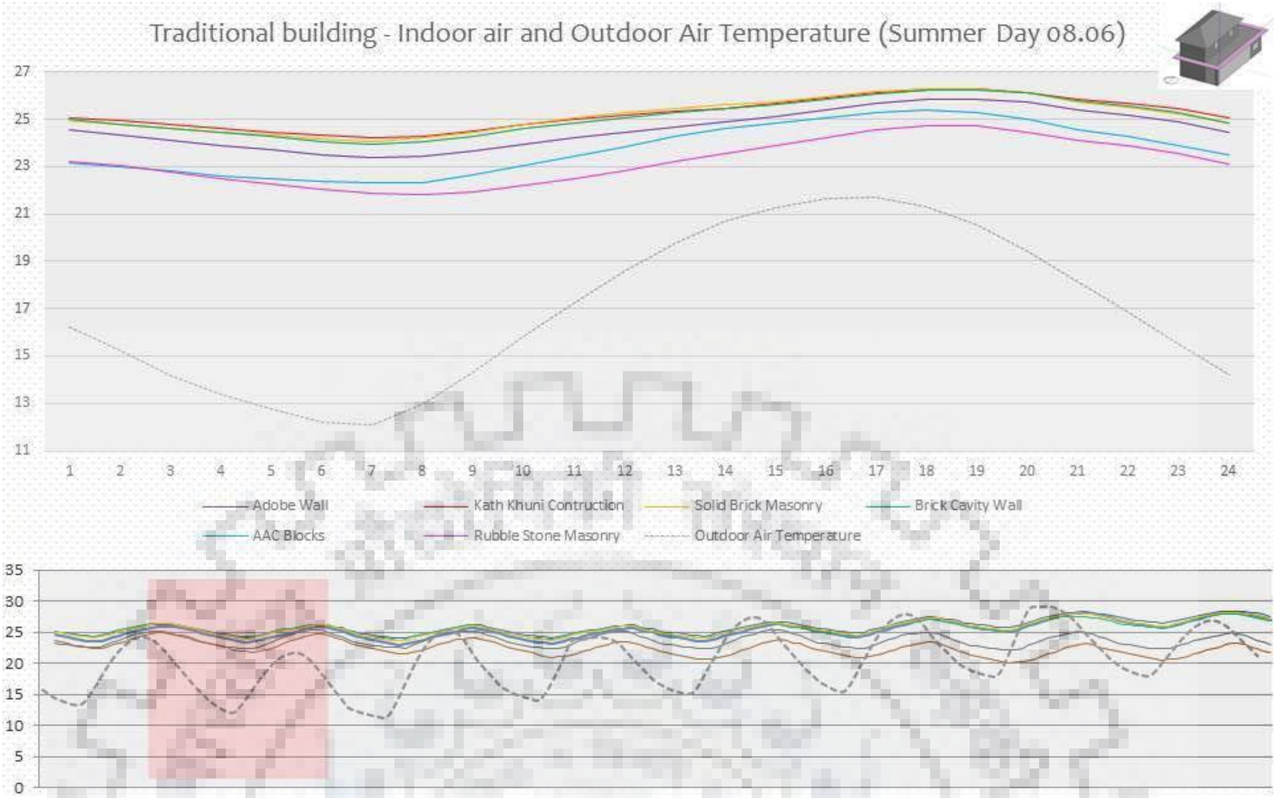


Figure 34 Summer -Indoor and outdoor temperatures for shortlisted materials in Traditional building

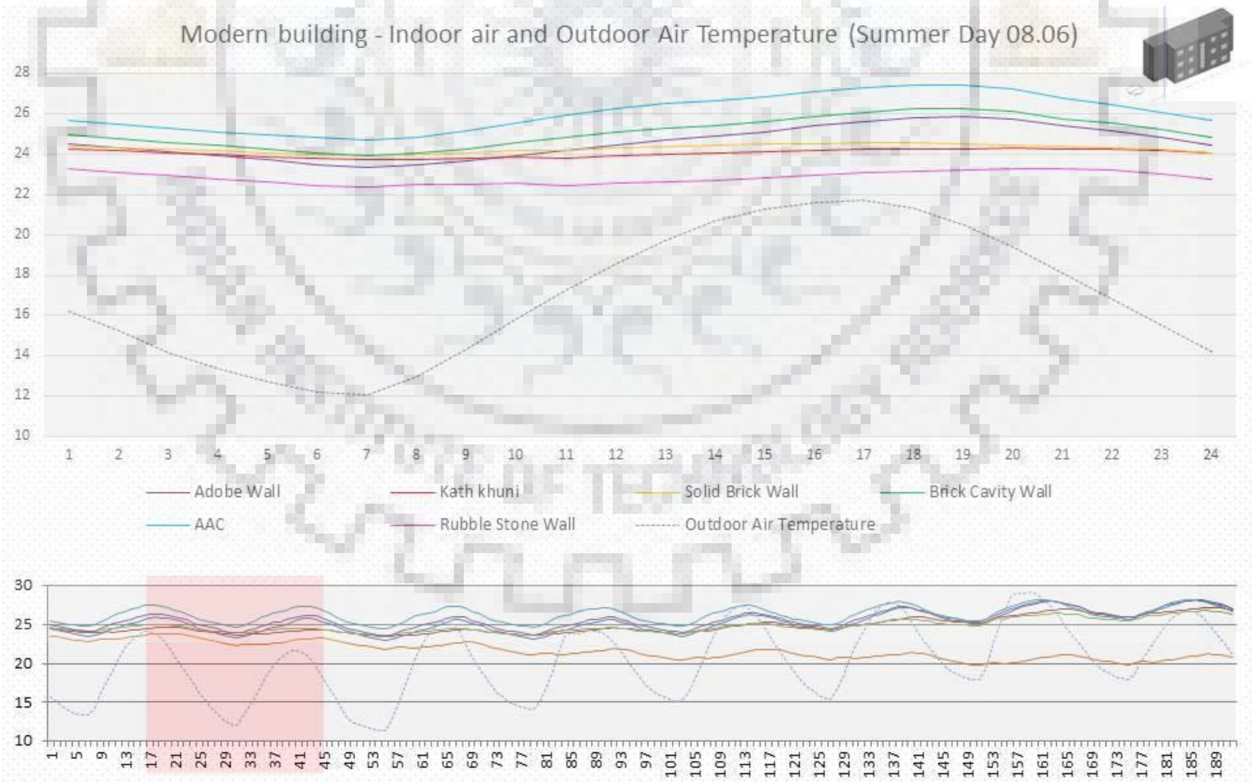


Figure 35 Summer -Indoor and outdoor temperatures for shortlisted materials in Modern Day building

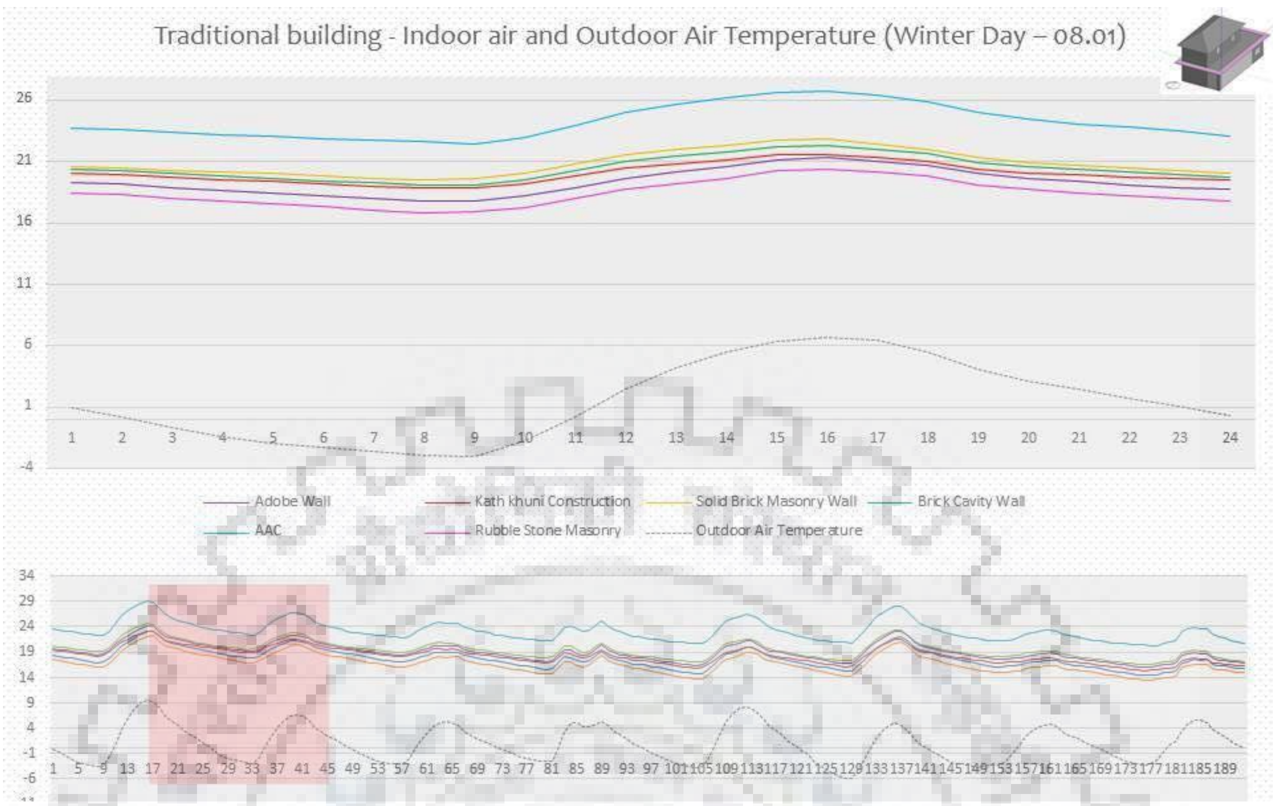


Figure 36 Winter- Indoor and outdoor temperatures for shortlisted materials in Traditional building

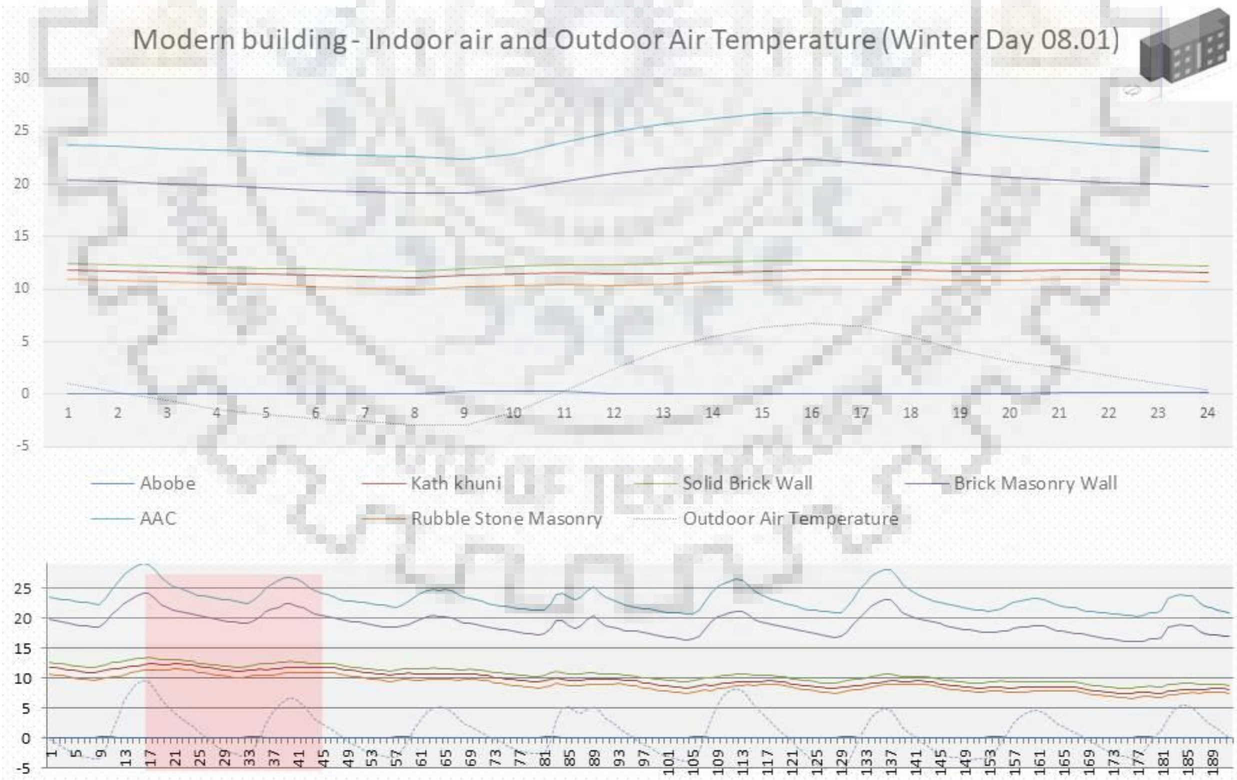
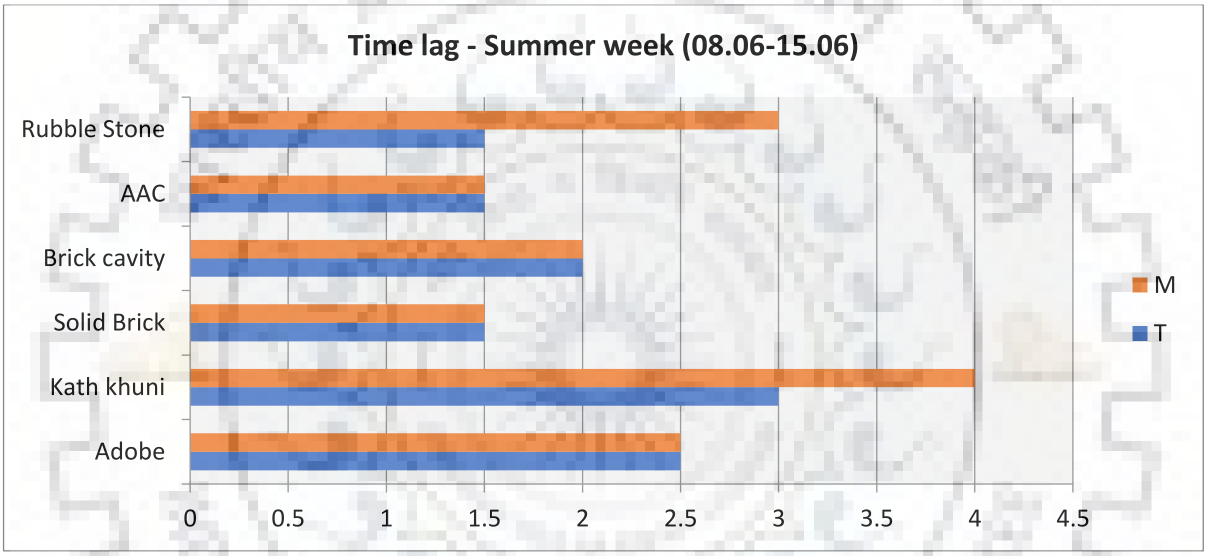
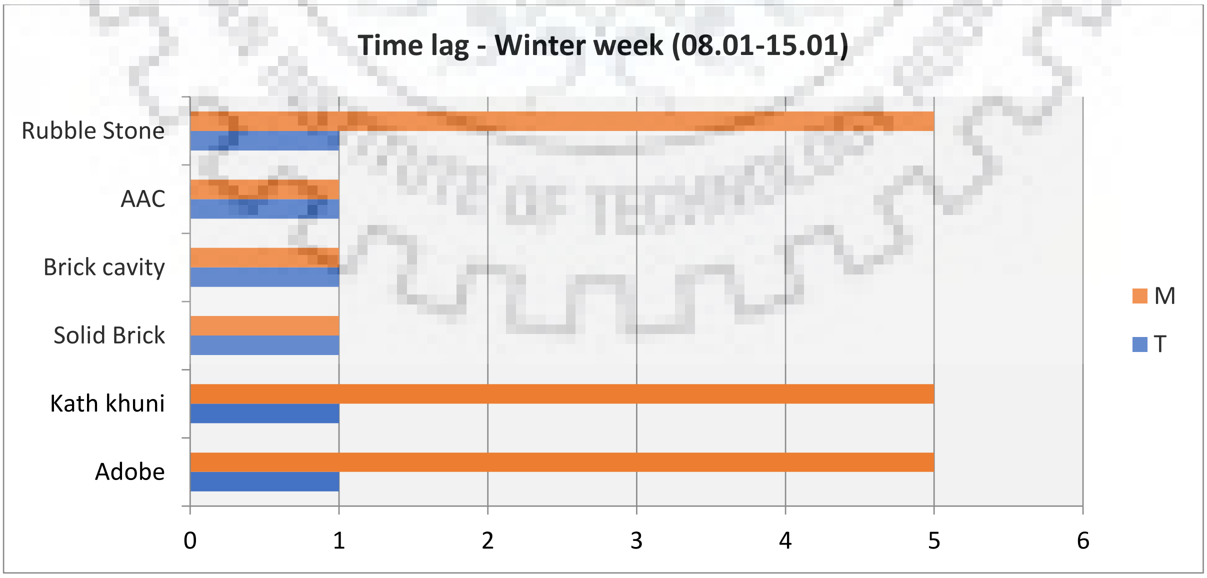


Figure 37 Winter Indoor and outdoor temperatures for shortlisted materials in Modern day building

Time Lag

It is the time taken to reach the peak temperature on outside air to reach the inside peak air temperature. This amount of time can help in giving the warmth inside at needed time. Here, in summer the Rubble stone wall and Kath khuni construction is having the most amount of time lag followed by Adobe wall Construction in Modern building and, In traditional building, Kathkhuni is performaing comparatively better than other materials. The time lag of 3 to 4 hours gives an advantage of warming up the indoor space while it is reducing temperature outside and thus providing better comfort. But, In winter week the only best performing materials are Rubble stone wall, Kathkhuni Construction and Adobe wall construction.





Heat gain is a measure of the total transfer of **heat** through envelop of a building from outside to the inside, either from conduction, convection, radiation, or any combination of these. And negative values of these show the Heat loss. The values in the following graph are calculated for the whole year through analytical assessment. Most of the values are seen in negative due to the presence of building in the cold climate. AAC block wall is performing the best since they are the only once gaining heat against the outside cold weather which is needed.

