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Study of thermal comfort in Terai region Nepal – A case of school building in Kapilvastu district

By

Sita Bhusal

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APPROVAL PAGE

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **“Study of thermal comfort in Terai region Nepal –A case of school building in Kapilvastu district”** submitted by Sita Bhusal in partial fulfillment of the requirements for the degree of Master in Climate Change and Development

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ABSTRACT

The average global temperature of surface has been risen by more than 0.9 degrees Celsius. Similarly the temperature of Nepal is warming at the rate faster rate than that of the global average temperature. Thermal discomfort will have an adverse effect on academic performance, so it is necessary to pay attention to improving the indoor thermal environment of the classroom. Adaptation to climate change is a functional requirement, and the best type of insulation is a well-defined thermal limit in the building. The construction of all existing schools in Nepal did not consider the comfort of the residents and the adaptability of the buildings to the local climate.

The focus of the research is to evaluate and compare the packaging effect of a non-insulated prototype school in Kapilvastu district with the effect of an insulated school. This study will help to report on the temperature in classrooms in Kapilvastu schools. Primary data would be collected through school survey and case studies while secondary data would be collected through various literatures. The comfort temperature of Kapilvastu has been calculated using the Nicol formla, the lowest temperature in which the people of Kapilvastu feel comfortable is 20.3°C, whereas the highest temperature in which the people of Kapilvastu feel comfortable is 28.6°. The findings based on calculations Material with lesser U-value can save 10-40% monthly cooling or heating load in summer than uninsulated buildings of Kapilvastu. To promote the thermal comfort in the school building, insulation and materials with a lower u-value are beneficial.

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Sita Bhusal(075/MSCCD/016)

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LIST OF ACRONYMS AND ABBREVIATIONS

ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
EEBDT	Energy Efficient Building Design Technology
NVSB	Naturally Ventilated School Building
TC	Thermal comfort
TS	Thermal sensation
CT	Comfort Temperature
PT	Preferred Temperature
PPD	Predicated Percentage of Dissatisfied
PMV	Predicated Mean Vote
U-Value	Thermal Transmittance
Ta	Air Temperature
Top	Operative Temperature T comfort temperature
TSV	Thermal Sensation Vote
ACS	Adaptive Comfort Standard
GHG	Greenhouse Gases
VOC	Volatile organic compou

CHAPTER 1: INTRODUCTION

1.1. Contextual background

Advancement in addressing climate factors in building help to decrease the consumption of energy of the building which help to improve thermal comfort of the users, the correlation of the local climate with the shape and the thermal performance of the building is the major considerations of the passive design approaches to reduce the energy use of the building and increase the thermal comfort of the users (Meir, 2009). However, improving indoor climate and reducing use of energy in buildings is one of the most important requirements. (Yu W. Zhao, 2020). Buildings sector only consume 40% of energy with comparison to different sectors While developed nations are expected to consume more energy than developing countries by 2020, it is expected that developing countries would consume more energy than developed countries. (Yu W. Zhao, 2020).

The students spend about their 30% of daily lives in school (De Giuli, 2012).Thermal comfort have been considered as important indicators for indoor quality defined by [Ansi/Ashrae] And defined as a mental state that expresses satisfaction with the thermal environment. Thermal comfort is affected by various parameters, such as heat, heat conduction, radiation, convection, and evaporative heat loss. The building design code promulgated by the Nepalese government does not solve the thermal comfort problem, so it is the main reason for the poor indoor thermal comfort. When we consider the possible connections between building performance, overall sustainability, and the benefits of production, health, and a comfortable environment, schools are one of the building types that inevitably arouse great interest (Haddad, 2012). The thermal conditions in the classroom must be carefully considered, mainly because the population density in the classroom is high, and thermal dissatisfaction will have a negative impact on students’ learning and performance (Fisk, 2000). Envelope of a building is separator from outdoor environment to the indoor environment but it acts as a prevention for climatic elements and protect the building directly (Givoni, 1976). Buildings interact with the environment through their facades (such as roofs, walls, openings, floors, and protrusions). These facades are called building envelopes. The enclosure acts as a thermal enclosure, which, if constructed carelessly, will cause energy to leak through each component. Therefore, each building component must be selected correctly to ensure building energy efficiency(Charde, 2014). Most developed countries are conducting study on the thermal comfort of school buildings and many other types of buildings. But in case of Nepal, study on thermal comfort in school building has not been studied. Few number of research has been conducted in a residential buildings (Rijal, et al., 2010); (Bajracharya, 2014).

In the context of Western and European countries to achieve interior thermal comfort, there are certain standards for the indoor environment. Nepal however, lacks such practice. Talking about the Nepal indoor climate adaptation can be obtained by bringing differentiation in daily activities, clothing's and food habits which makes people completely unaware of their building's poor thermal performance. Students spend long period of time in school buildings, and a good indoor environment with thermal comfort can help to uplift the conditions for students' performance. The link between indoor climatic conditions and performance of students has been demonstrated in general; however, little is known about the specific role of thermal comfort (Haddad, et al., 2012). Thoughtful school design and operation helps to improve health performance and thermal comfort of all the student. This can also most often be done without increasing greenhouse gas emissions by using appropriate green material. School provides shelter for the occupants with visual indoor comfort and appropriate indoor thermal comfort, it is the most useful function of school. Building design and combination of indoor and outdoor climatic condition varies the comfort level of the school building .If we are not responsible to design climate responsive building it will creates uncomfortable indoor environments and it will increase the requirement of maintaining thermal comfort with the use of artificial means.