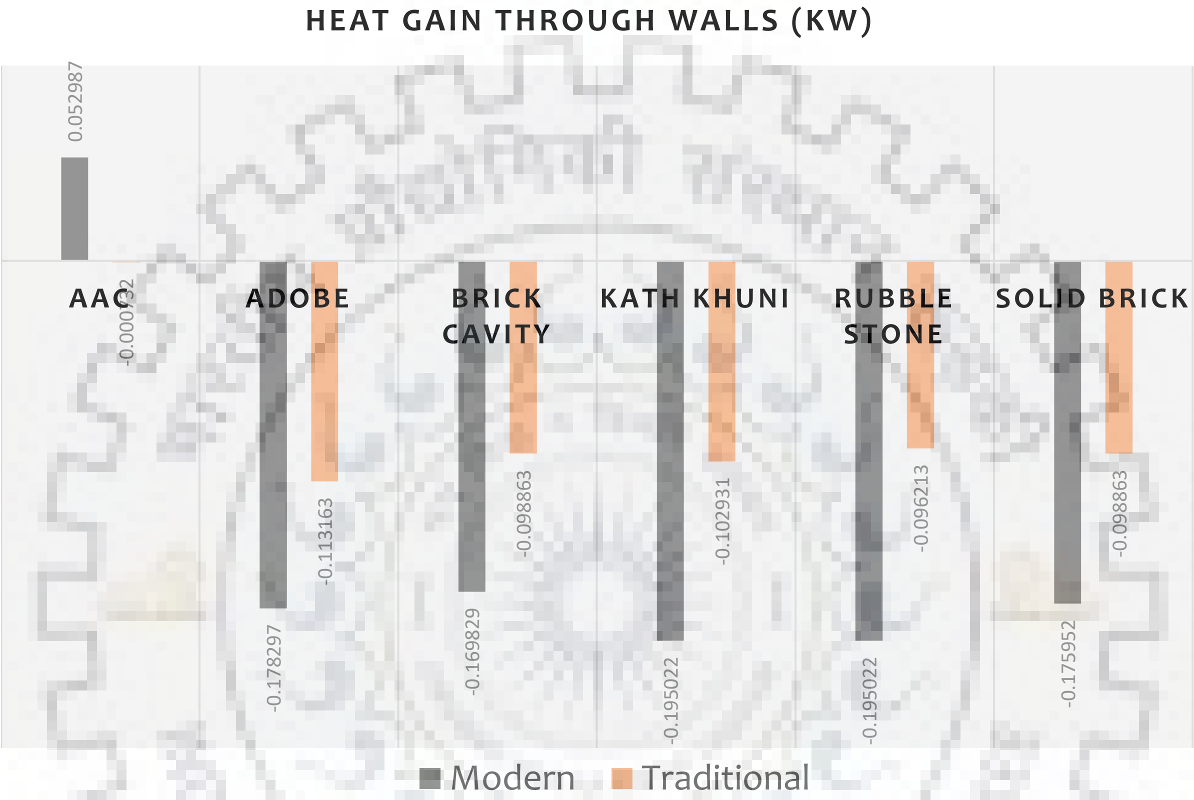
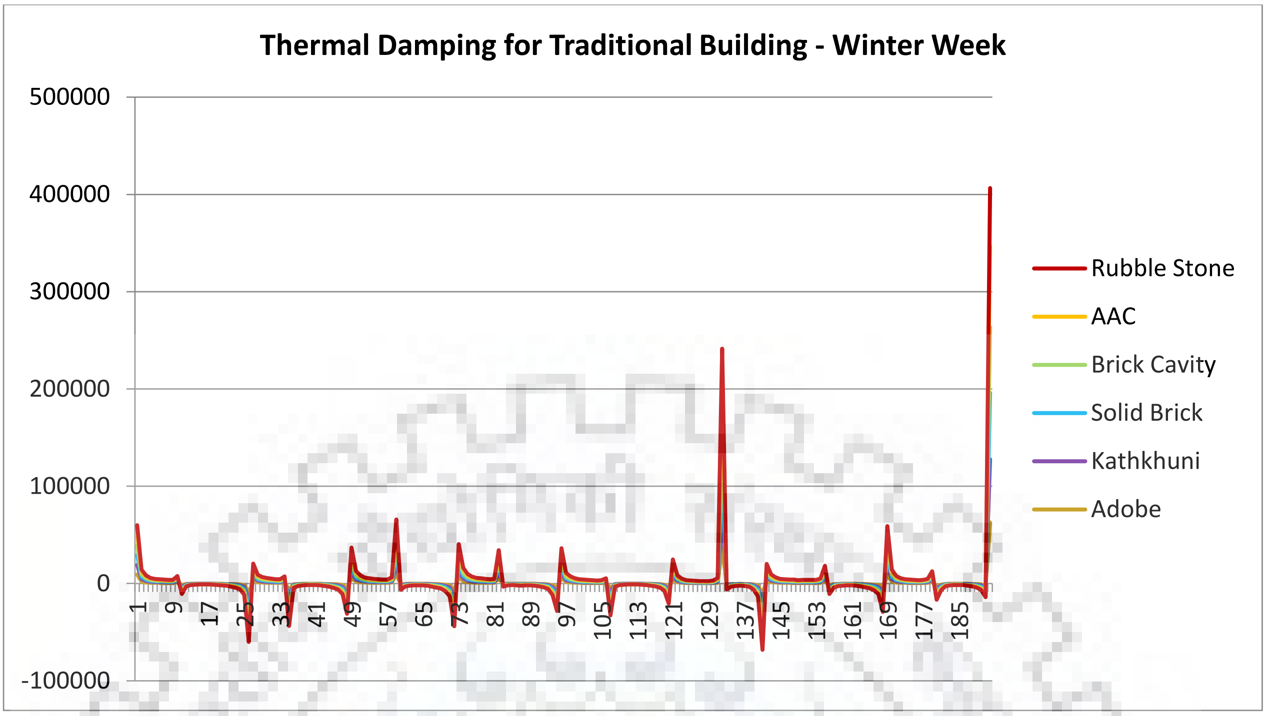


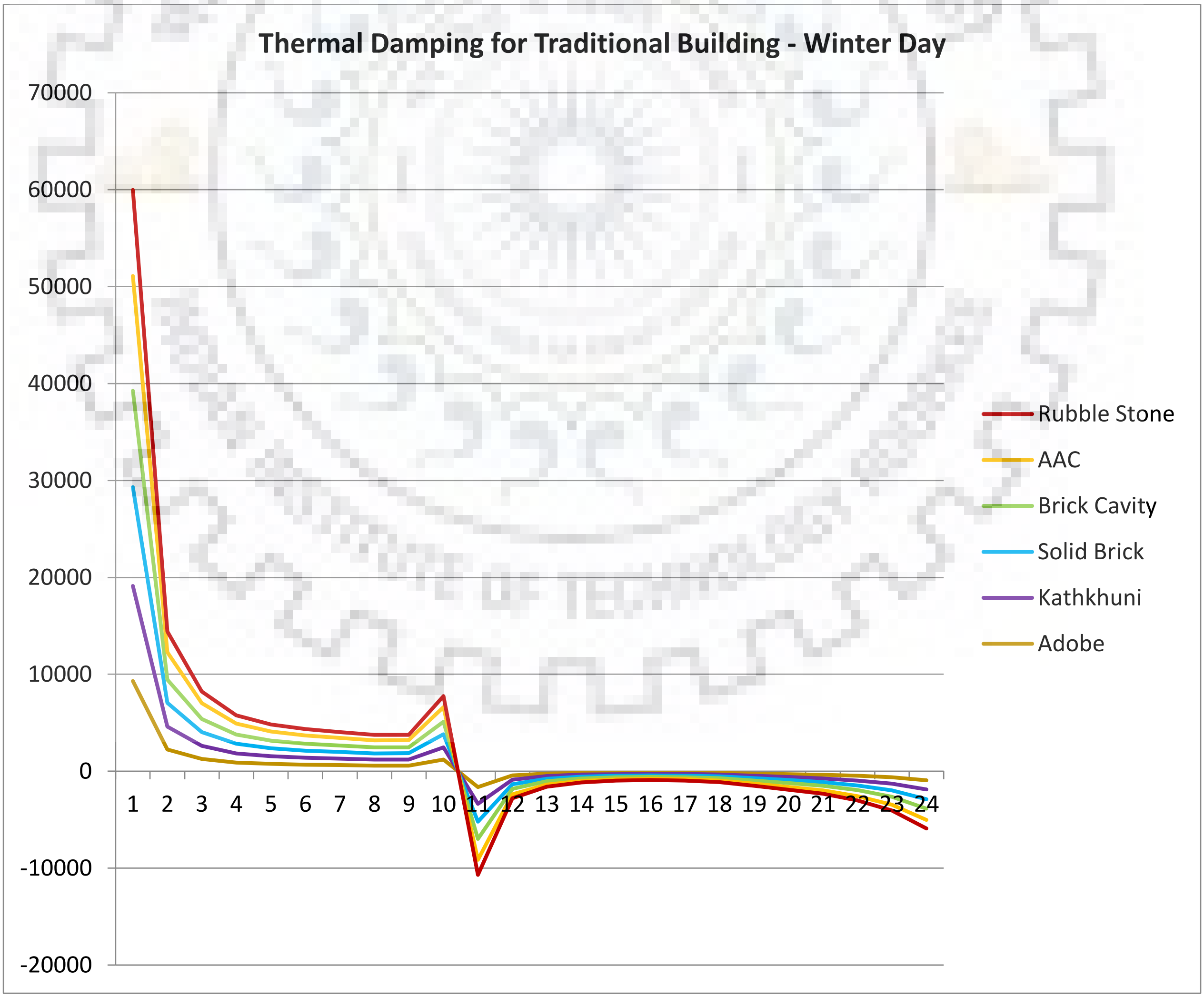
Figure 38 Heat gain (KW) through walls for selected materials

Thermal Damping:

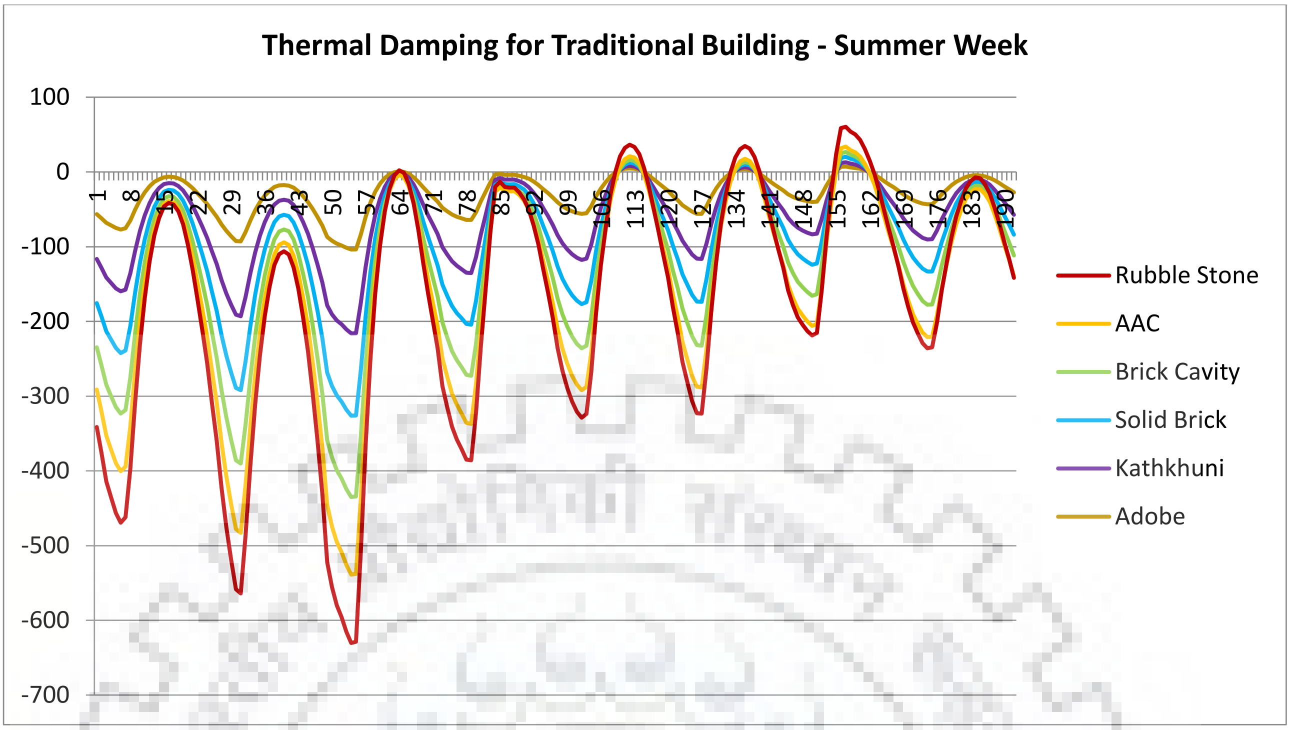
A study by Tsilingiris (2002) validates that by looking at the factor relating damping efficiency, the actual performance of wall system can be computed. Here both Traditional and Modern day building's Thermal Damping is calculated according to the formula given in NBC and all the wall materials and construction techniques shortlisted were compared. Here, Adobe wall followed by Kathkhuni construction and solid brick wall, is providing comparatively better thermal damping than other building materials and construction in both Summer and Winter days in both types of the buildings.



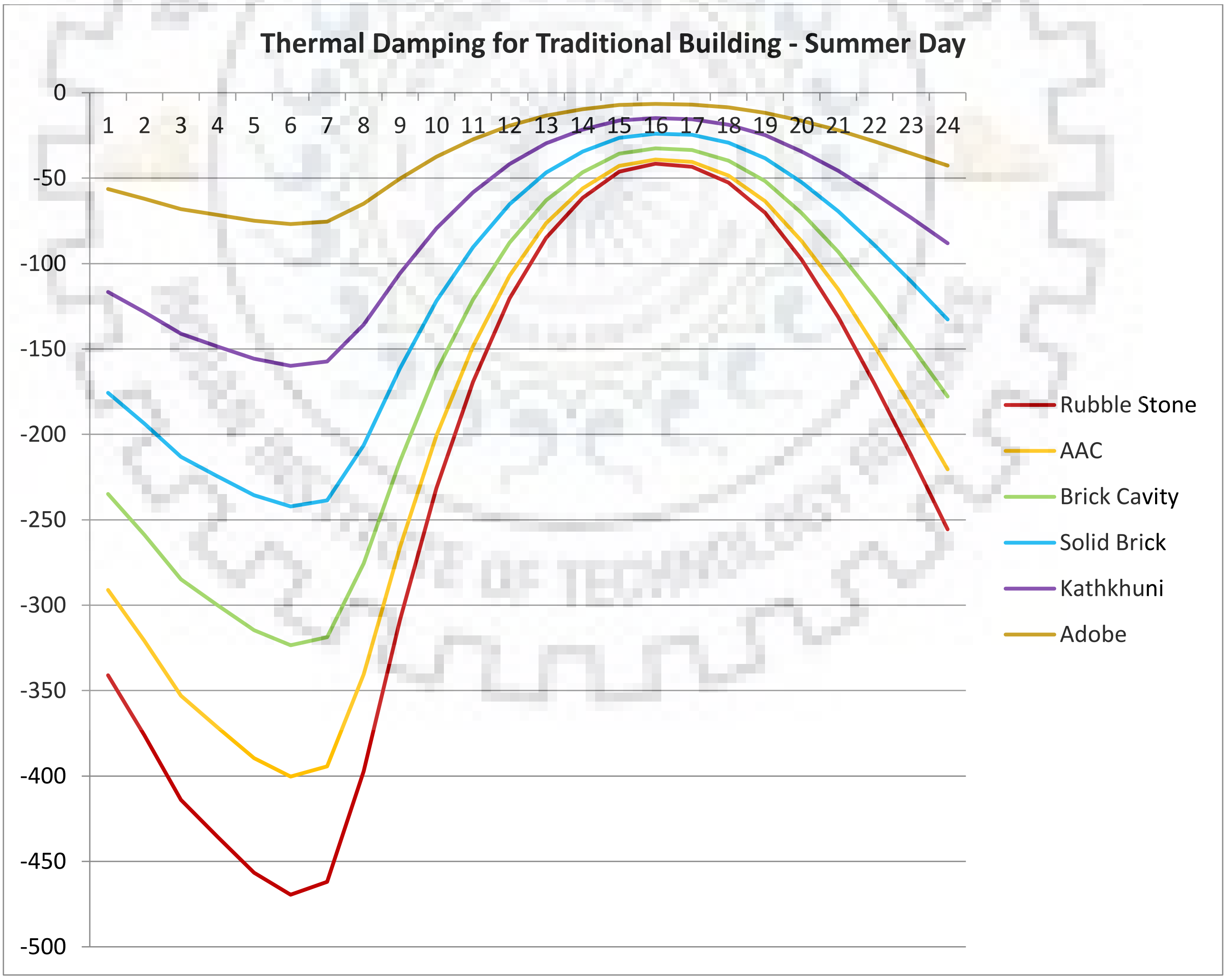
Thermal Damping for Traditional Building - Winter Week
500000
400000
300000
200000
100000
0
-100000
1 9 17 25 33 41 49 57 65 73 81 89 97 105 113 121 129 137 145 153 161 169 177 185
Rubble Stone
AAC
Brick Cavity
Solid Brick
Kathkhuni
Adobe



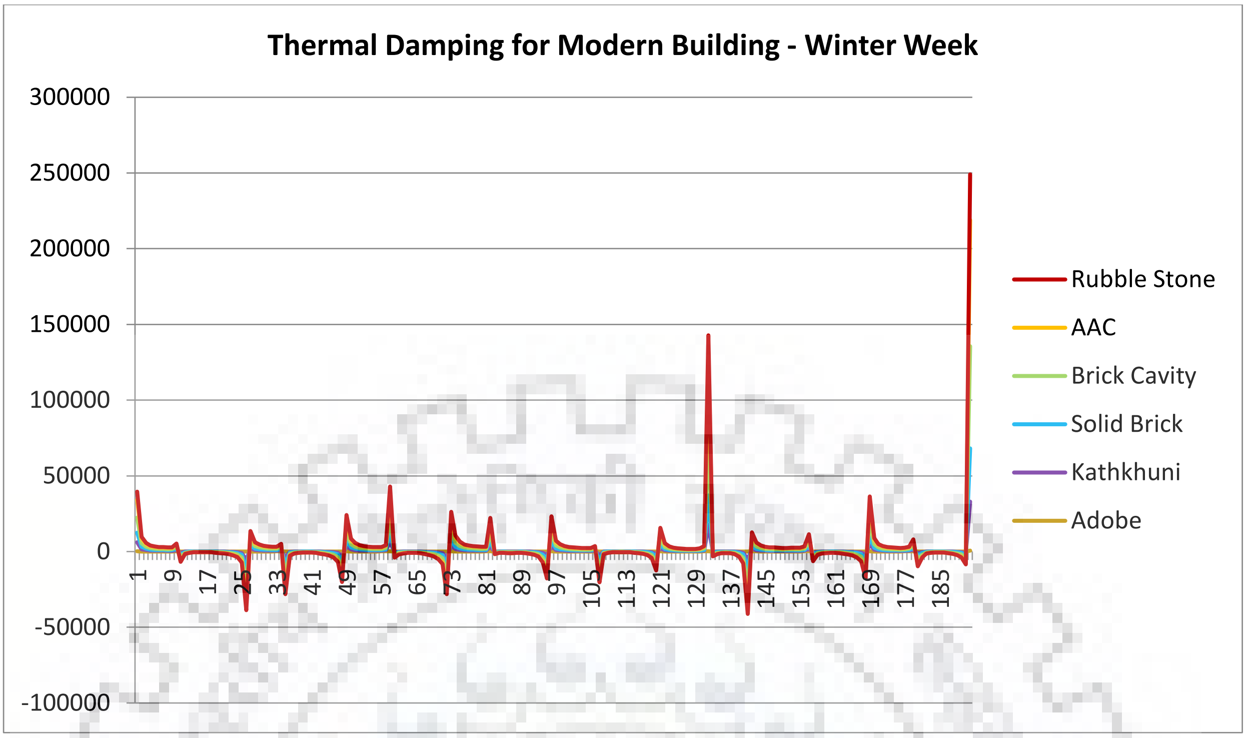
Thermal Damping for Traditional Building - Winter Day
70000
60000
50000
40000
30000
20000
10000
0
-10000
-20000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Rubble Stone
AAC
Brick Cavity
Solid Brick
Kathkhuni
Adobe



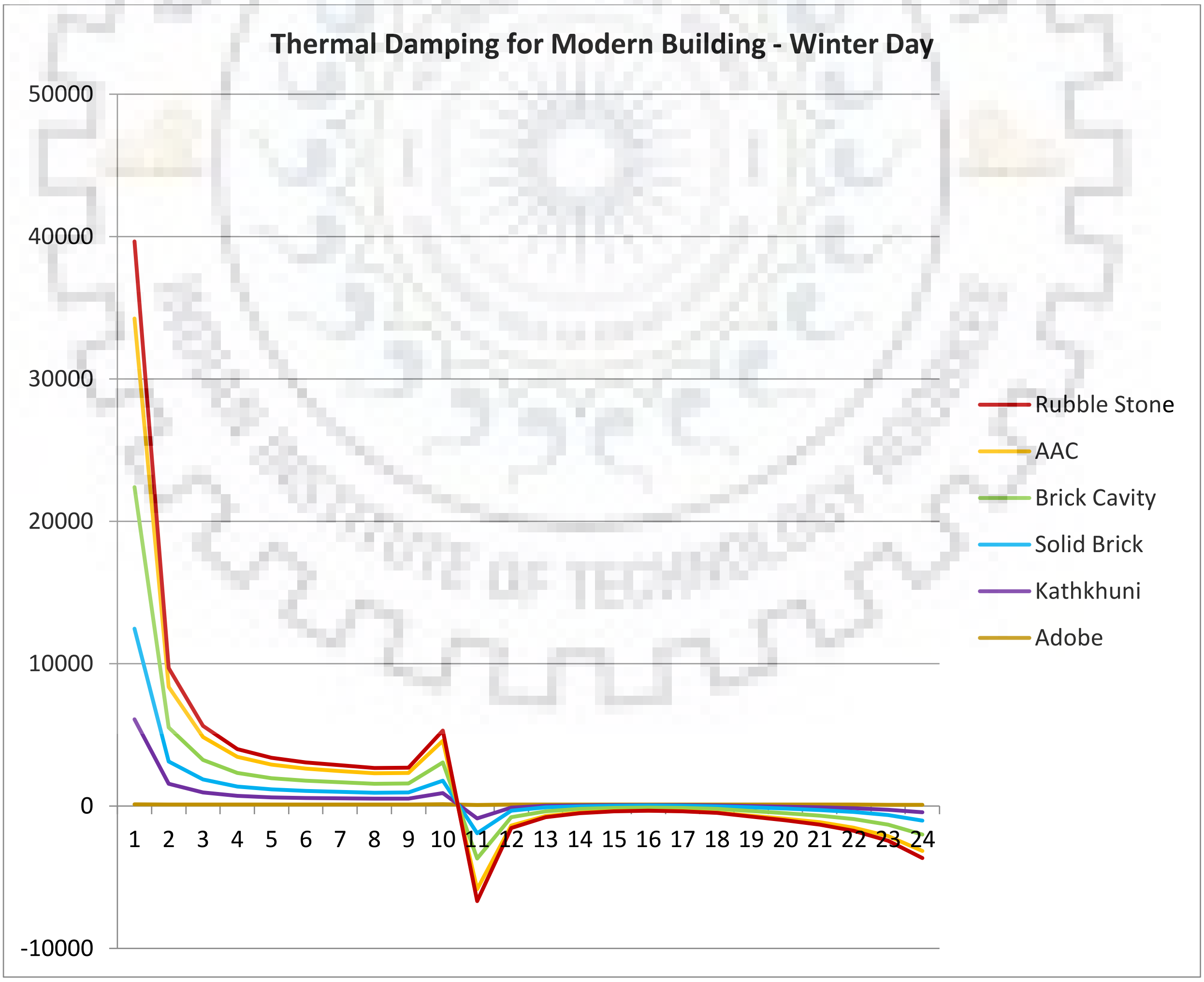
Thermal Damping for Traditional Building - Summer Week
100
0
-100
-200
-300
-400
-500
-600
-700
Rubble Stone
AAC
Brick Cavity
Solid Brick
Kathkhuni
Adobe



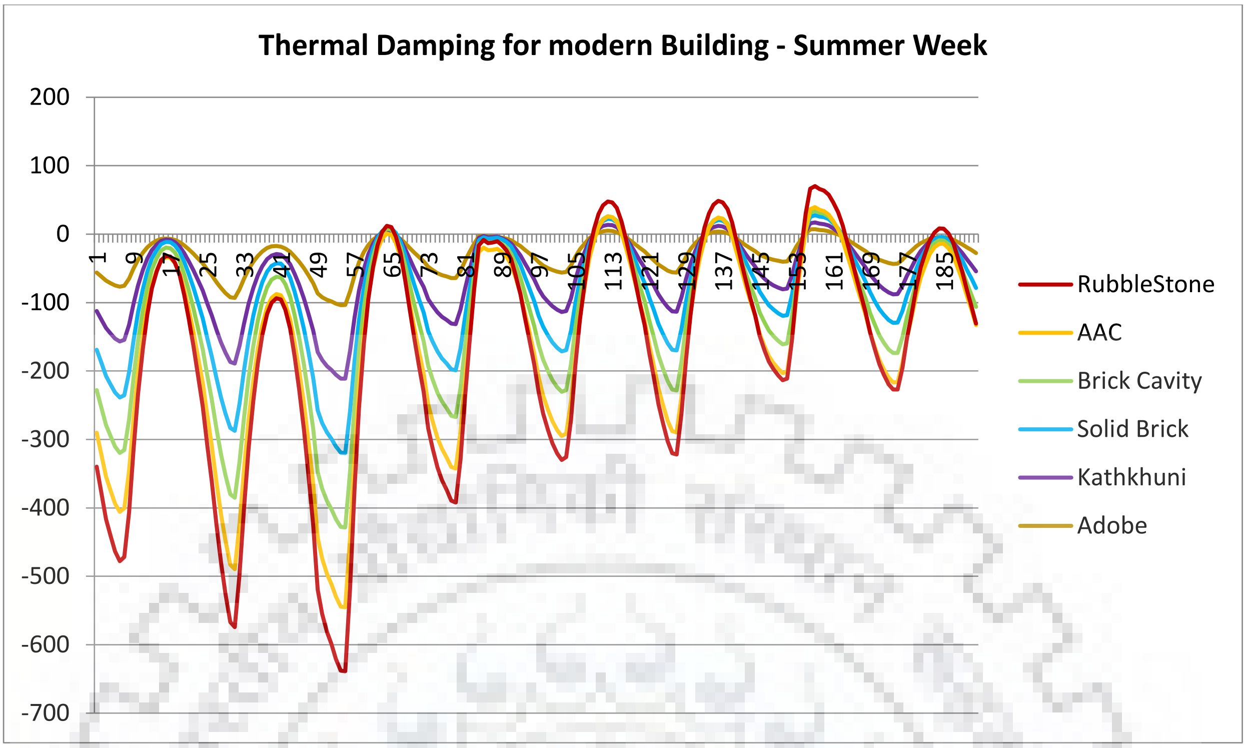
Thermal Damping for Traditional Building - Summer Day
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
-500
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Rubble Stone
AAC
Brick Cavity
Solid Brick
Kathkhuni
Adobe



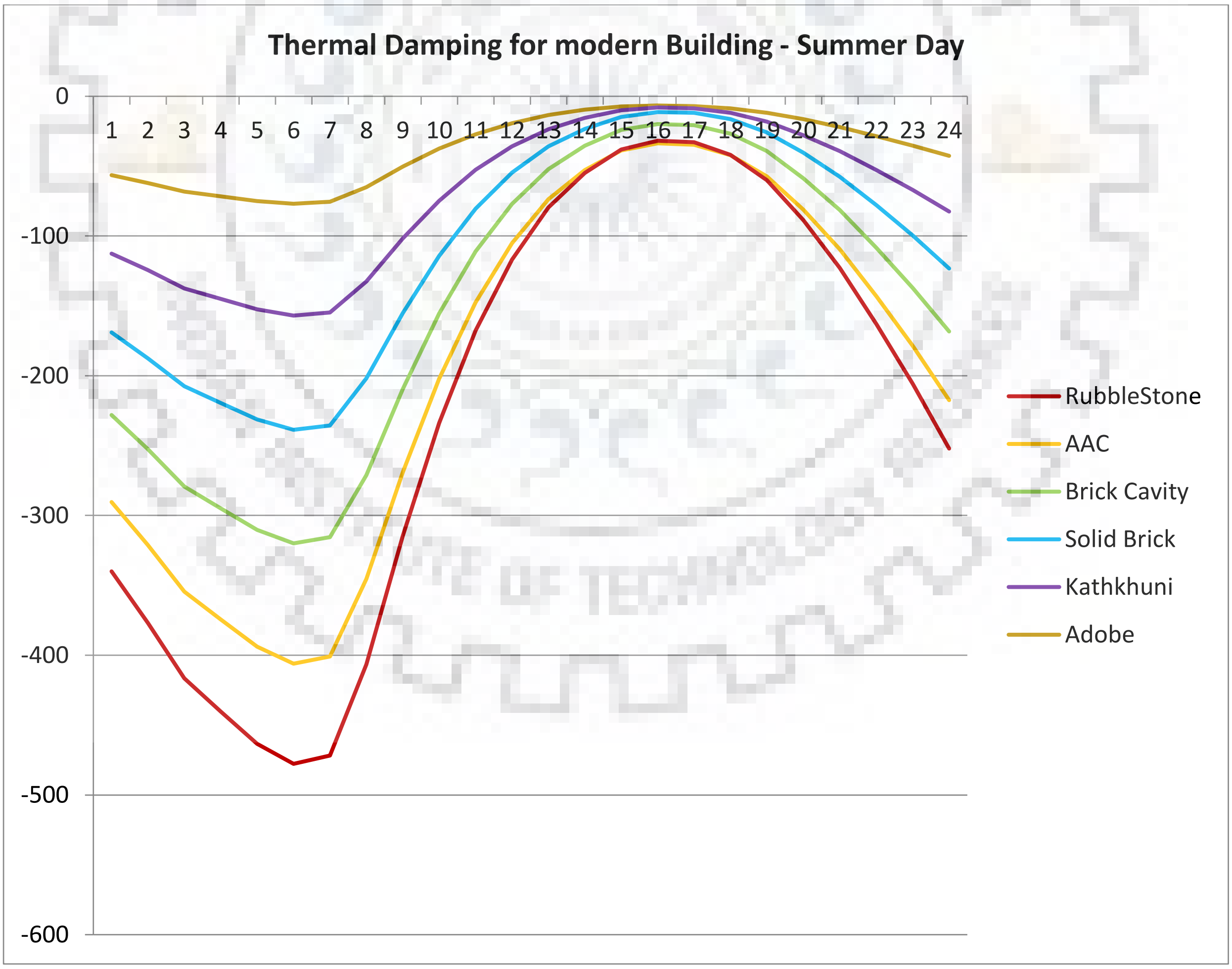
Thermal Damping for Modern Building - Winter Week
300000
250000
200000
150000
100000
50000
0
-50000
-100000
1
9
17
25
33
41
49
57
65
73
81
89
97
105
113
121
129
137
145
153
161
169
177
185
Rubble Stone
AAC
Brick Cavity
Solid Brick
Kathkhuni
Adobe



Thermal Damping for Modern Building - Winter Day
50000
40000
30000
20000
10000
0
-10000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Rubble Stone
AAC
Brick Cavity
Solid Brick
Kathkhuni
Adobe



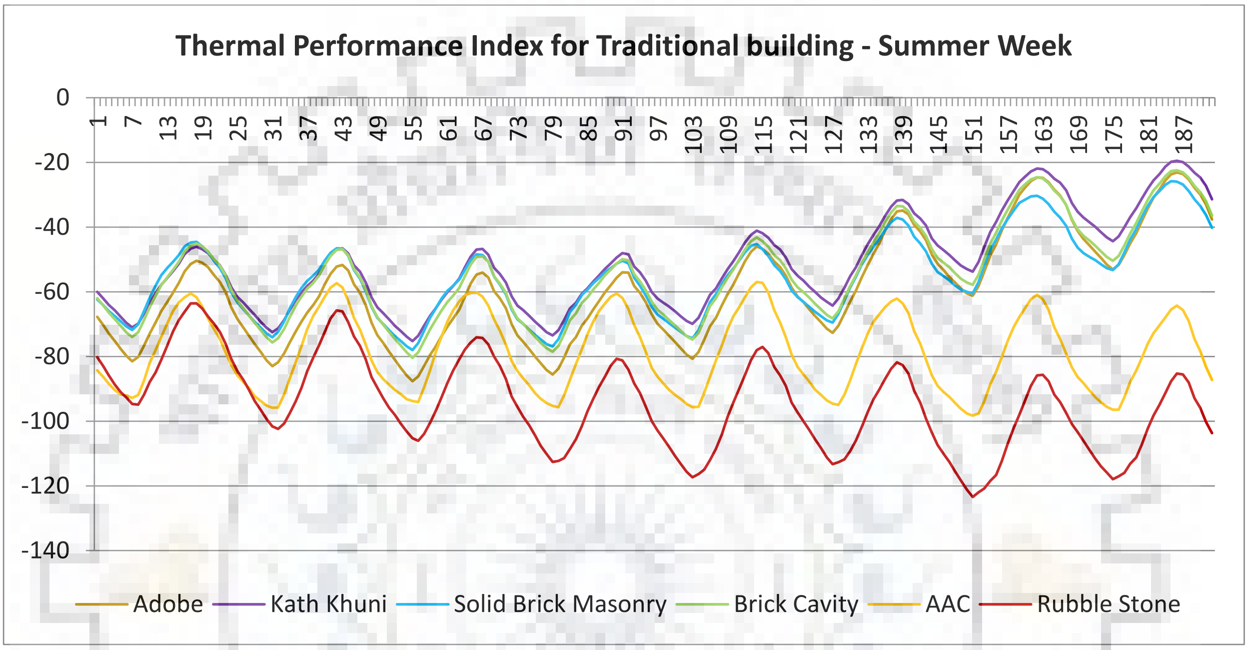
Thermal Damping for modern Building - Summer Week
200
100
0
-100
-200
-300
-400
-500
-600
-700
1
9
17
25
33
41
49
57
65
73
81
89
97
105
113
121
129
137
145
153
161
169
177
185
RubbleStone
AAC
Brick Cavity
Solid Brick
Kathkhuni
Adobe



Thermal Damping for modern Building - Summer Day
0
-100
-200
-300
-400
-500
-600
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
RubbleStone
AAC
Brick Cavity
Solid Brick
Kathkhuni
Adobe

Thermal Performance Index

According to Nation Building Code of India the Thermal Performance Index were computed and the materials and techniques were compared. It was observed that Solid Brick Masonry, Kathkhuni construction, Adobe wall construction were performing comparatively better in all the given conditions. Whereas AAC blocks wall performed better in traditional building in winter and in modern building in both the seasons.



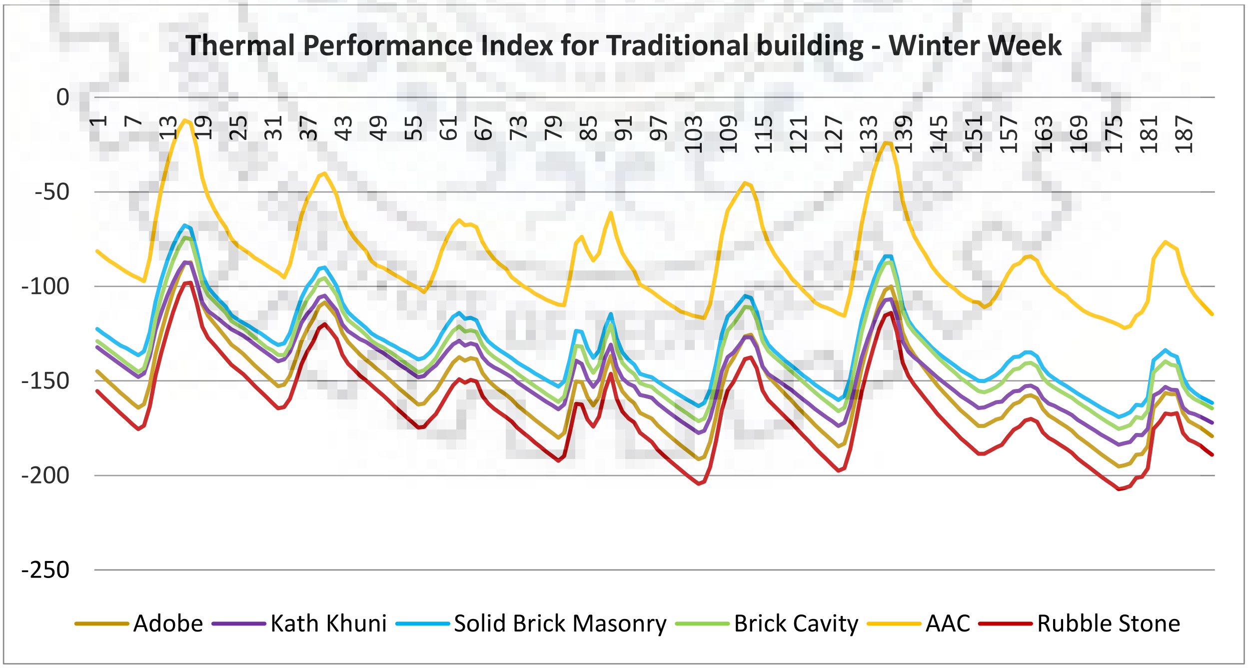
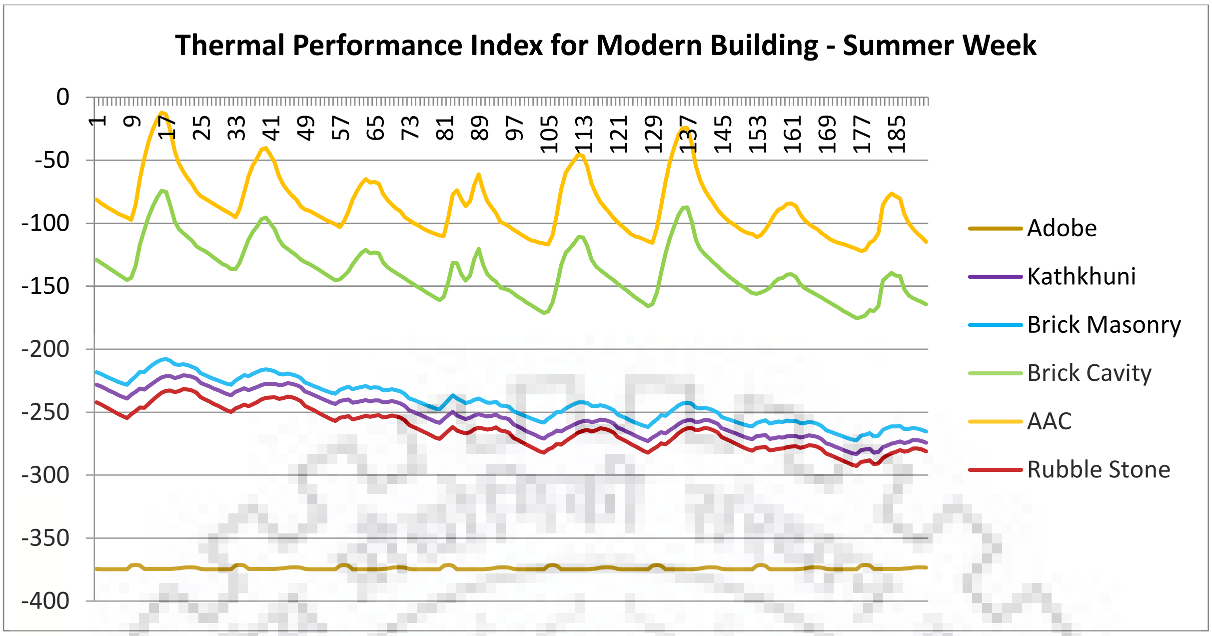