Climate change may be caused by both anthropogenic and natural forcing, but at present time unsustainable way of construction activities and large amount of greenhouse gass (GHGs) emissions are main reason of erratic climate change. More than 1.6 degrees Fahrenheit has been added to the global average temperature i.e (0.9 degrees Celsius).while, the temperature of Nepal is warming at the rate faster than that of the global average. Rising global temperatures give rise to significant impacts on climate and weather. (Karki, et al., 2009). Now days diffrent places have been suffering from changes in rainfall pattern, which result extreme droughts, floods, or intense rain, similarly some place are suffering from severe and more more frequent more frequent heat waves. (Chaulagain, et al., 2019)

Nepal is a South Asian landlocked country sandwiched between India and China, with 28°N latitude and 84°E longitude. Affected by uneven terrain, regional weather systems and geographical conditions, it has an extremely diverse and complex climate. In the

Terai (southern Nepal), summer temperature exceed 40degree Celsius and above 45 degree Celsius in some areas, while winter temperature ranges from 7-23 degree Celsius. This paper outlined a number of field experiments and simulation assessments carried out in Terai to enhance the heat sustainability of school buildings. Adapting to climate change and changing weather patterns can increase the resilience of buildings, thereby increasing the resilience of cities and villages. The thermal conditions in the classroom must be carefully considered, mainly because the population density in the classroom is high, and thermal dissatisfaction will have a negative impact on students' learning and performance (Fisk, 2000).

1.2. Problem statement

Nepal's temperature is rising faster than the global average. The architectural design of the school prioritizes thermal comfort. The purpose is to create an adaptive indoor climate that is acceptable to residents and helps improve health and is satisfied with the improved climatic factors. A research on climate proof school building is very necessary in case of hot humid Terai reason of Nepal cause classrooms are extremely cold in winter and extremely hot in the summer season leading to discomfort in indoor environment. Most of the existing schools in Nepal did not consider the thermal comfort of the indoor and outdoor and the adaptation of the buildings to the local climate during the construction. Therefore, it is essential to ensure the quality of construction and the thermal comfort of users.

1.3. Objectives of research Study

Main Objectives

- Main objectives of the study is to increase thermal condition of the school building by upgrading thermal comfort in the indoor area.

Specific objectives of the research

- To report the thermal environment of the Kapilvastu school classroom.
- To find out comfort temperature of the study area.
- To differentiate effect of envelope in the uninsulated school building with thermally insulated building material.

1.4. Need of research

Taking Nepal as an example, most of the existing schools did not consider the thermal comfort of the residents and the adaptation of the buildings to the local climate. Therefore, it is necessary to provide the residents with thermal comfort and maintain the building quality of buildings. Because students are highly sensitive to temperature, an indoor thermal so survey of school buildings is essential. Study of thermal comfort in Terai region Nepal is very necessary in case of school building of Terai region (Meir, 2009). However, in the hot and humid monsoon season, it is recommended to use lightweight construction materials with a lower U value. Light weight and well insulated roofs are recommendable for this climate (Bodach, 2016). In Kapilvastu district 135,427 students are studying in 431 different community schools and different educational institutions according to kathmandupost. Many researches has been done on the office buildings, residential, and other commercial building has been done but almost nothing has been done yet in the school buildings (Rijal, 2010).

1.5. Importance of Research

The temperature of Nepal is warming at the rate faster than that of the global average. Thermally uncomfortable environment in classroom cause negative impact on students' academic performance. The focus of this research is to evaluate and compare the effect of a non-insulated prototype school in Kapilvastu district with the insulated school. No any research related to thermal comfort has been conducted yet in the school building and other types of building in Kapilvastu district. This study will help to report the thermal environmental conditions of classrooms in the schools of Kapilvastu. This study will be very useful for designers and policymakers to make design guideline of kapilvastu area and will help for designing sustainable school building with low energy consumption. This research will help to understand the thermal environment of Kapilvastu school classrooms.

1.6. Limitation of the study

Due to the limitation of time of three month, the study will be focus only thermal comfort in the indoor area of school building of Terai region to increase the learning performance of the students by improving climate factors in the school building with the use of appropriate passive design strategies. As well as, the research would only include school building no other types of building. Due to Covid 19 Pandemic, no questionnaire survey was collected to determine the perception of the students from 7-point ASHRAE scale, only field measurement and temperature data were collected.

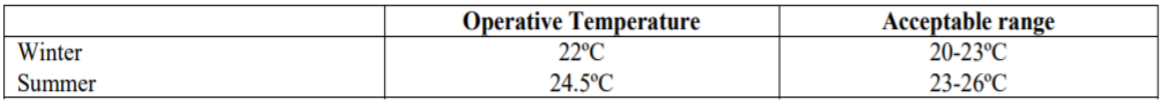
CHAPTER 2: LITERATURE REVIEW

The the first phase of the investigation is a literature review. The goal of the literature review is to map Nepal's various climate zones. It will explore common environmentally friendly building materials and information about Terai buildings in Nepal, as well as climate-friendly building design strategies and passive energy-saving building technologies. These data and techniques will be used later in the indoor climate simulation. ASHRAE Standard 552004 suggest temperature range of 20°C to 24°C in winter, 24°C to 26°C in summer, and a relative humidity of 50% of indoor air as a thermal comfort zone for people (Chaulagain, et al., 2019).

2.1. Historical Background

In 1967, Fanger invented physiological mechanisms of the human body, and it is near to neutral to establish the real equation for comfort. According to his analysis as a research on the origin of thermal Comfort 562 function of exercise level, the only physiological systems impacting heat balance were perspiration rate and mean skin temperature. (Charles, 2003). Then after he manipulated data after the study by (McNall, et al., 1967) form a study to derive a linear link between mean skin temperature and activity level in order to form a linear relationship between activity levels and sweat rate. In the thermal balance equation, Two linear connections are employed in to build a comfort equation that describes all possible combinations of six PMV input variables to obtain a neutral thermal sensation. It was compared and validated against studies once it was obtained. (Nevins, et al., 2002) and (McNall, et al., 1967) , The participants were asked to score their thermal sensations in response to different temperatures. The last equation defines thermal comfort as the disparity between the heat flow required for optimal comfort during a specific activity and the body's actual heat flow in a given thermal environment. Last, the equation generated a correlation index to forecast the proportion of discontent based on the seven-point ASHARE thermal sensation scale, which is known as the PMV index (Fanger, 1973). (PPD).The final parameter is derived from PMV and forecasts the percentage of persons who are unhappy with the current heat conditions. The PMV model is used in the thermal comfort model to establish acceptable thermal comfort.

Table 1 ASHRAE Standard recommendations.



	Operative Temperature	**Acceptable range**
Winter	22^{o}C	20-23^{o}C
Summer	24.5^{o}C	23-26^{o}C

The allowable humidity is 50%, the average relative velocity is less than 0.15 m/s, the average radiation temperature is equal to the air temperature, and the metabolic rate is 1.2 m/s, according to ASHARE. Clothing has a thermal insulation rating of 0.9 clo in the winter and 0.5 clo in the summer.

2.2. Public buildings

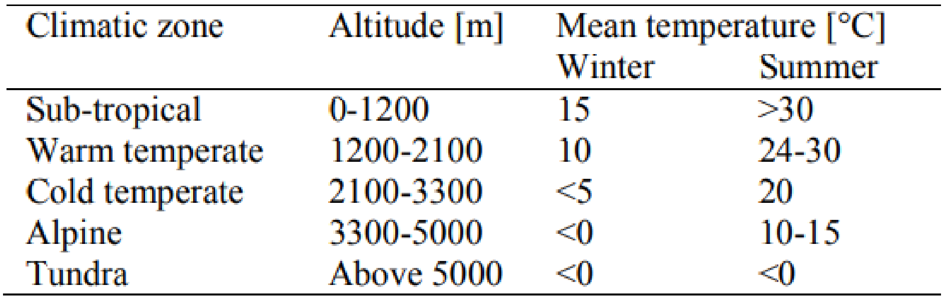
Public buildings are those buildings which are accessible to the public and they are funded from the public sources. The list of public buildings includes libraries, public schools, courthouses and post offices. Public building means a type of building for the use of general public and it includes college, theatre, school, public concert room, hospital , restaurant, public lecture room, marriage palace, for any other public function, such as a public exhibition hall or a public place of assembly or entertainment for people. According to the National Building Code, NBC 206 defines "a public building as any government, non-government or private building used to provide services, facilities, products, and opportunities to the public." (DUDBC, 2015)

2.3. Climate in Nepal

Due to the diverse terrain, Nepal has a large climate diversity (CBS 2014a). The tropical area in the south of the country is called Terai, and it has a warm and humid subtropical climate. The climate in the central plateau region is mild, except for cold winter nights, and generally the temperature is pleasant. The climate in the north's higher mountain ranges ranges from alpine to arctic tundra, with very cold mean temperatures. In Nepal, the seasons are classified into two or four categories. Winter and summer are the two main seasons, according to Shrestha 2007, with a rainy and dry period throughout summer. Summer is from April to September, and winter is from October to March. Spring is from March to May, summer is from June to August, fall is from September to November, and winter is from December to February, according to some sources (CBS 2014a). Spring is a gloomy season with periodic rainfall, with temperatures gradually rising until the monsoon arrives. The monsoon, which washes up from India throughout the summer, dumps the majority of its precipitation in the Terai region, which is located in the middle of the country. The mid-land regions and higher altitudes see decreased temperatures in the winter, although the subtropical parts remain warm all year.

Nepal has a a diverse set of climates, ranging from hot sub-tropical to frigid tundra. The climate of the country is influenced by a number of geographical elements, including latitude, prevailing as well as local winds, height, slope orientation, sun radiation, and vegetation. (Bodach, 2014). In the Terai (southern Nepal), summer temperature exceed 40degree Celsius and above 45 degree Celsius in some areas, while winter temperature ranges from 7-23 degree Celsius. Terai is located in a lowland area in north India and southern Nepal. This lowland is characterized by high grasslands, forests, shrub, and clay-rich swamps.