Figure 39 TPI for Traditional building



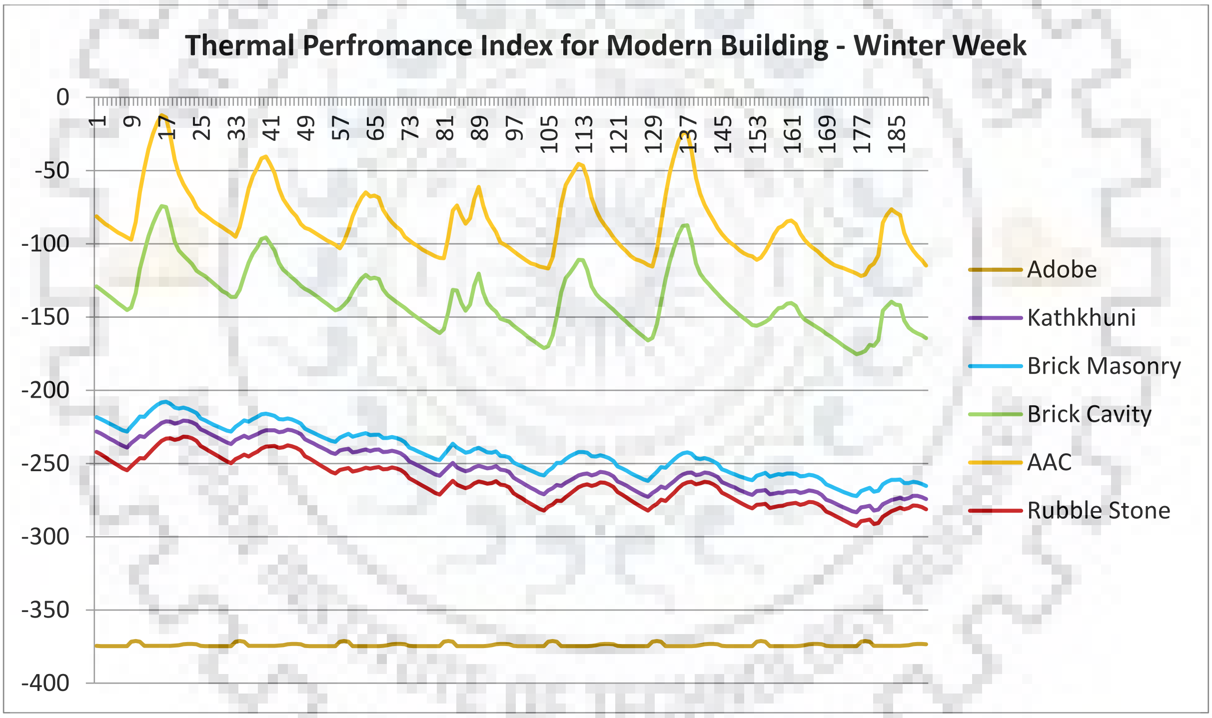
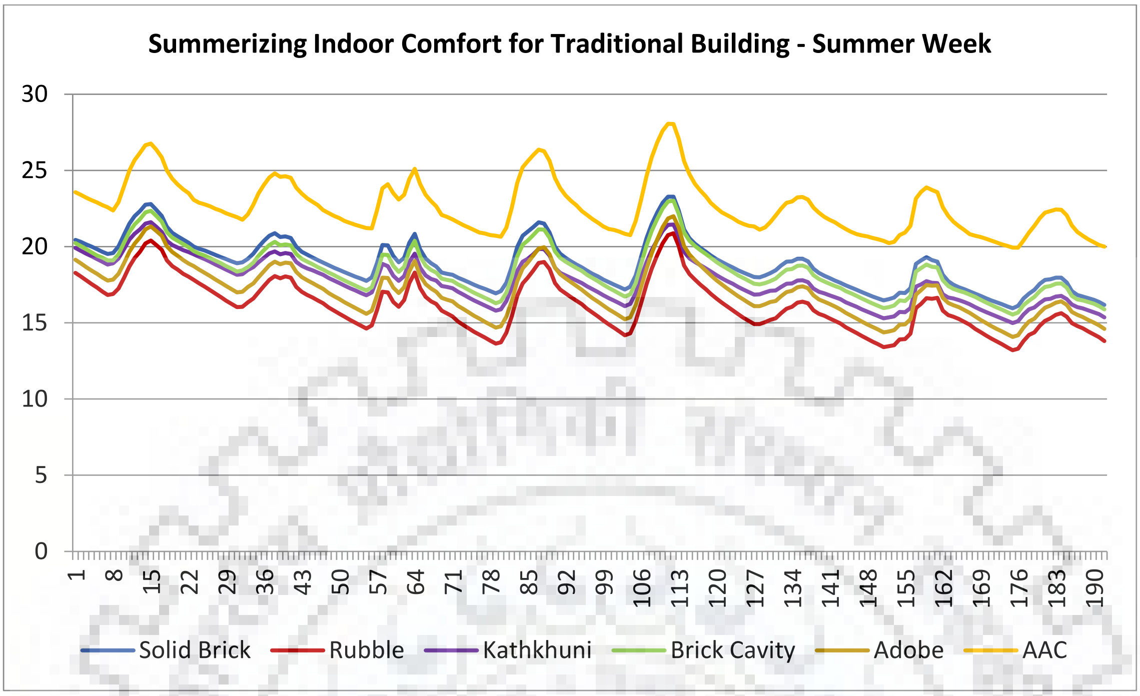
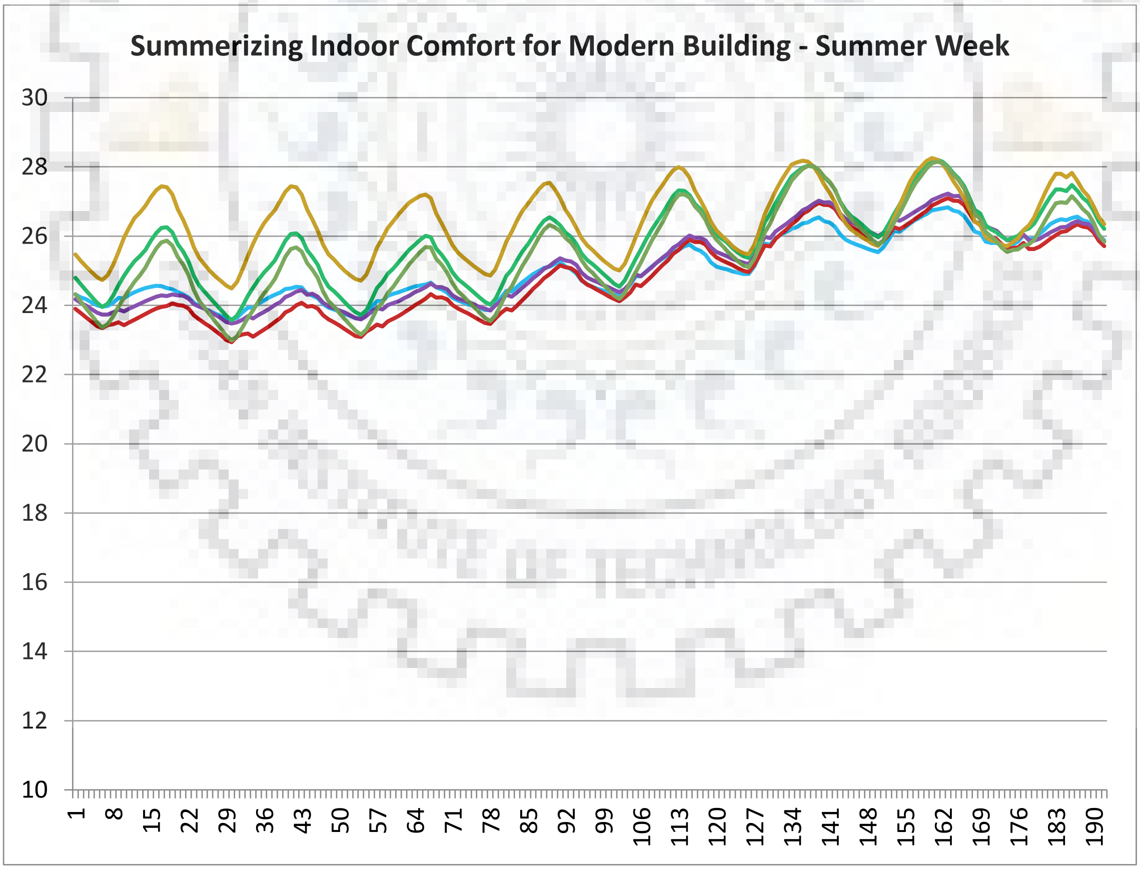
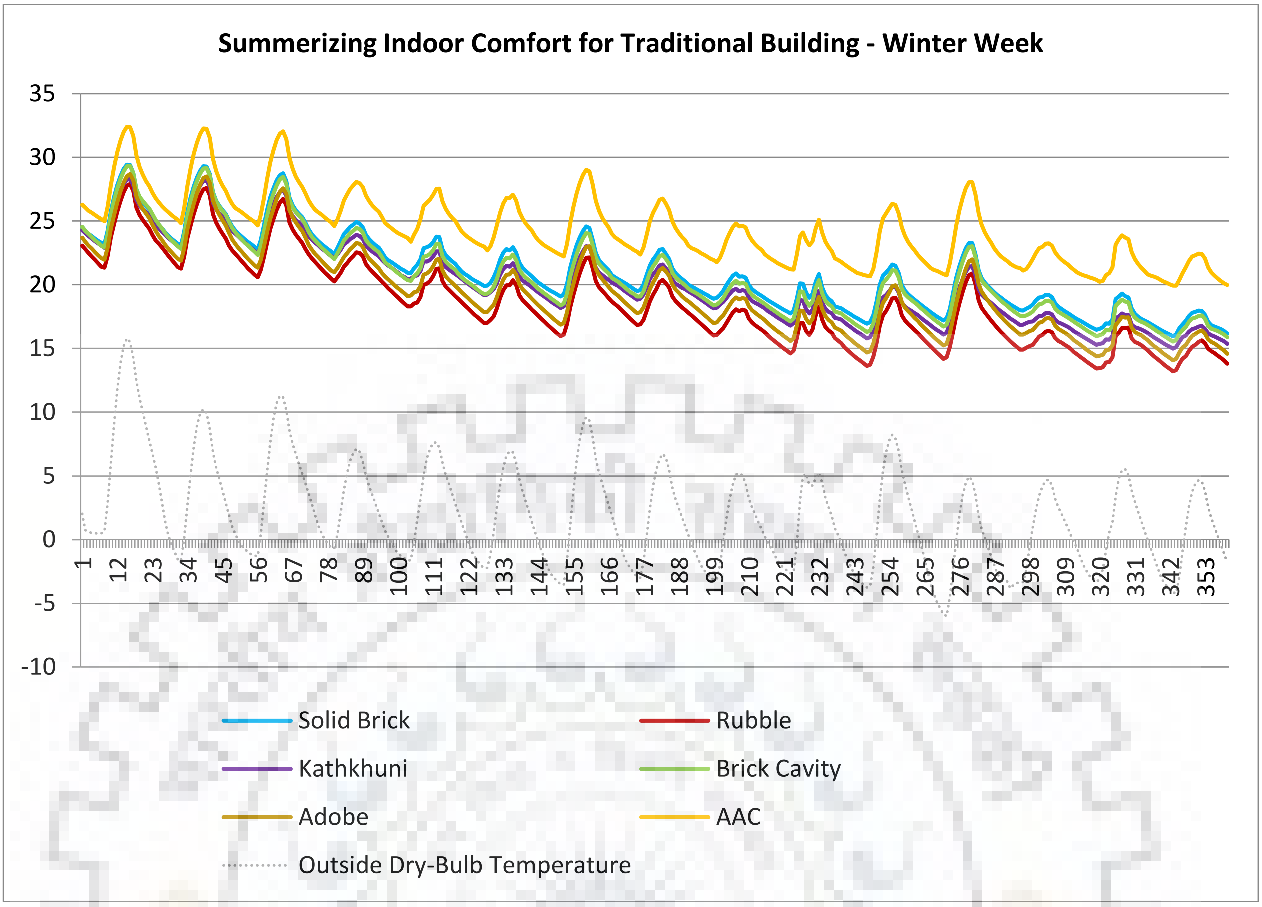
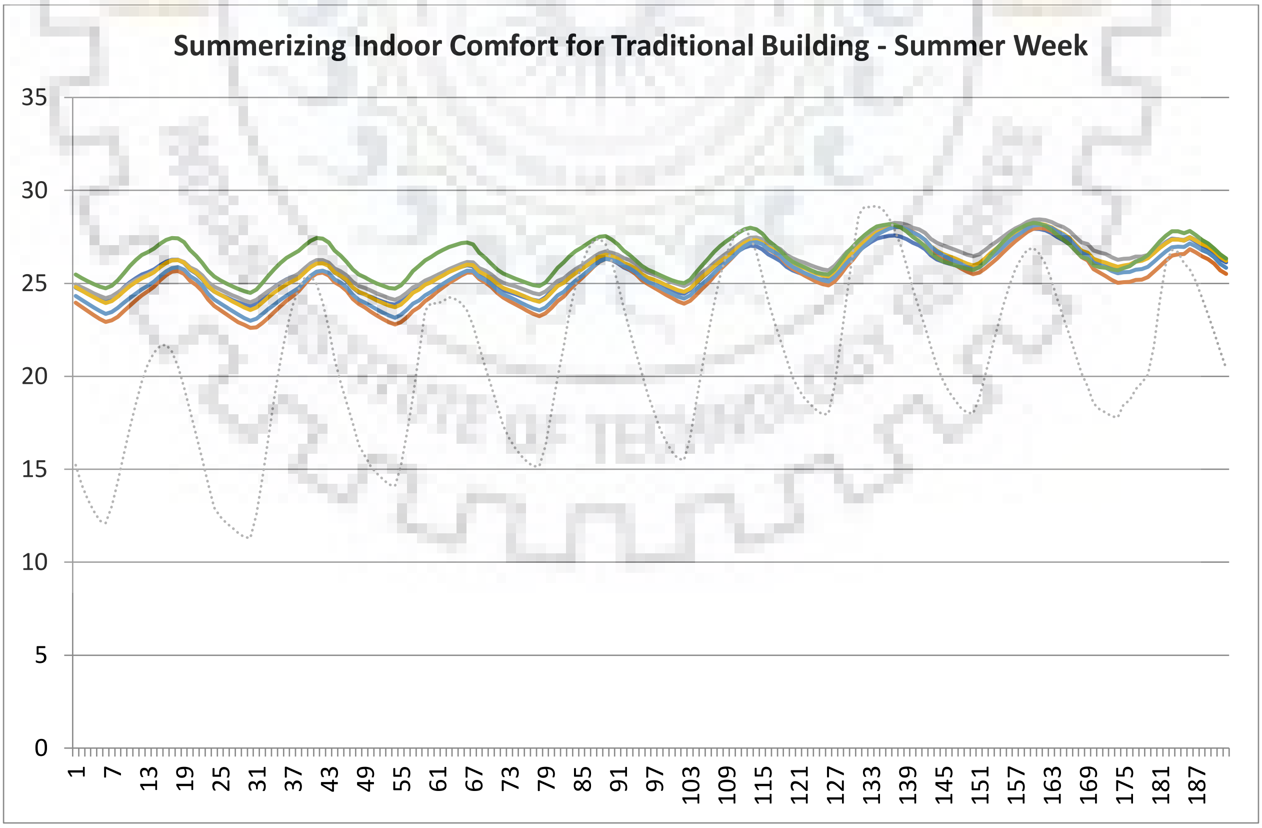


Figure 40 TPI for modern day building


Summerizing Indoor Comfort for Traditional Building - Summer Week
30
25
20
15
10
5
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
106
113
120
127
134
141
148
155
162
169
176
183
190
Solid Brick
Rubble
Kathkhuni
Brick Cavity
Adobe
AAC


Summerizing Indoor Comfort for Modern Building - Summer Week
30
28
26
24
22
20
18
16
14
12
10
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
106
113
120
127
134
141
148
155
162
169
176
183
190

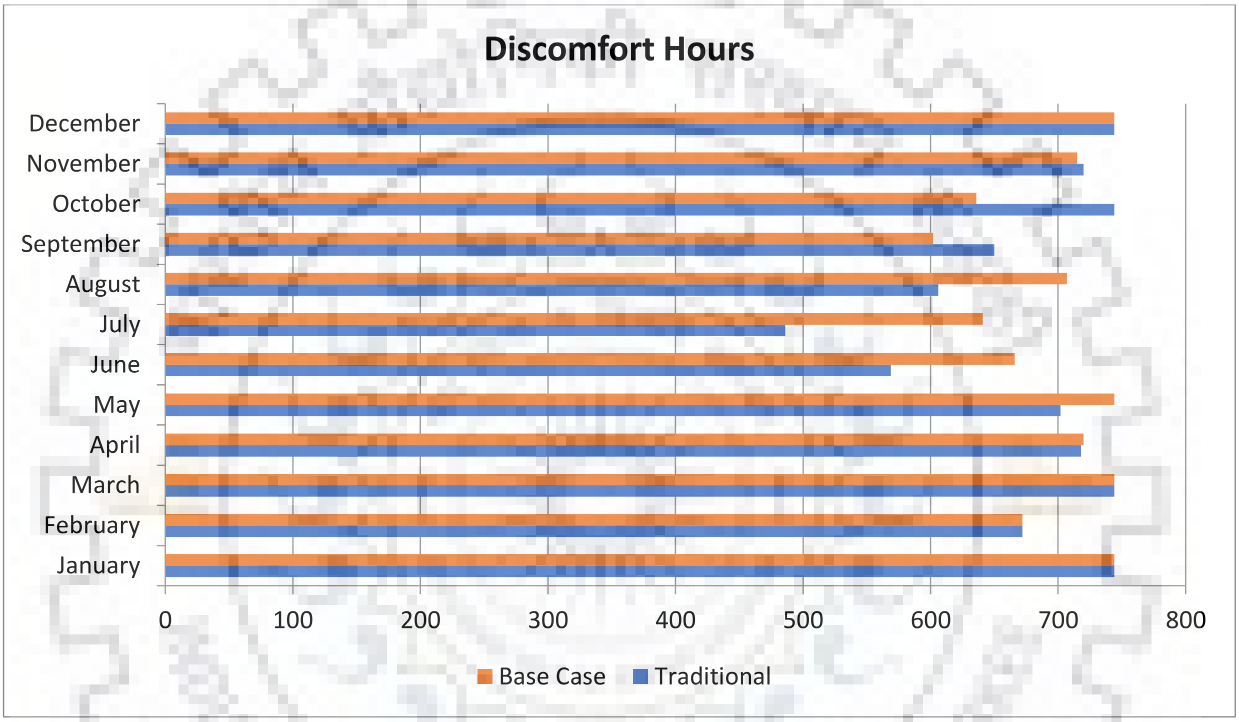

Summerizing Indoor Comfort for Traditional Building - Winter Week
35
30
25
20
15
10
5
0
-5
-10
1
12
23
34
45
56
67
78
89
100
111
122
133
144
155
166
177
188
199
210
221
232
243
254
265
276
287
298
309
320
331
342
353
Solid Brick
Rubble
Kathkhuni
Brick Cavity
Adobe
AAC
Outside Dry-Bulb Temperature


Summerizing Indoor Comfort for Traditional Building - Summer Week
35
30
25
20
15
10
5
0
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
103
109
115
121
127
133
139
145
151
157
163
169
175
181
187

The base case for modern building was prepared and studied to be compared further for the cases that have been prepared.