Table 2 Climatic zones in Nepal (Borgkvist, 2017



Climatic zone	Altitude [m]	Mean temperature [°C]	
		Winter	Summer
Sub-tropical	0-1200	15	>30
Warm temperate	1200-2100	10	24-30
Cold temperate	2100-3300	<5	20
Alpine	3300-5000	<0	10-15
Tundra	Above 5000	<0	<0

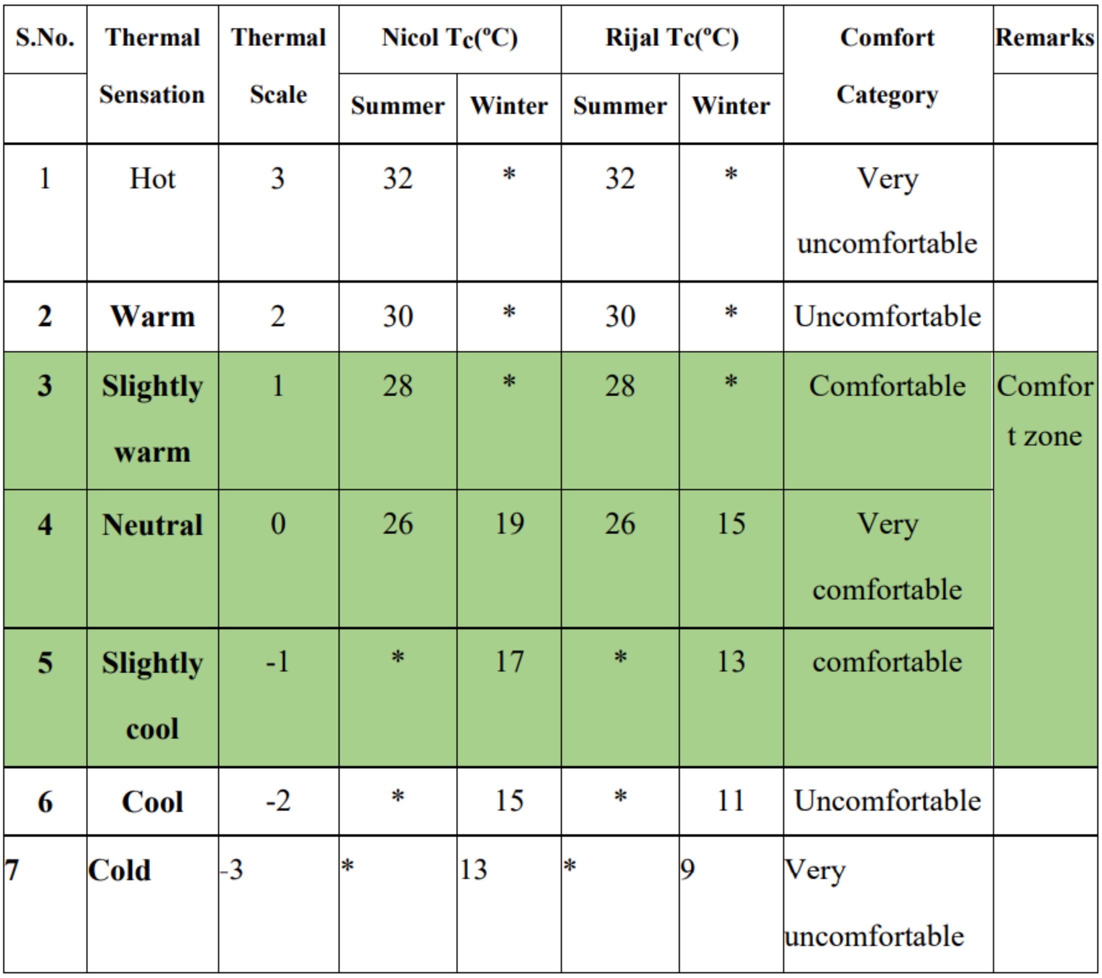
2.4. Thermal comfort

Thermal insulation is a mental state that conveys our body's contentment with the thermal environment, according to the ANSI/ASHRAE 55 Standard-2000R (2001).The main parameters for human thermal comfort are split into environmental variables such as mean radiant temperature, air temperature, mean radiant temperature, humidity, and air velocity, as well as personal variables such as clothing and metabolic rate (activity). Other environmental factors that might produce localized thermal discomfort include wind, large vertical temperature changes between the head and feet, radiant temperature asymmetry, and warm or cold floors.

2.5. Adaptive thermal comfort

The term "thermal comfort" refers to the feeling of being warm and comfortable. It's the subjective experience of being pleased with one's thermal surroundings; subjective evaluation is required" (ASHRAE 55, 2010). Because there are huge physical and psychological differences between people, it is difficult to please everyone in space. The 'adaptive comfort temperature,' according to Nicol, is the temperature that humans find comfortable in a given setting. The basic assumption of the adaptive method is expressed by the adaptive principle Adaptive thermal comfort in school buildings has been stressed in several studies around the country. These investigations developed their own comfort models and temperature preferences. Thermal comfort is an important aspect in representing human satisfaction. Everyone need varied ambient conditions in order to be comfortable. As a result, thermal insulation is determined by a variety of human and environmental factors, it is difficult to scientifically assess. The table below summarizes the results of thermal comfort tests undertaken in various places to assess the comfort of children in school buildings. The adaptive indoor temperature in Kathmandu considering the studies of Rijal and Nicol comfort temperature (Tc) is shown in table 3 (Bajracharya, 2014).

Table 3 Nichol and Rijal comfort model for indoor comfort temperaturer

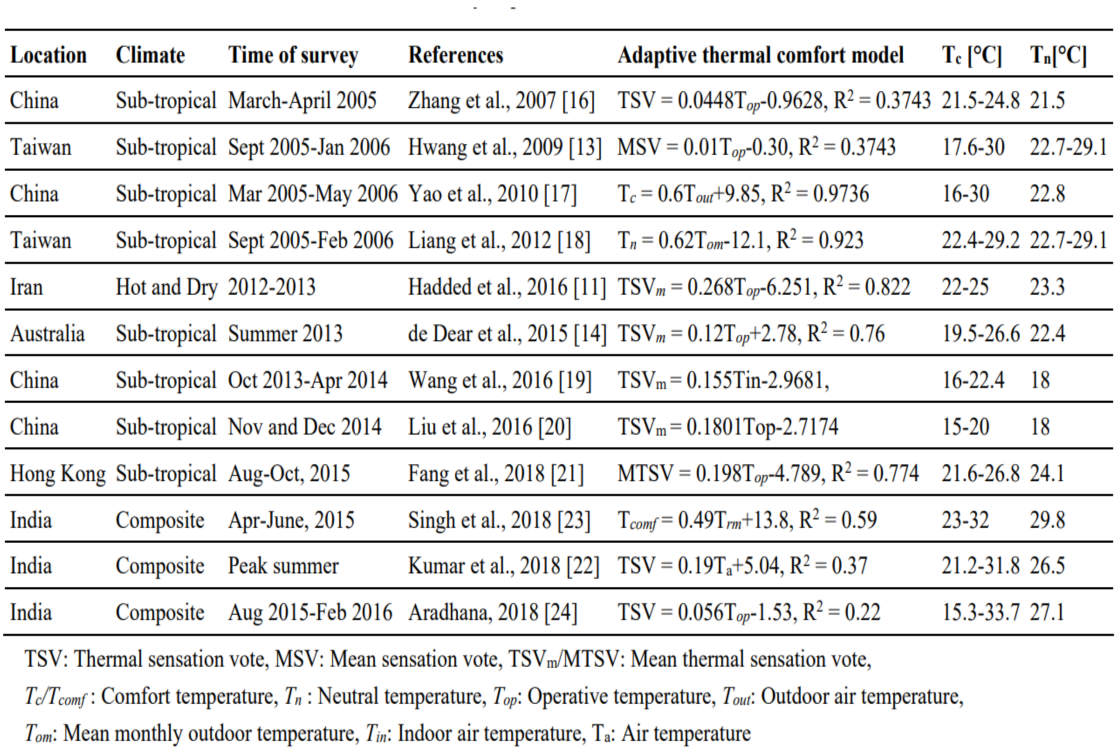


S.No.	**Thermal Sensation**	**Thermal Scale**	**Nicol Tc(°C)**		**Rijal Tc(°C)**		**Comfort Category**	**Remarks**
			Summer	**Winter**	**Summer**	**Winter**		
1	Hot	3	32	*	32	*	Very uncomfortable	
2	**Warm**	2	30	*	30	*	Uncomfortable	
3	**Slightly warm**	1	28	*	28	*	Comfortable	Comfort zone
4	**Neutral**	0	26	19	26	15	Very comfortable	
5	**Slightly cool**	-1	*	17	*	13	comfortable	
6	**Cool**	-2	*	15	*	11	Uncomfortable	
7	**Cold**	-3	*	13	*	9	Very uncomfortable	

2.5.1. Impact of Thermal comfort in human life

One of the most significant elements of thermal comfort is to consider when designing the interior temperature of a structure, as it has a considerable health and safety implications. Some studies have found that there is a close relationship between environmental temperature and the cause of specific diseases. The delayed effect of high temperature on the incidence is shorter than that of cold, and it is also affected by social demographic and environmental factors. Sufficient research indicates that mortality may be related to cold waves and heat waves (Ye et al., 2012). It has been found that heat exposure is associated with an increased risk of cardiovascular, cerebrovascular, stress, and respiratory death. In recent years, cold-induced cardiovascular morbidity has increased in both adolescents and the elderly.