Discomfort hours:

They are calculated according to the Adaptive comfort formula given by ASHRAE. It is the number of how many hours in that particular season/year requires heating. And Degree hours is a cumulative value of how many degrees and hours is exceeding the comfort temperatures calculated in that region.



If we look at the base case, September is the month with least number of discomfort hours. Following the month July and October comes, since the representative traditional building is located in cold climate. And the least comfortable months are December and January since these are the coldest months. March is also the least comfortable month. If we look at the traditional building July, June and August are the having the least discomfort hours, whereas in these months of peak summer, the base case is not performing well by having more than 65% of the discomfort hours in the months.

Time lag and Decrement factor for rooms

To observe how the spatial planning of the building is affecting the thermal performance of those buildings the values of Time lag and Decrement factor were studied and discussed. Three rooms were chosen in the building to observe in modern building i.e. Dining Room, Drawing room and Master Bedroom. And the walls chosen are external walls and without any fenestration. And the further observations for time lag and decrement factor were collected.

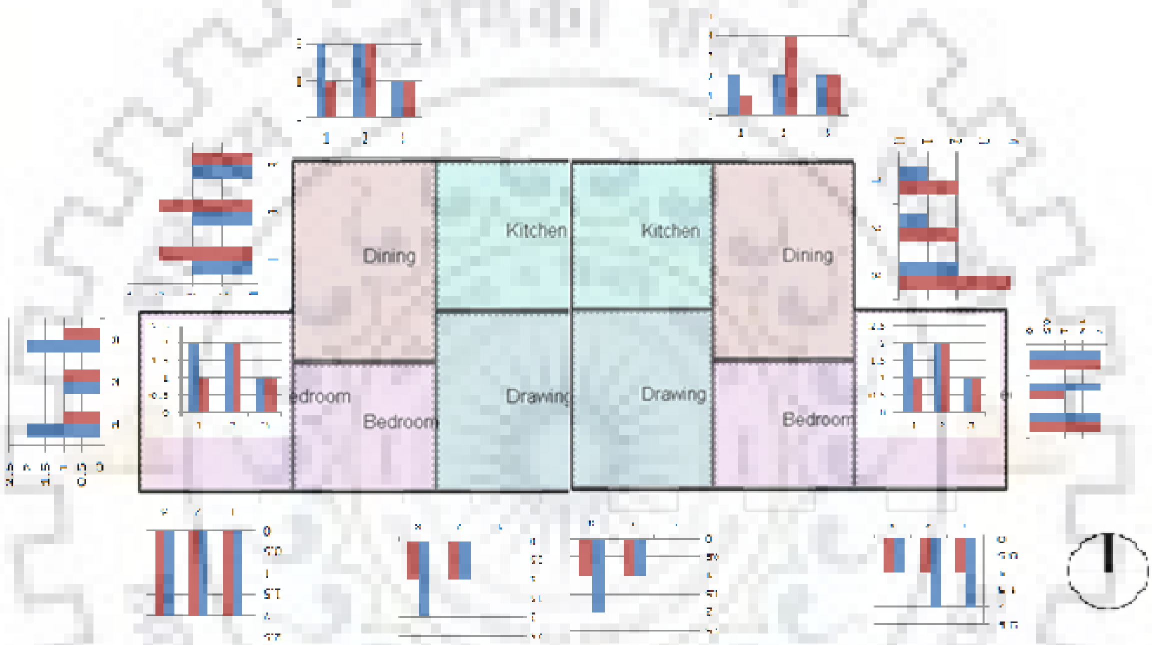


Figure 41 Time lag for selected walls

Here, it was observed on the Ground floor and First floor, the time lag is not changing much around all the orientation. The time lag is lower than the time lag is in winter due to heat loss that is happening in summer is more than winter. But on the top floor i. e. second floor the time lag is increasing towards east and west orientations. And East facing wall is having more time lag value than west facing one. It was observe the maximum decrement factor is face by south facing wall due to the maximum exposure to the sun. But after South the east and west facing walls are facing significant amount of decrement factor due to exposure to the sun. The time lag values and decrement factor values of the south facing wall, the rooms in south are staying warm for long time. The bedrooms are given in south, and due to longer time lag they are providing warmth in the needed time i. e. in the evening. Most of the exposed surface area is also in south to provide the comfort temperature inside rooms.

TIME LAG (MODERN BUILDING)

Table 3 Time lag for Modern Day buiding

Floor	Flat No.	Room	North Facing Wall Summer	North Facing Wall Winter	East Facing Wall Summer	East Facing Wall Winter	South Facing Wall Summer	South Facing Wall Winter	West Facing Wall Summer	West Facing Wall Winter
Ground Floor	1	Dinning	2	1	1	2	-	-	-	-
		Master Bedroom	2	1	2	2	2	1	-	-
	2	Dinning	2	1	-	-	-	-	2	3
		Drawing	-	-	-	-	1	1	-	-
		M.B.	2	2	-	-	2	2	2	1
First Floor	1	Dinning	2	2	1	2	-	-	-	-
		Drawing	-	-	-	-	1	1	-	-
		M.B.	2	2	2	1	2	1	-	-
	2	Dinning	2	4	-	-	-	-	2	3
		Drawing	-	-	-	-	1	1	-	-
		M.B.	2	2	-	-	2	2	1	1

Floor	Flat No.	Room	North Facing Wall Summer	North Facing Wall Winter	East Facing Wall Summer	East Facing Wall Winter	South Facing Wall Summer	South Facing Wall Winter	West Facing Wall Summer	West Facing Wall Winter
Second Floor	1	Dinning	**1**	**1**	**2**	**4**	**-**	**-**	**-**	**-**
		Drawing	**-**	**-**	**-**	**-**	**2**	**1**	**-**	**-**
		M.B.	**1**	**1**	**2**	**2**	**1**	**1**	**-**	**-**
	2	Dinning	**2**	**2**	**-**	**-**	**-**	**-**	**2**	**2**
		Drawing	**-**	**-**	**-**	**-**	**2**	**1**	**-**	**-**
		M.B.	**2**	**2**	**-**	**-**	**2**	**2**	**2**	**1**

DECREMENT FACTOR (MODERN BUILDING)

Table 4 Decrement factor for Modern day building

Floor		Room	North Facing Wall Summer	North Facing Wall Winter	East Facing Wall Summer	East Facing Wall Winter	South Facing Wall Summer	South Facing Wall Winter	West Facing Wall Summer	West Facing Wall Winter
Gound Floor	1	Dinning	1.02	0.52	**5.13**	0.37	-	-	-	-
		Drawing	-	-	-	-	-	-	-	-
		Master Bedroom	0.24	-0.58	**5.84**	2.27	1.13	**5.62**	-	-
	2	Dinning	0.31	0.53	-	-	-	-	**6.81**	0.27
		Drawing	-	-	-	-	1.5	5.6	-	-
		Master Bedroom	0.27	-0.92	-	-	0.95	**5.98**	**6.9**	1.86
First Floor	1	Dinning	1.01	0.66	**5.15**	0.34	-	-	-	-
		Drawing	-	-	-	-	1.39	5.37	-	-
		Master Bedroom	0.22	-0.59	5.81	2.28	1.09	5.9	-	-
	2	Dinning	0.29	0.67	-	-	-	-	**6.82**	0.44
		Drawing	-	-	-	-	**5.37**	**5.37**	-	-
		Master Bedroom	0.27	-0.91	-	-	0.91	5.97	**6.86**	1.82

Floor		**Room**	**North Facing Wall Summer**	**North Facing Wall Winter**	**East Facing Wall Summer**	**East Facing Wall Winter**	**South Facing Wall Summer**	**South Facing Wall Winter**	**West Facing Wall Summer**	**West Facing Wall Winter**
Second Floor	1	Dinning	5.41	0.59	1.02	0.65	-	-	-	-
		Drawing	-	-	-	-	**5.32**	1.66	-	-
		Master Bedroom	-0.58	0.19	2.28	**5.78**	**5.85**	1.38	-	-
	2	Dinning	0.28	0.55	-	-	-	-	**6.85**	1.26
		Drawing	-	-	-	-	1.71	**5.32**	-	-
		Master Bedroom	0.25	-0.89	-	-	1.12	**5.95**	**6.81**	1.79

6. CONCLUSION

Thermal performance of residential building in cold climate is one of the untouched, critical and important areas to research in India. When India saw mass production and industrialization along with population explosion and increased demand, people chose for economical solutions rather than focusing on what is needed in that area. It is a need to identify the means and methods from our traditions for the modern era. We have seen landslides and floods due to haphazard urbanization in Himachal Pradesh, but thermal performance and its bad effects are the most ignored areas of construction sector. This dissertation was conducted to add into the knowledge of this area for the betterment of humans.

Though this dissertation is theoretical study, it is strongly based on the literature study done. The literature study helped in contextualizing of the study area, scope and limitations. The representative traditional and modern day buildings were chosen very critically for this study. The shortlisted building materials and techniques were also decided based on the historic and current day uses in the location Dharamshala. These materials and techniques were studied for their thermal performance in both type of the buildings with the help of parameters like TPI, Thermal Transmittance (U), Time Lag, Thermal Damping, Heating degree days, etc.

The traditional buildings are performing better than modern day buildings because the indoor temperature maintained in traditional buildings is more balanced and comfortable for the residents, whereas the indoor temperatures in modern day building were observed more deflecting in different seasons and daytimes.Though the spatial design of the modern day buildings is completely different from traditional buildings, it creates the limitation of directly applying the materials and techniques from traditional buildings to modern day buildings. But the advanced building technologies can help in using some elements from the traditional buildings.

The comparative study based on selected parameters recommended the combinations of traditional and modern day building materials and techniques with other more recommendations. It also recommended achieving same or similar U-value of tradition construction systems in modern day buildings can help in better thermal performance.

We can learn from the examples like MLA Hostel in Shimla. As the study has demonstrated, we can always learn from traditions and historical events.

7. RECOMMENDATIONS

- Traditional building was performing better than modern day building because of its compactness and small windows were helping reducing the heat loss that was happening due to more open plan and more WWR in modern day building. It is recommended that if there is need of construction smaller building, the building's spatial design should be kept compact and with smaller windows. But modern day buildings are comparatively bigger in size serving more numbers of families. In this case, if designer wants to achieve better thermal performance for the building in terms of spatial design, It is recommended to design the building in compact way, gaining more warmth from the sun in winters for needed rooms in the house/flat. Other option for this can be the inspiration from verandah in modern-day building; the new building can be designed inward looking.
- It was seen that the traditional materials and techniques like Solid Brick Wall, Brick Cavity wall and Kathkhuni construction has given better performance than modern building materials and techniques like AAC blocks. For the colder locations than Dharamshala, these materials and techniques can be considered for the modern day residential buildings. They can be combined with the modern day materials and techniques.
- AAC blocks are recommended as an economical choice for building wall material to make the winters comfortable in the residential, but there should be enough measures taken to improve thermal performance in summer season. Because AAC blocks might create discomfort in summer days and can cause unbearable indoor temperatures.
- According to the peak high and peak low temperature of the day, Rubble stone is improving the thermal performance in peak high temperature, and other materials are almost keeping the indoor temperature comfortable. It is recommended in the cold climate, which is not extreme, the south face of the building to be built or cladded (for economic reasons) with rubble stone to improve the thermal performance.
- According to peak temperature, AAC block wall is providing warmth in the morning time, whereas other materials perform better in the evening. It is not recommended to use AAC blocks wall in the locations where diurnal variation is relatively high. The evenings might become unbearable due to its heat radiation property and time lag.

- Brick cavity wall is recommended as economical construction technique for the smaller residential building where the wall will not reduce carpet area so much that it will cause increase in total building cost or the loss, depending on the user's requirements.
- Adobe wall is recommended for the balanced change in indoor temperatures in comparison of outdoor temperature. So it will not unbearable when user moves from outdoor to indoor. It is more recommended for the spaces where the user contact first from outdoor to indoor like lobby, verandah, waiting area, etc.
- Design elements like compactness of the building and small windows are recommended for better thermal performance in summer season.
- Since the technique – Kathkhuni construction is not possible for the modern day building, the U-value can be balanced to the Kathkhuni wall by using same (Slate, Wood) or similar materials from kathkhuni as internal or external (as per the location requirements) cladding to achieve similar thermal performance of Kathkhuni construction
- The spaces in a residential building which are in need of more warmth are recommended to be oriented on the east and/or south face of the building.

SCOPE FOR FUTURE RESEARCH

- This study can be carried further with the field measurements.
- The effect of different insulating materials and techniques can be studied further with the methodology and analytical framework used for this dissertation.
- Especially the U-value calculation (Manual and Software base) of traditional technique of Kath khuni construction can be more valued with the experimental study. For this technique the research gap for insulating qualities can be studied.
- The same study can be conducted for other vernacular practices in the world for preliminary study.
- The limitation for this study of extreme climates can be considered.

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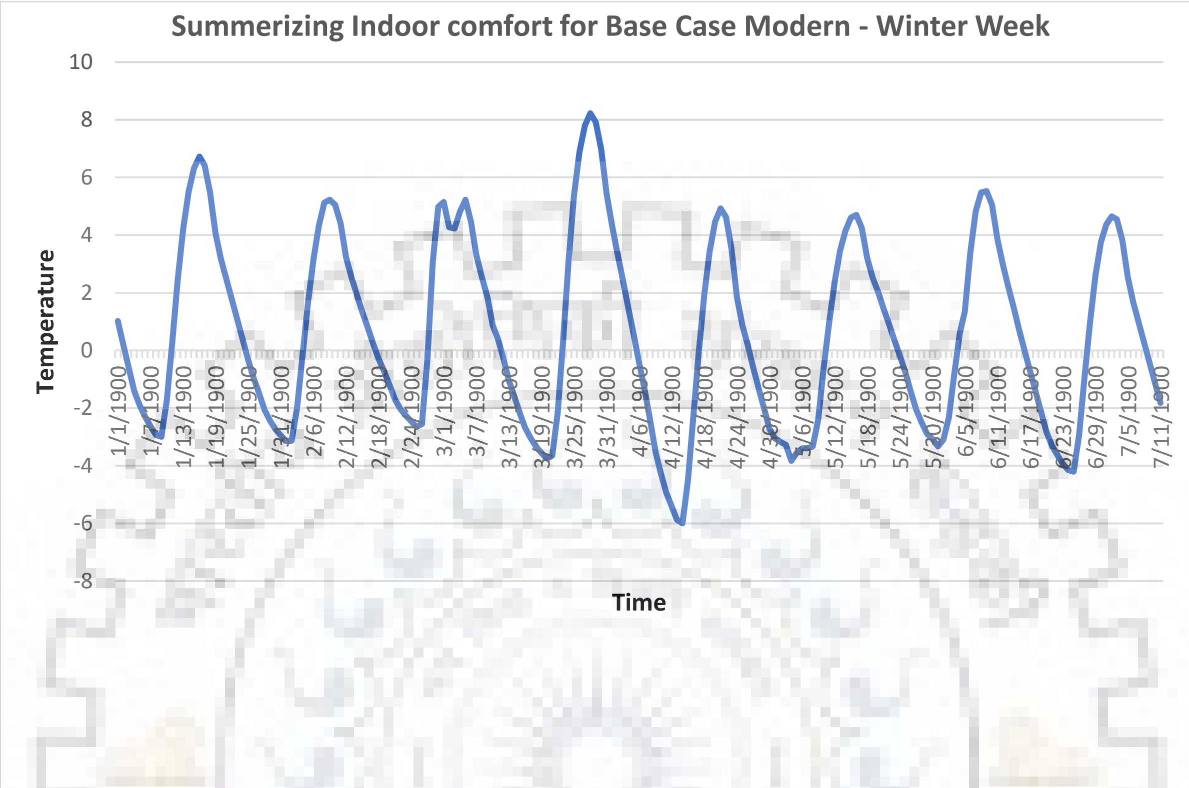
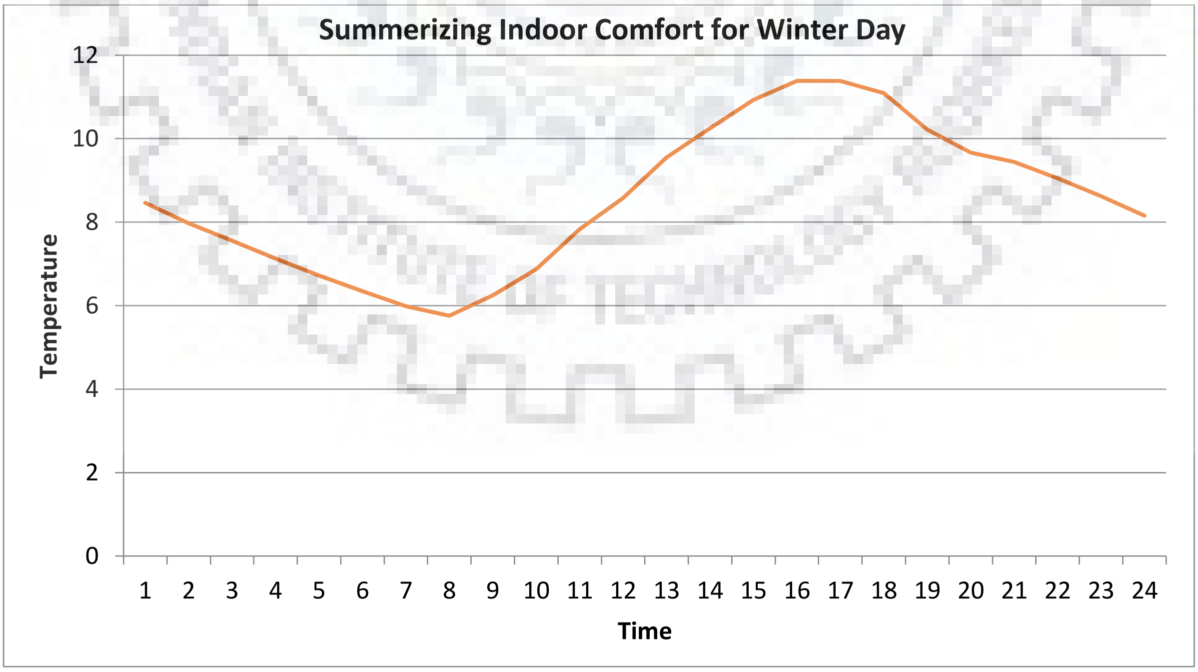
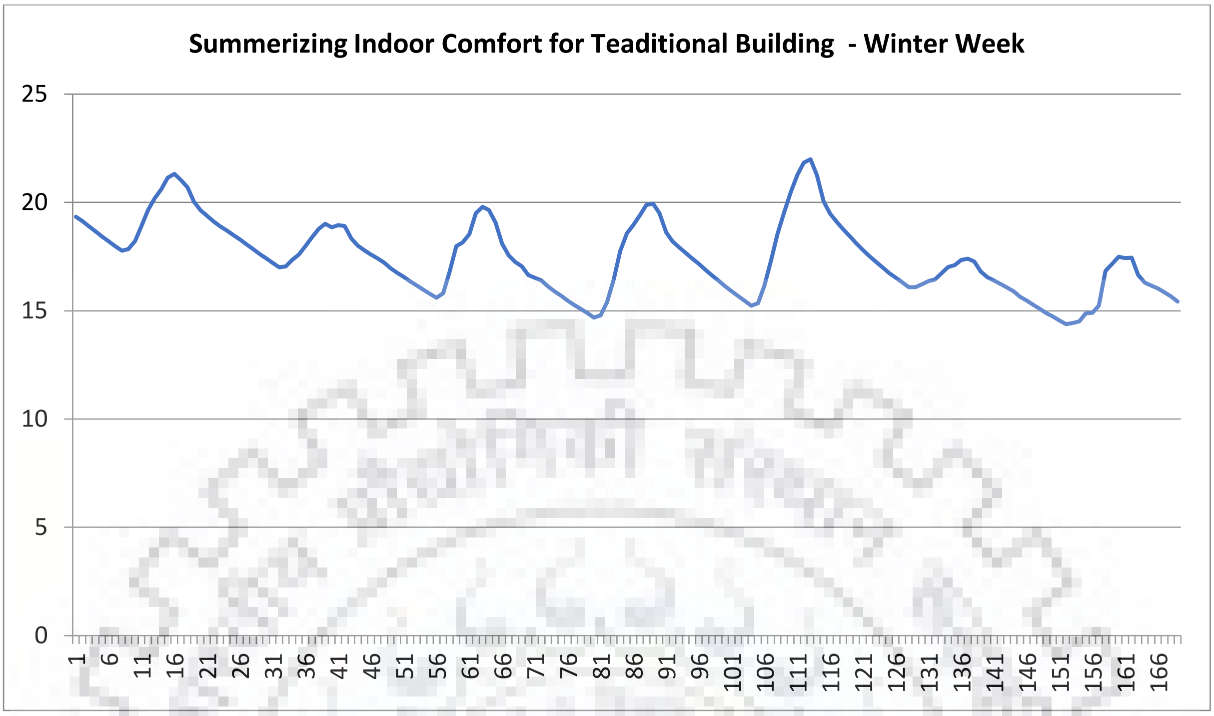
ANNEXURES

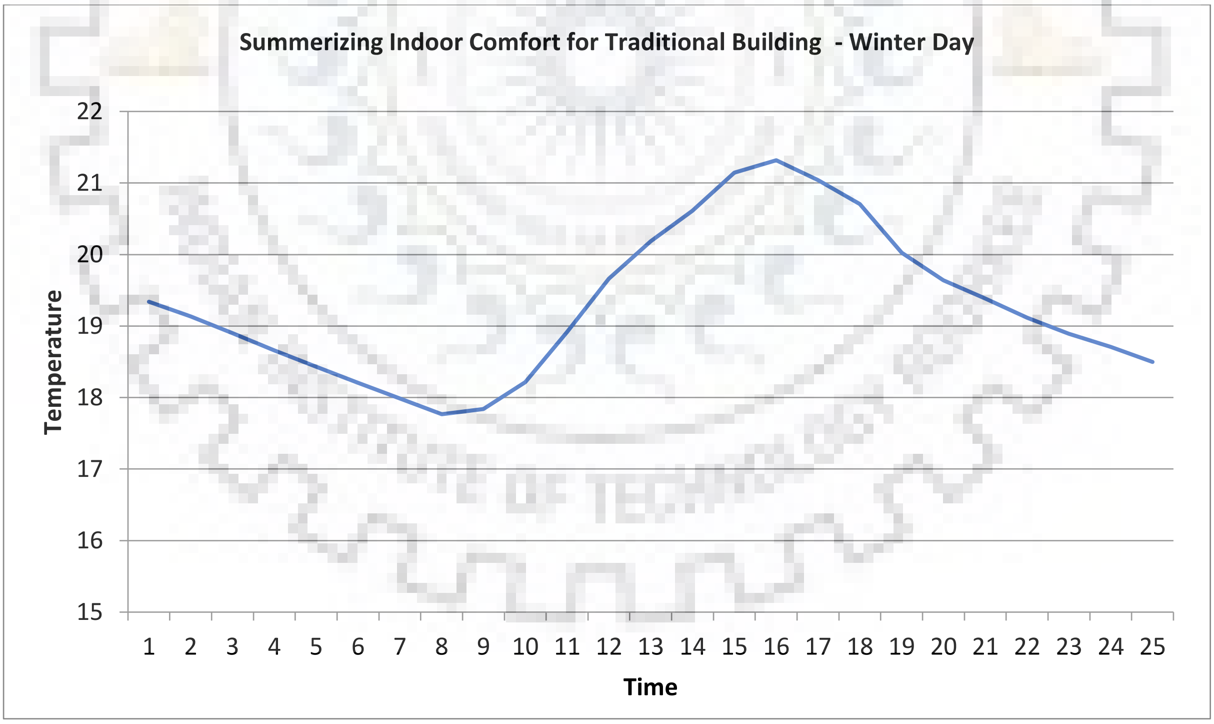
Summarizing Indoor Comfort for Modern Representative building for a winter week

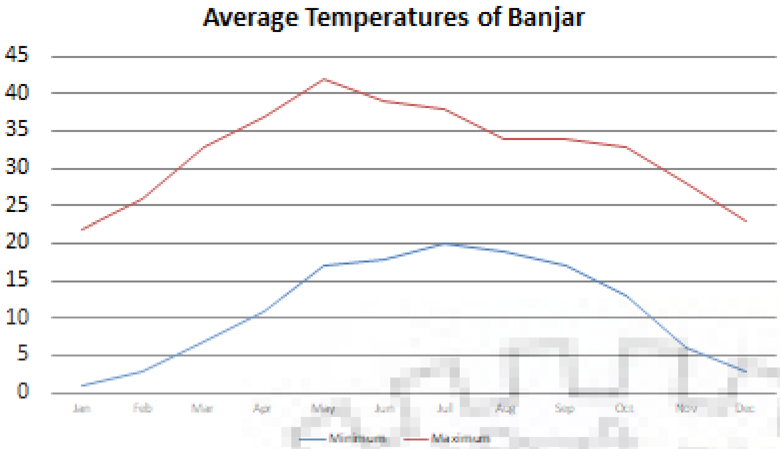




Summarizing Indoor Comfort for Traditional Representative building for a winter week







Average Temperatures of Banjar
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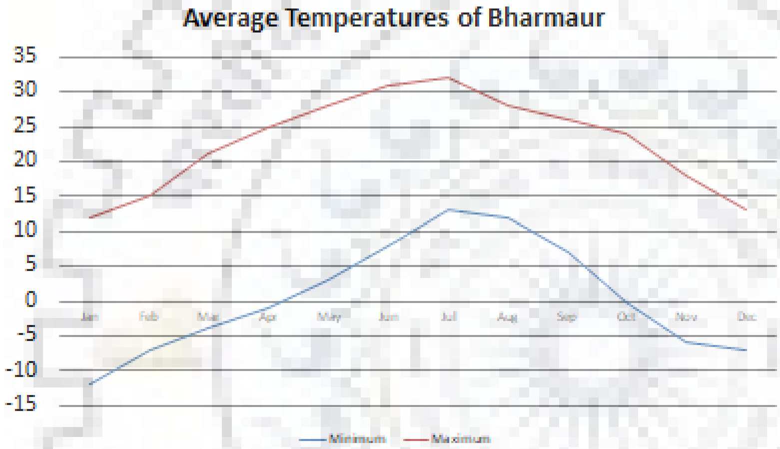
Dec
Minimum
Maximum



Average Temperatures of Bharmaur
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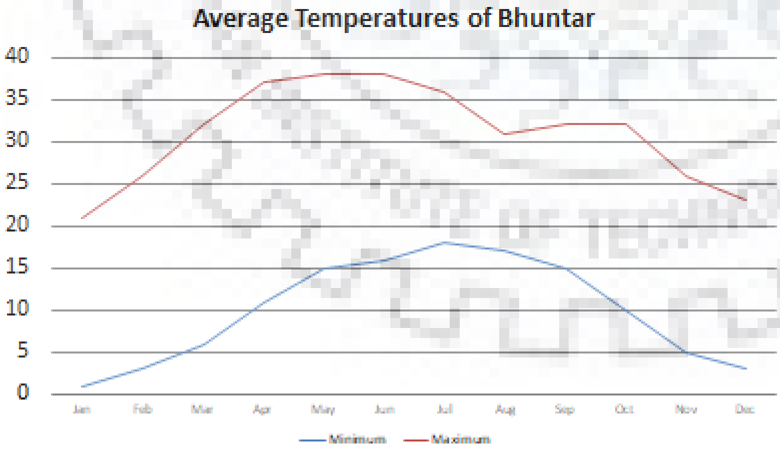

Average Temperatures of Bhuntar
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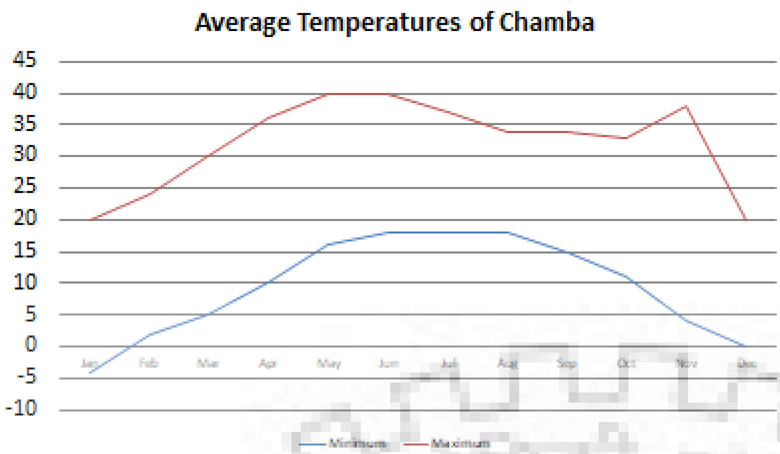
Average Temperatures of Chamba
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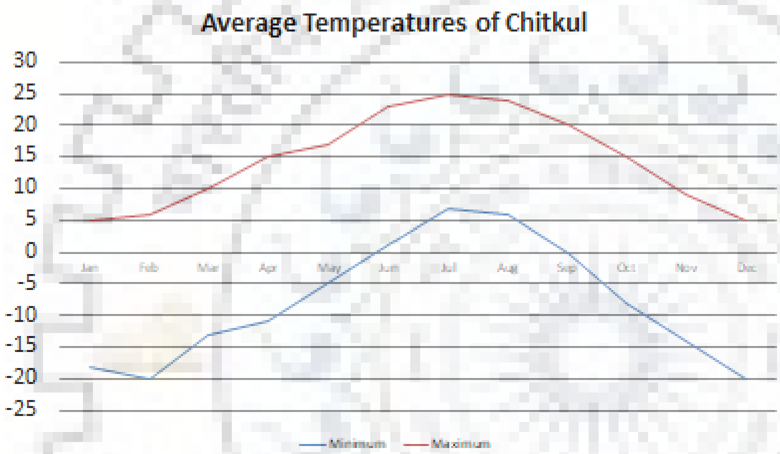
Average Temperatures of Chitkul
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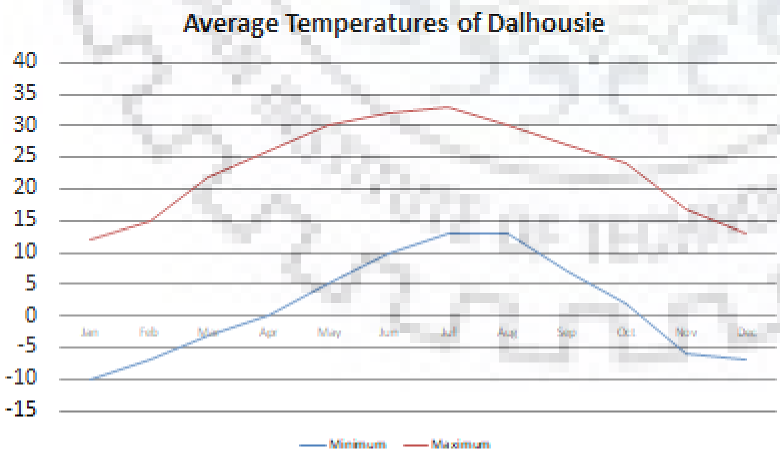
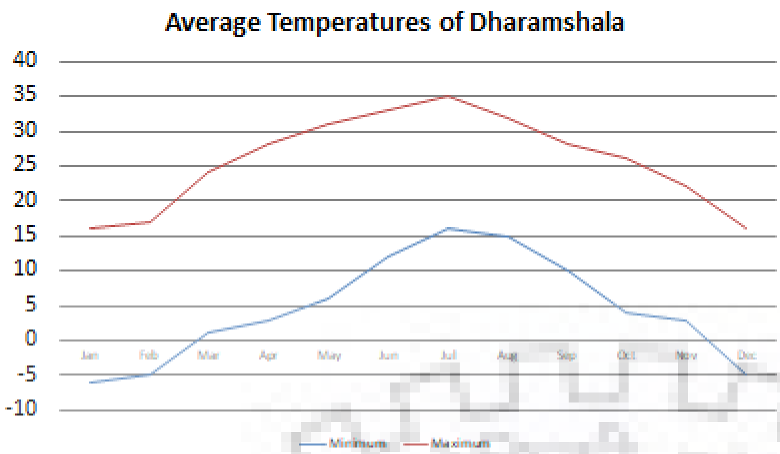
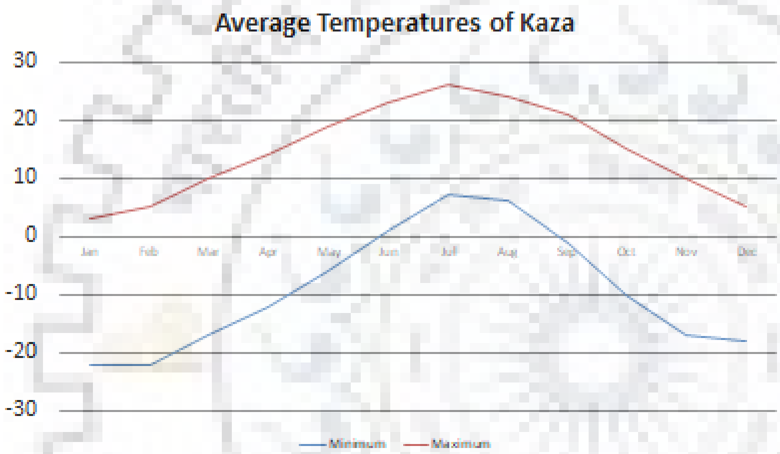
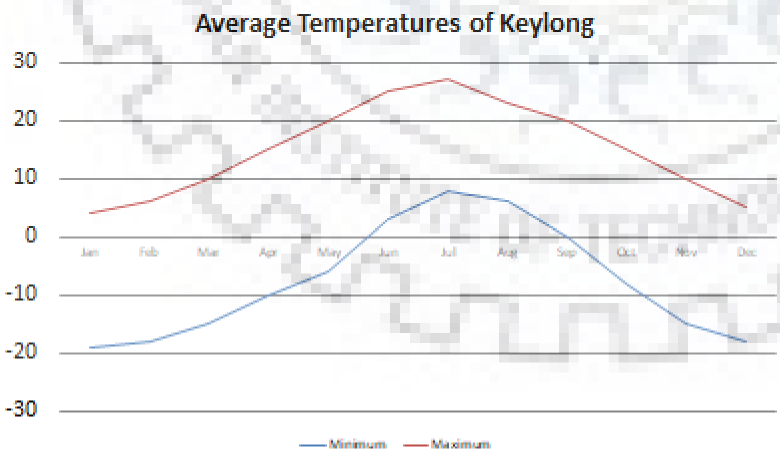
Maximum

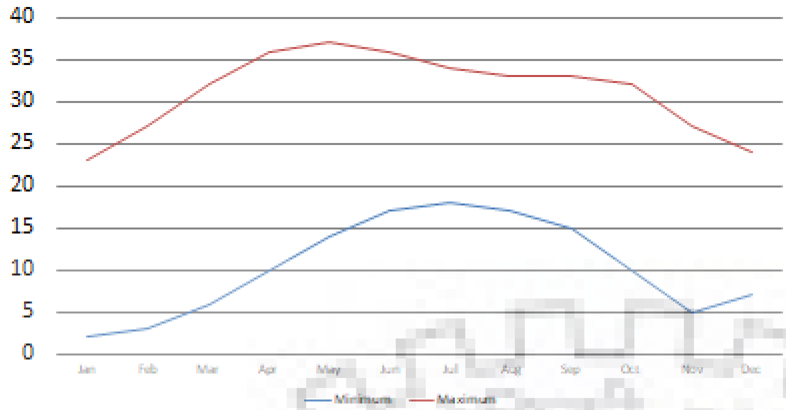

Average Temperatures of Dalhousie
40
35
30
25
20
15
10
5
0
-5
-10
-15
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Minimum
Maximum


Average Temperatures of Dharamshala
40
35
30
25
20
15
10
5
0
-5
-10
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Minimum
Maximum