Table 4 Summary of previous thermal comfort studies



Location	Climate	Time of survey	References	Adaptive thermal comfort model	T_c [°C]	T_n[°C]
China	Sub-tropical	March-April 2005	Zhang et al., 2007 [16]	$TSV = 0.0448T_{op}-0.9628, R^2 = 0.3743$	21.5-24.8	21.5
Taiwan	Sub-tropical	Sept 2005-Jan 2006	Hwang et al., 2009 [13]	$MSV = 0.01T_{op}-0.30, R^2 = 0.3743$	17.6-30	22.7-29.1
China	Sub-tropical	Mar 2005-May 2006	Yao et al., 2010 [17]	$T_c = 0.6T_{out}+9.85, R^2 = 0.9736$	16-30	22.8
Taiwan	Sub-tropical	Sept 2005-Feb 2006	Liang et al., 2012 [18]	$T_n = 0.62T_{om}-12.1, R^2 = 0.923$	22.4-29.2	22.7-29.1
Iran	Hot and Dry	2012-2013	Hadded et al., 2016 [11]	$TSV_m = 0.268T_{op}-6.251, R^2 = 0.822$	22-25	23.3
Australia	Sub-tropical	Summer 2013	de Dear et al., 2015 [14]	$TSV_m = 0.12T_{op}+2.78, R^2 = 0.76$	19.5-26.6	22.4
China	Sub-tropical	Oct 2013-Apr 2014	Wang et al., 2016 [19]	$TSV_m = 0.155Tin-2.9681,$	16-22.4	18
China	Sub-tropical	Nov and Dec 2014	Liu et al., 2016 [20]	$TSV_m = 0.1801Top-2.7174$	15-20	18
Hong Kong	Sub-tropical	Aug-Oct, 2015	Fang et al., 2018 [21]	$MTSV = 0.198T_{op}-4.789, R^2 = 0.774$	21.6-26.8	24.1
India	Composite	Apr-June, 2015	Singh et al., 2018 [23]	$T_{comf} = 0.49T_{rm}+13.8, R^2 = 0.59$	23-32	29.8
India	Composite	Peak summer	Kumar et al., 2018 [22]	$TSV = 0.19T_a+5.04, R^2 = 0.37$	21.2-31.8	26.5
India	Composite	Aug 2015-Feb 2016	Aradhana, 2018 [24]	$TSV = 0.056T_{op}-1.53, R^2 = 0.22$	15.3-33.7	27.1

TSV: Thermal sensation vote, MSV: Mean sensation vote, TSV_m/MTSV: Mean thermal sensation vote,
T_c/T_{comf} : Comfort temperature, T_n : Neutral temperature, T_{op}: Operative temperature, T_{out}: Outdoor air temperature,
T_{om}: Mean monthly outdoor temperature, T_{in}: Indoor air temperature, T_a: Air temperature

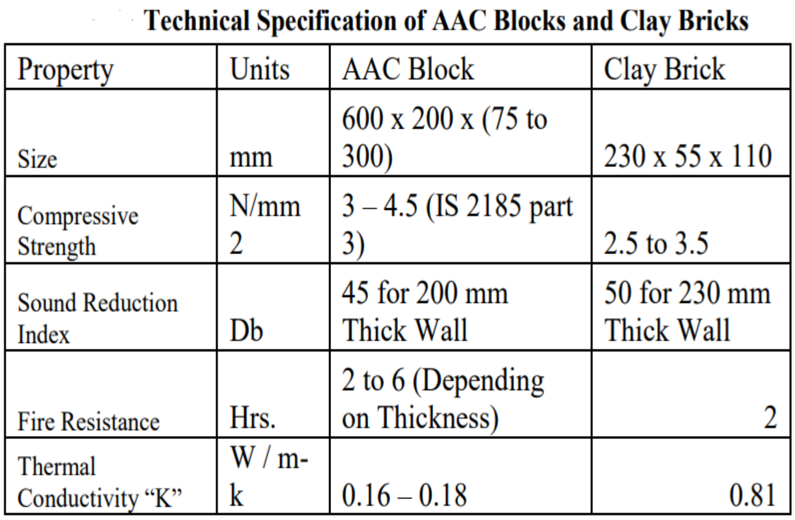
The purpose of the thermal envelope for thermal comfort.

The building envelope, Donald Watson believes so (1983), is a device that controls heat exchange between the interior and outside environments. It interacts with the external climatic environment to create a new microclimate zone within the building. Excluding heat intake thermal energy from external factors and rejecting it existent in the interior are the two basic control choices.

Thermal Effects of Building Materials

The building envelope serves as a barrier between the environment, both indoors and out, as well as preventing the elements from directly affecting the structure (Givoni, 1976). This shell can be made out of a variety of materials, including opaque, translucent, and transparent. He also pointed out that, on the one hand, heat can penetrate into buildings through transparent and translucent materials, and on the other hand, changes in other building materials can be used to influence through open windows.

Table 5 Technical specification of AAC Blocks and Clay.



Technical Specification of AAC Blocks and Clay Bricks

Property	Units	AAC Block	Clay Brick
Size	mm	600 x 200 x (75 to 300)	230 x 55 x 110
Compressive Strength	N/mm 2	3 – 4.5 (IS 2185 part 3)	2.5 to 3.5
Sound Reduction Index	Db	45 for 200 mm Thick Wall	50 for 230 mm Thick Wall
Fire Resistance	Hrs.	2 to 6 (Depending on Thickness)	2
Thermal Conductivity “K”	W / m-k	0.16 – 0.18	0.81

Earth: Earth is one of the most precious natural resources in the word which is one of the versatile and oldest material commonly used throughout the world as construction building material (Stulz & Mukerji, 1993). Earth is cheap, and It offers great heat insulation and compressive strength.

Timber: Timber is one of the oldest and most adaptable building materials. Timber is very useful material in terms of health aspects and indoor thermal comfort (Stulz & Mukerji, 1993). Timber is a complicated material that comes in a variety of species and may be used for a variety of purposes as a building material.