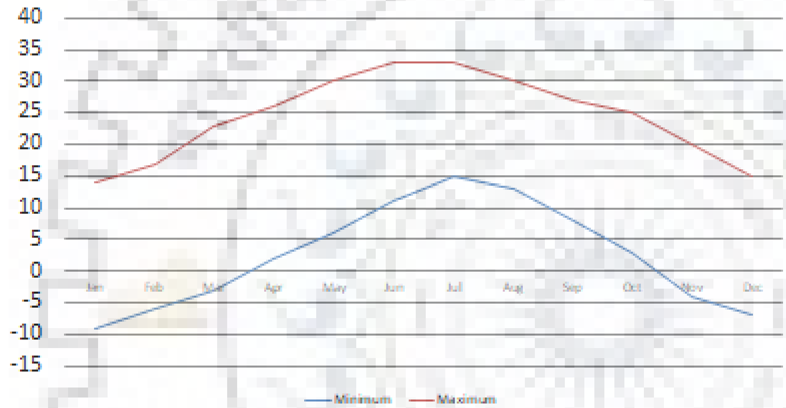

Average Temperatures of Kaza
30
20
10
0
-10
-20
-30
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Minimum
Maximum


Average Temperatures of Keylong
30
20
10
0
-10
-20
-30
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Minimum
Maximum

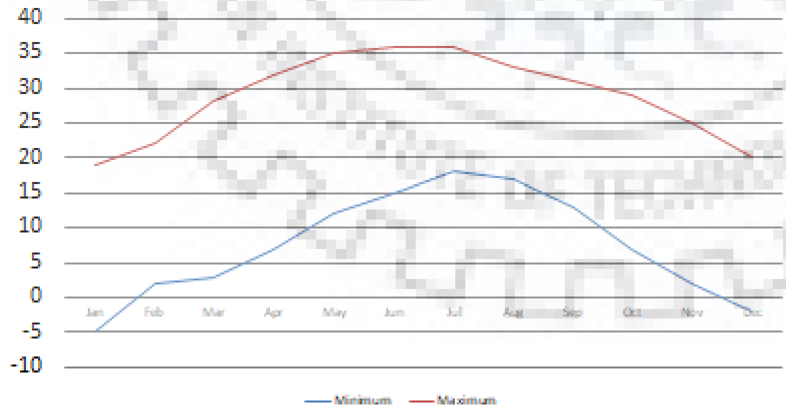
Average Temperatures of Kullu



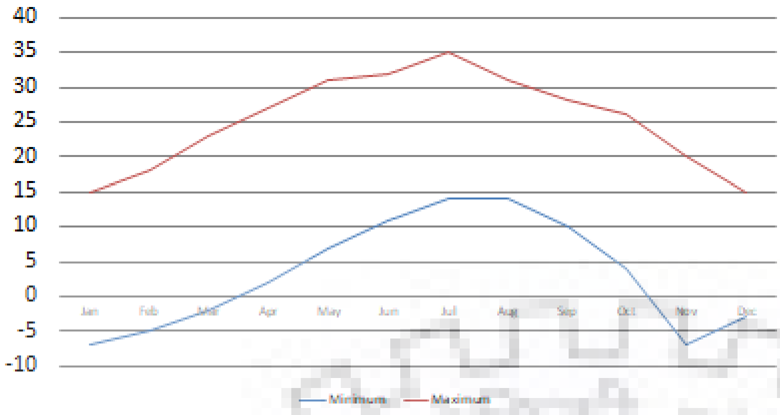
Average Temperatures of Manali



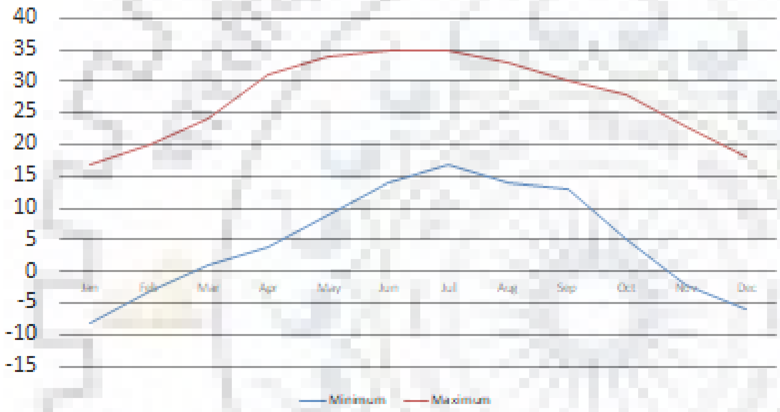
Average Temperatures of Manikaran



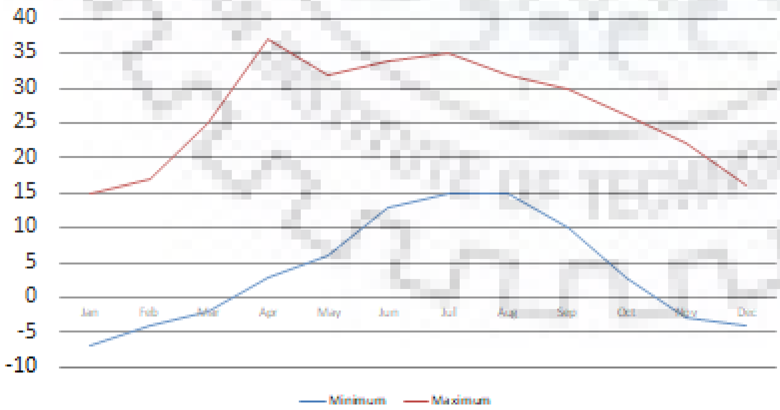
Average Temperatures of Mcleod Ganj

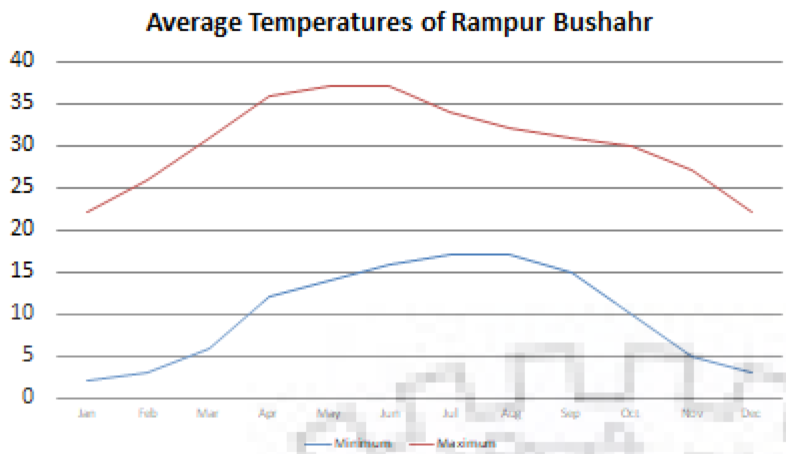


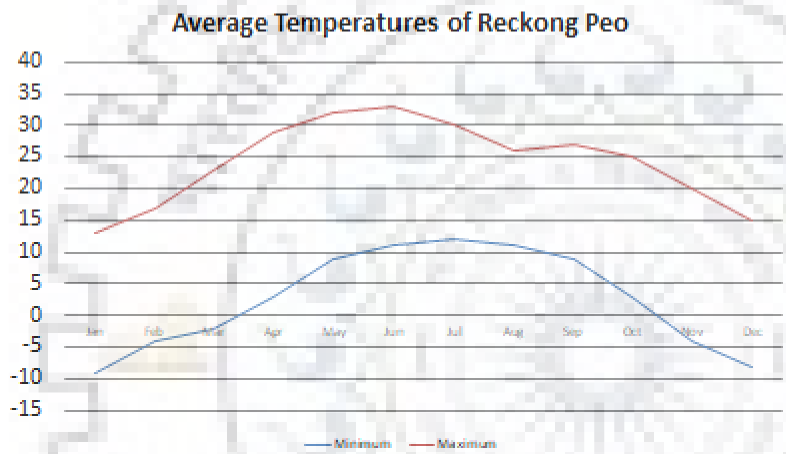
Average Temperatures of Naggar

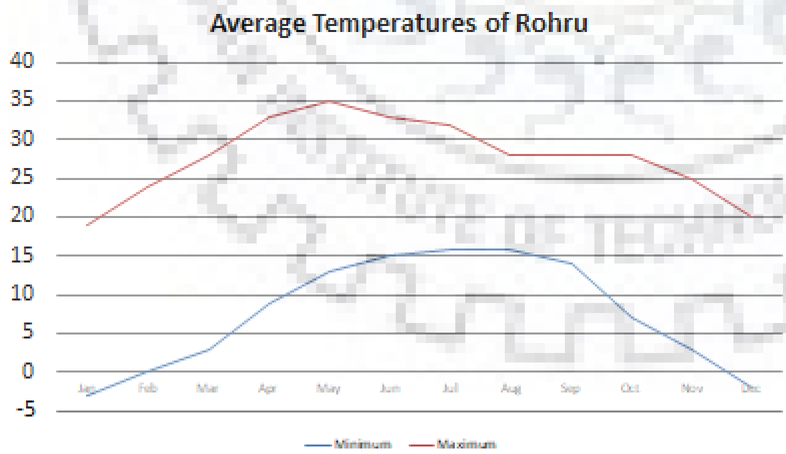


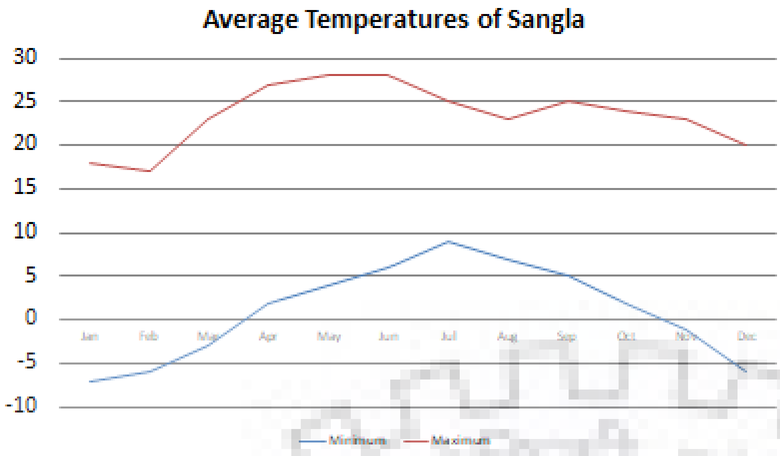
Average Temperatures of Palampur

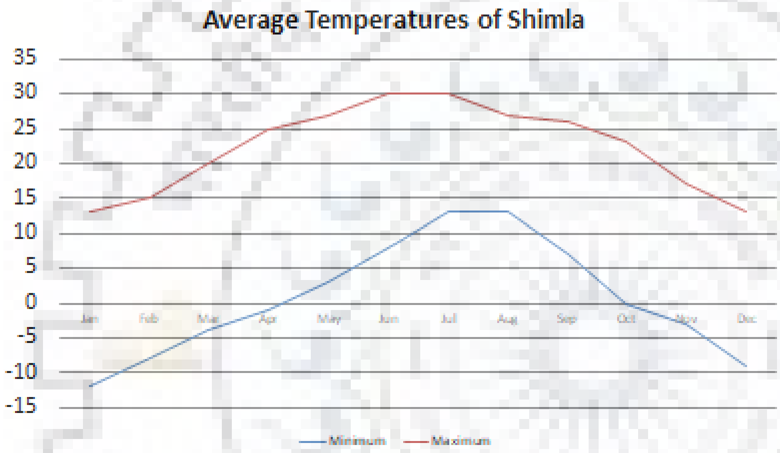


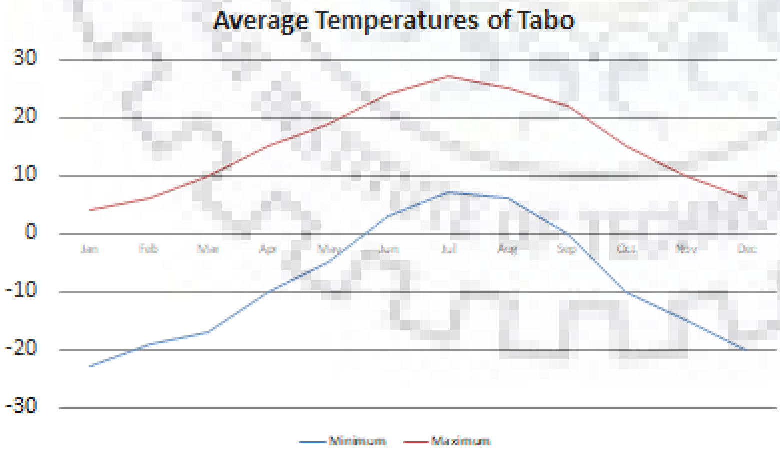

Average Temperatures of Rampur Bushahr
40
35
30
25
20
15
10
5
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Minimum Maximum


Average Temperatures of Reckong Peo
40
35
30
25
20
15
10
5
0
-5
-10
-15
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Minimum Maximum


Average Temperatures of Rohru
40
35
30
25
20
15
10
5
0
-5
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Minimum Maximum


Average Temperatures of Sangla
30
25
20
15
10
5
0
-5
-10
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Minimum
Maximum

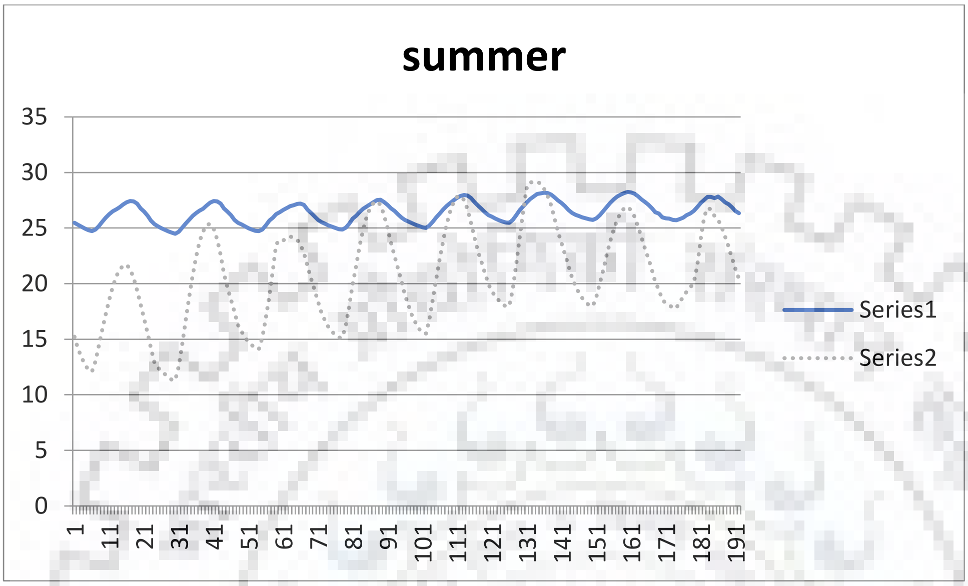

Average Temperatures of Shimla
35
30
25
20
15
10
5
0
-5
-10
-15
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Minimum
Maximum

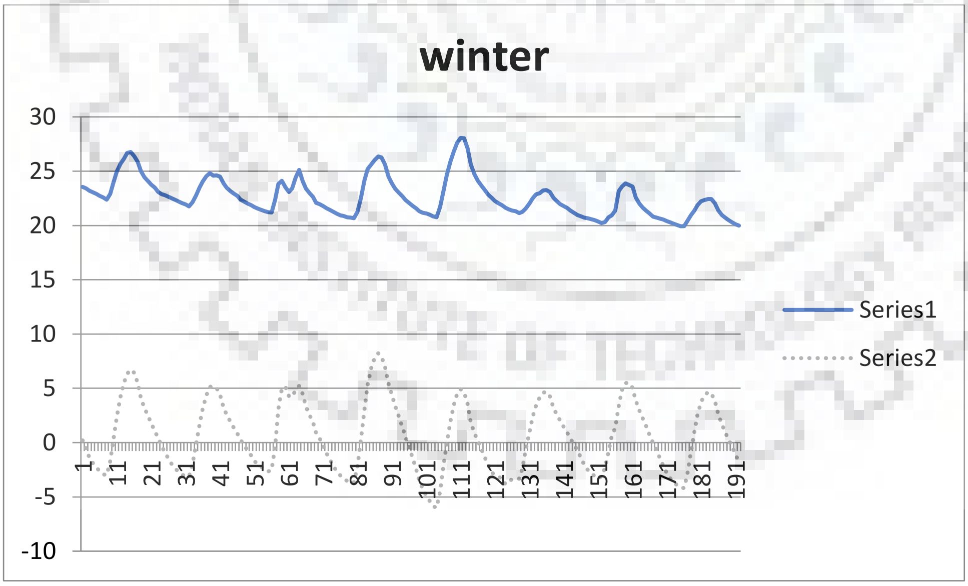

Average Temperatures of Tabo
30
20
10
0
-10
-20
-30
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Minimum
Maximum