Fired Clay Products: The concept of burning clay dates back over 4000 years. High thermal capacity, fire resistance, high thermal capacity, compressive strengths that are high, porosity to allow the structure to breathe, weather resistance and cost savings, interoperability of broken and low-quality bricks are some of the benefits of these materials. (Stulz & Mukerji, 1993).

2.6. Thermal insulation

Insulating a structure is amongst the most efficient ways to preserve energy. Insulation necessitates forethought in order to keep a home warm in the winter and cool in the summer.

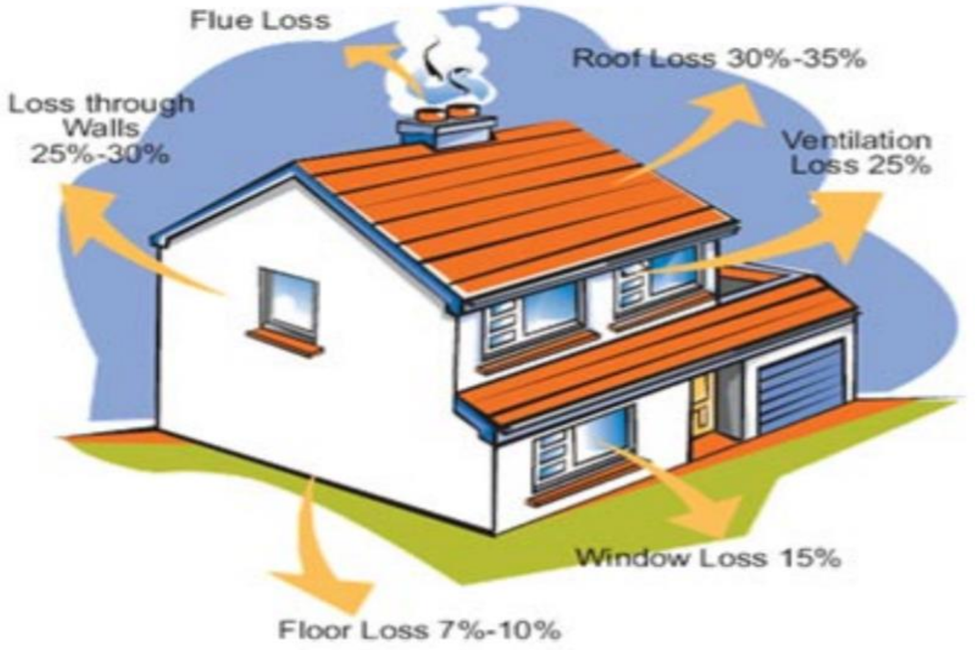


Figure 1 Contribution of buildings elements in heat transfer (Source: Salih, 2015-2016)

60% of the heat in a building is transferred through the ceilings and walls. About 15% of the heat is passed through the windows. About a quarter of the heat is transported through the building's vents and doors. (Salih, 2015-2016)

2.6.1. Types of insulating material

Fiberglass insulation materials

Fiberglass can be used as the most usable insulation material for the recent time. Therefore, glass fibers are made by weaving thin glass filaments into insulating materials; glass fibers can reduce the transfer of heat. Fiberglass is mainly a material that is used to make two types of insulation like loose fill and blankets, and it can also be found in the form of duct insulation and rigid boards. Manufacturers are now developing medium and high-density fiberglass webs with higher R-values than standard webs. Glass fiber is one of the non-flammable insulating materials. Fiberglass insulation has a R value ranging from 2.9 to 3.8 per inch. It is also a cost-effective sort of insulation, hence it is the preferred option.

Insulation material of mineral wool

Mineral wool is a term that refers to a variety of insulating materials. Recycled glass was used to create fibre glass. All forms of mineral wool have no additional fire resistance properties because they are a poor choice for applications where extreme high temperatures may exist. Mineral wool is a non-flammable substance. Mineral wool is a particularly effective material choice for large-area insulation when combined with other more fire-resistant insulating materials. Mineral wool has a R value ranging from 2.8 to 3.5 per inch.

Celluose insulation

Cellulose is a kind of most widely utilized environmentally acceptable insulating materials. Cellulose is a bulk substance manufactured from recycled paper, cardboard, and other similar materials. The R-value of cellulose varies from 3.1 to 3.7 per inch. Cellulose insulation products are a great way to keep your home safe from fire.

Insulation material with Plastic

Insulation material with Plastic are manufactured from recycled plastic bottles . The fibres are shaped into insulation batts that are similar to those made from high-density fiberglass. The insulation is coated with a fire retardant to keep it from catching fire, but it never melts when exposed to flames. Plastic fiber insulation's R value varies depending on the density of the batting, ranging from 3.8 per inch at 1.0 lb/ft3 to 4.3 per inch at 3.0 lb/ft3. When dealing with plastic fiber insulation, it does not tend to irritate the skin, although batts might be difficult for handeling and cutting with normal instruments.

Natural fiber insulation materials

Natural fiber insulation materials is one of the best insulating material, Borate is also used to treat sheep wool for insect, fire, and mound resistance. It can store a lot of water, which could be advantageous in some walls, but frequent soaking and drying can cause the material to lose its borate content. Sheep wool batts have an R-value of roughly 3.5 per inch, which is comparable to fibrous insulation. When it comes to absorbing and neutralizing dangerous elements, sheep wool is a sort of material. It's a found naturally protein produced up of 18 different types of amino acid chains, with 60% having a highly reactive side chain. Wool can absorb harmful and odorous chemicals thanks to these reaction zones.