Summerizing Indoor Comfort

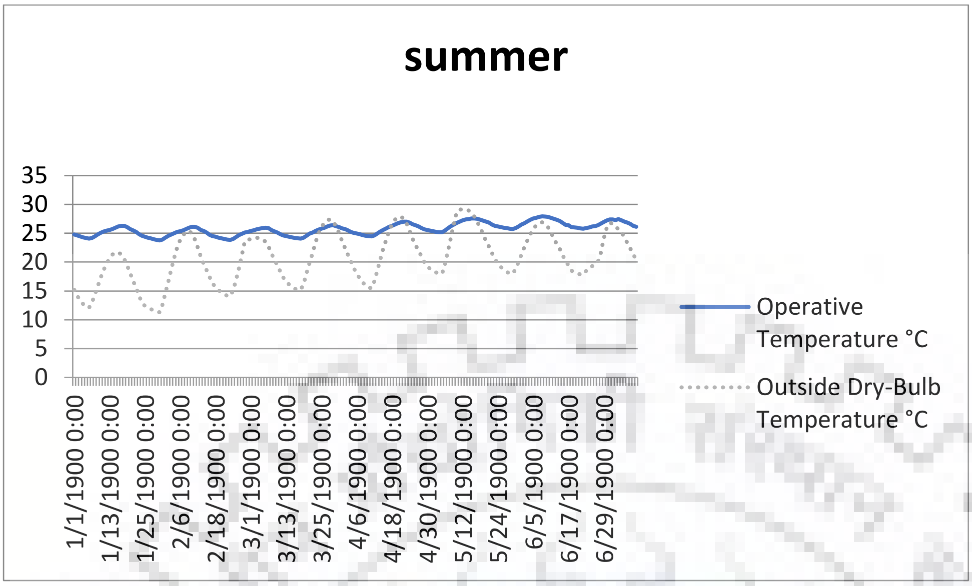
Modern Building

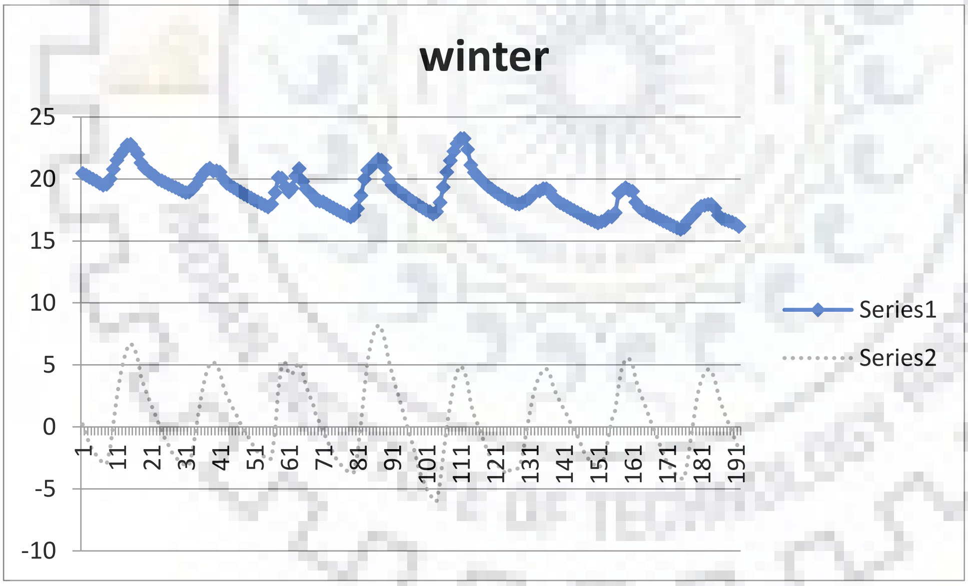
AAC



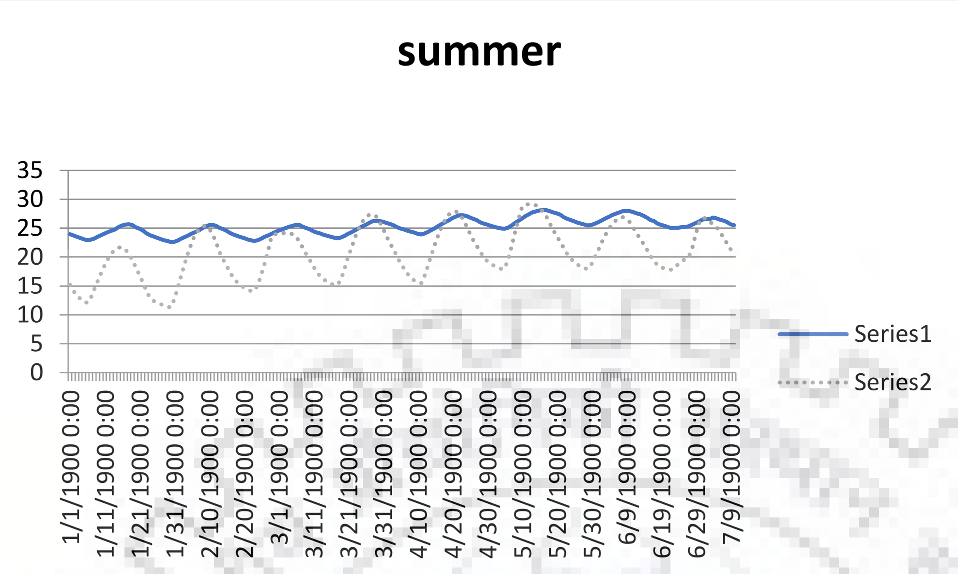


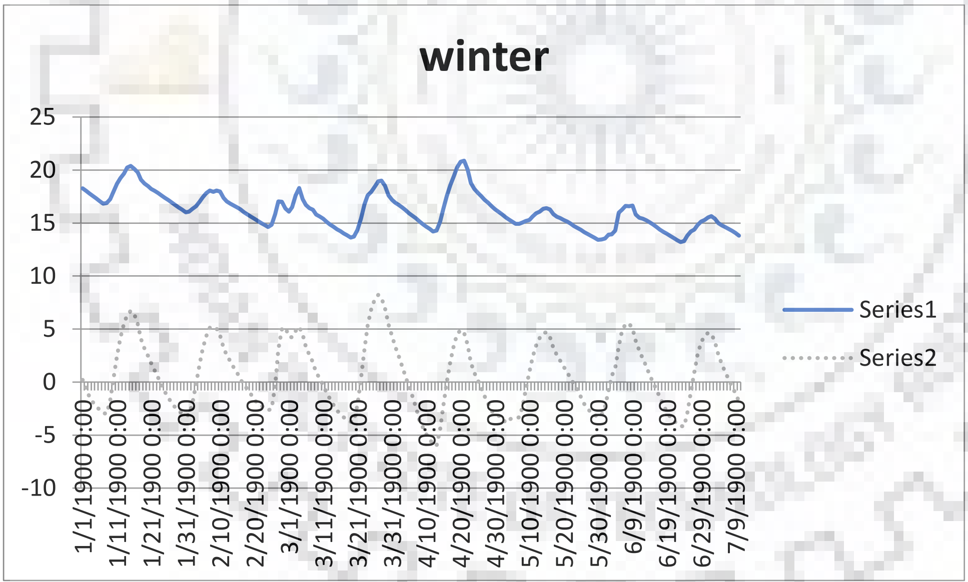
Solid Brick


summer
35
30
25
20
15
10
5
0
1/1/1900 0:00
1/13/1900 0:00
1/25/1900 0:00
2/6/1900 0:00
2/18/1900 0:00
3/1/1900 0:00
3/13/1900 0:00
3/25/1900 0:00
4/6/1900 0:00
4/18/1900 0:00
4/30/1900 0:00
5/12/1900 0:00
5/24/1900 0:00
6/5/1900 0:00
6/17/1900 0:00
6/29/1900 0:00
Operative Temperature °C
Outside Dry-Bulb Temperature °C


winter
25
20
15
10
5
0
-5
-10
1
11
21
31
41
51
61
71
81
91
101
111
121
131
141
151
161
171
181
191
Series1
Series2

Rubble


summer
35
30
25
20
15
10
5
0
1/1/1900 0:00
1/11/1900 0:00
1/21/1900 0:00
1/31/1900 0:00
2/10/1900 0:00
2/20/1900 0:00
3/1/1900 0:00
3/11/1900 0:00
3/21/1900 0:00
3/31/1900 0:00
4/10/1900 0:00
4/20/1900 0:00
4/30/1900 0:00
5/10/1900 0:00
5/20/1900 0:00
5/30/1900 0:00
6/9/1900 0:00
6/19/1900 0:00
6/29/1900 0:00
7/9/1900 0:00
Series1
Series2


winter
25
20
15
10
5
0
-5
-10
1/1/1900 0:00
1/11/1900 0:00
1/21/1900 0:00
1/31/1900 0:00
2/10/1900 0:00
2/20/1900 0:00
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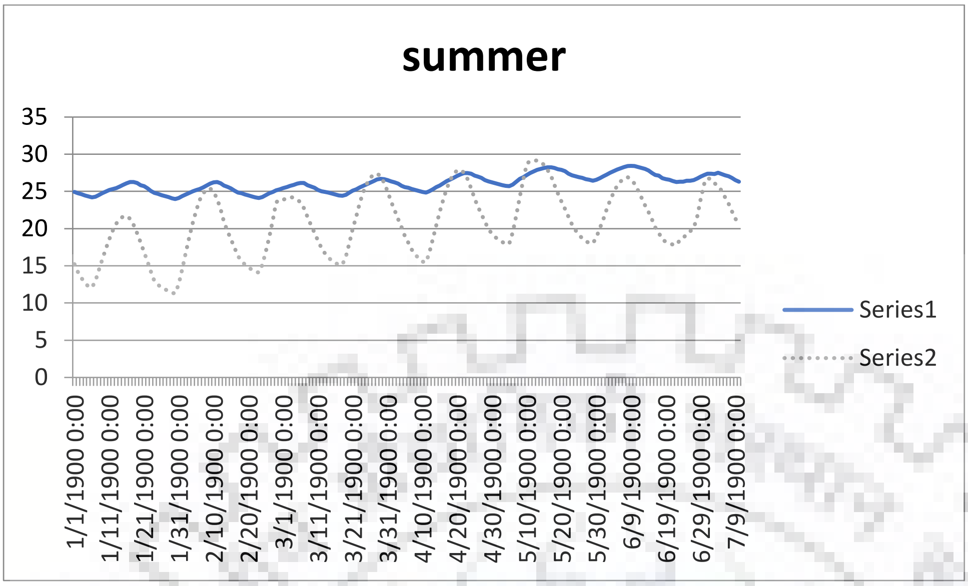
5/20/1900 0:00
5/30/1900 0:00
6/9/1900 0:00
6/19/1900 0:00
6/29/1900 0:00
7/9/1900 0:00
Series1
Series2

Kathkhuni


summer
35
30
25
20
15
10
5
0
1/1/1900 0:00
1/11/1900 0:00
1/21/1900 0:00
1/31/1900 0:00
2/10/1900 0:00
2/20/1900 0:00
3/1/1900 0:00
3/11/1900 0:00
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4/20/1900 0:00
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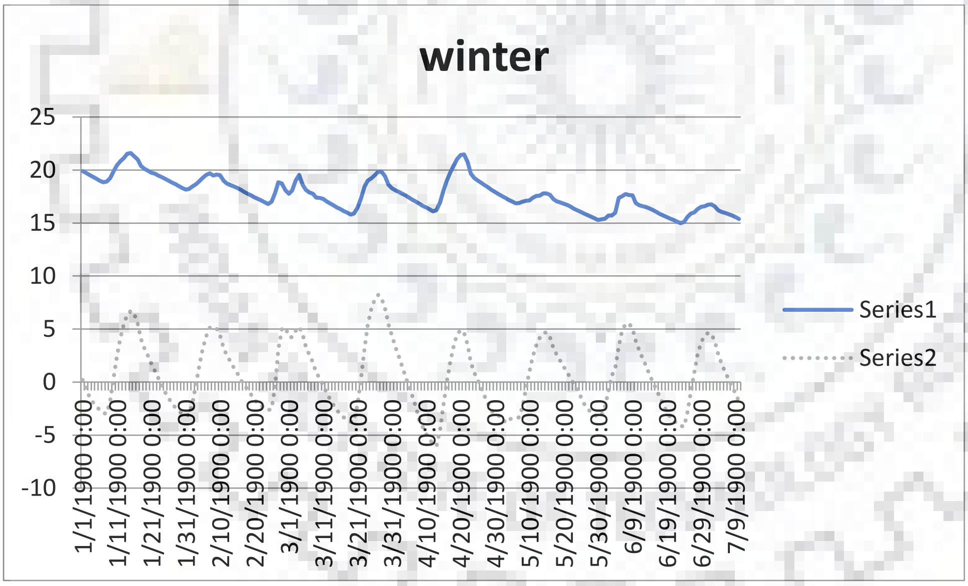
Series1
Series2


winter
25
20
15
10
5
0
-5
-10
1/1/1900 0:00
1/11/1900 0:00
1/21/1900 0:00
1/31/1900 0:00
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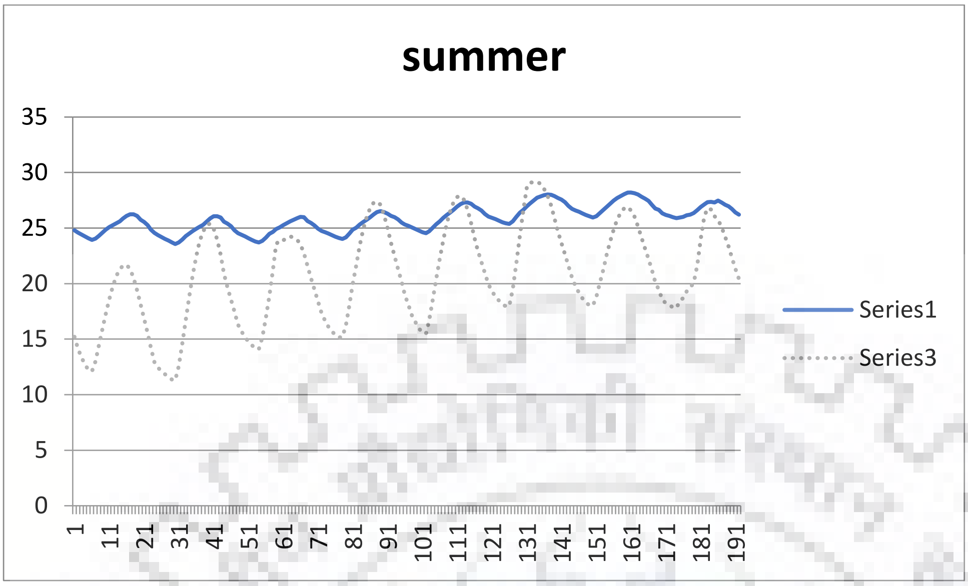
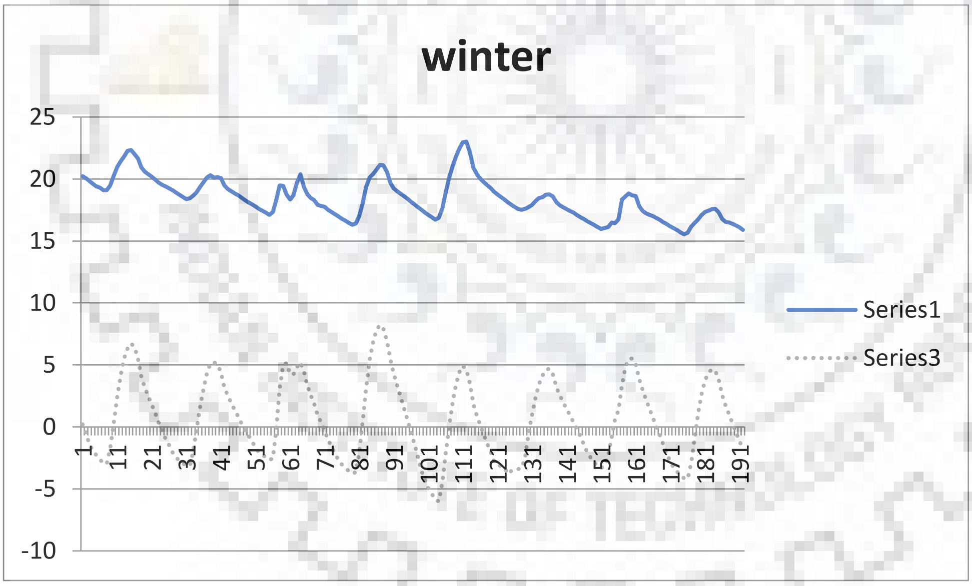
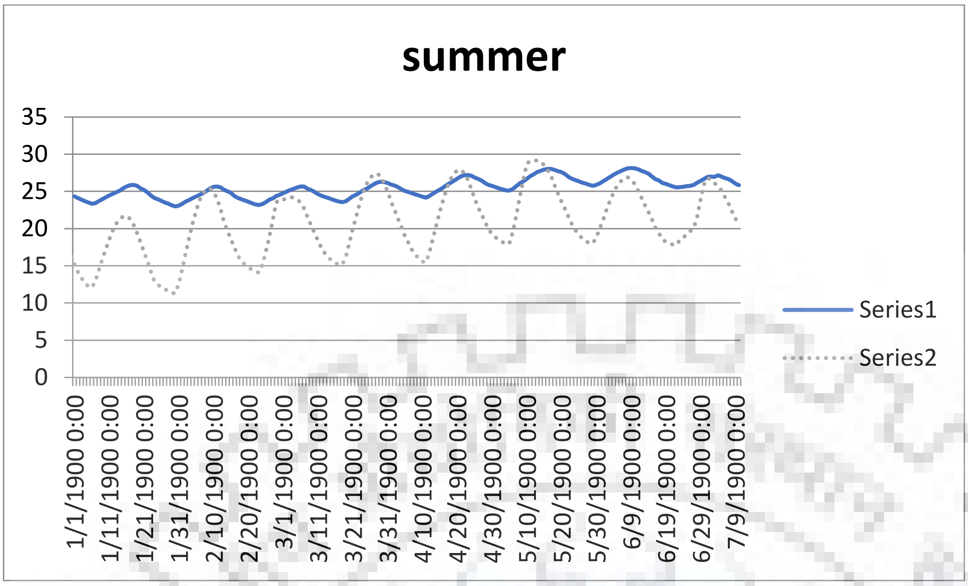
5/10/1900 0:00
5/20/1900 0:00
5/30/1900 0:00
6/9/1900 0:00
6/19/1900 0:00
6/29/1900 0:00
7/9/1900 0:00
Series1
Series2

Brick Cavity





Adobe


summer
35
30
25
20
15
10
5
0
1/1/1900 0:00
1/11/1900 0:00
1/21/1900 0:00
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2/10/1900 0:00
2/20/1900 0:00
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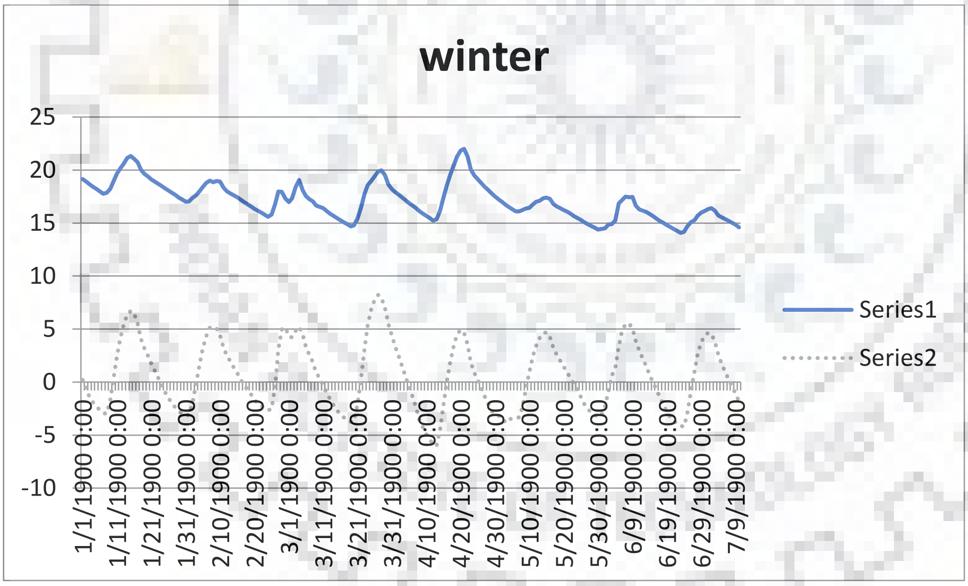
7/9/1900 0:00
Series1
Series2


winter
25
20
15
10
5
0
-5
-10
1/1/1900 0:00
1/11/1900 0:00
1/21/1900 0:00
1/31/1900 0:00
2/10/1900 0:00
2/20/1900 0:00
3/1/1900 0:00
3/11/1900 0:00
3/21/1900 0:00
3/31/1900 0:00
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4/30/1900 0:00
5/10/1900 0:00
5/20/1900 0:00
5/30/1900 0:00
6/9/1900 0:00
6/19/1900 0:00
6/29/1900 0:00
7/9/1900 0:00
Series1
Series2