2.6.2 **Properties of insulation materials**

Conduction

Conduction is the passage of heat from a hot to a cool surface across the thickness of a material's wall. The heat conductivity of different substances varies. Concrete and steel, in comparison to the insulating material cork, have a high conductivity. The amount of heat transferred through conduction is determined by the temperature differential between the wall's surfaces, wall thickness, the area of heat-exposed surfaces, the material's coefficient of thermal conductivity, and the time lag.

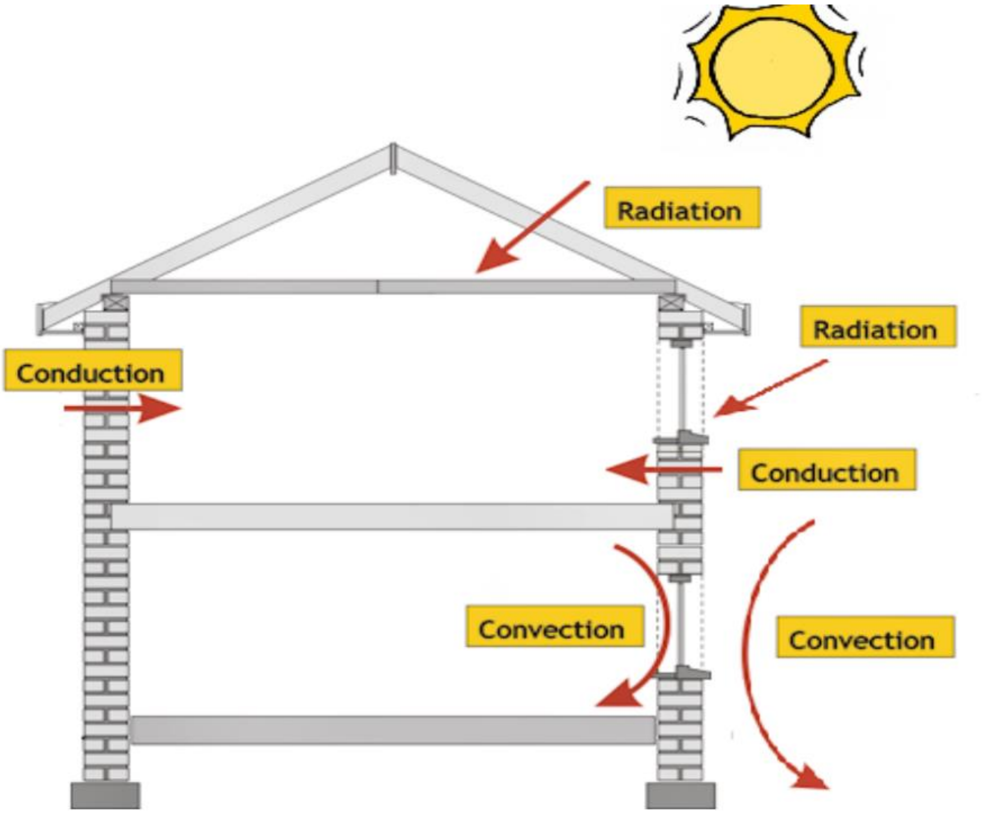


Figure 2 Modes of heat transfer (Source: Salih, 2015-2016)

The rate of heat conduction (Qcond) through any element such as roof, floor and wall as well as under steady-state can be written as:

$Q_{cond} = A \times U \times \Delta T$

Where, A - surface area [m2]

U - thermal transmittance [W/ m2 K]

ΔT - temperature difference between inside and outside air [K]

U= 1/RT Where RT is the total thermal resistance

Convection

Convection is a type of heat transfer caused by the ambient air near the surface, in which air molecules transmit thermal energy from a hot zone to a cold zone, and the air molecules have a low temperature and density. Convection is the term for this process. The rate of heat transfer is aided by air movement.

Radiation

It is the transfer of radiant heat that does not necessitate the use of a medium, such as the sun's heat to the earth. The radiant heat from the source is transported to the colder areas.

R-value

One of the most essential factors in assessing a building's energy efficiency is its thermal resistance (R-value). The thermal resistance of a single material layer is defined as the relationship between thickness and conductivity (d/) under steady-state circumstances. The overall sum of the R-values for each layer of the element, including the film resistance of the air layers adjacent to the element's surface, can be used to compute the total thermal resistance of a building element. For non-reflective materials, the outside film resistance ranges from 0.03 m2K/W to 0.04 m2K/W, depending on the wind, and the inner film resistance ranges from 0.11 m2K/W to 0.16

Thermal conductivity

The temperature that travels via conduction through a substance, which is the principal way that heat is transported through insulation, is characterized as thermal conductivity of a substance. The (lambda) value, or k value, is a measure of thermal conductivity; the lower the figure, the better the performance. This determined value represents a material's ability to conduct heat via its mass. The thermal conductivity values of various insulators and other materials can be employed to determine their insulating efficiency. The quantity of heat/energy that can be carried in unit time through a medium can be characterized as thermal conductivity.

U-value

The thermal transmittance (U-value) is commonly used to calculate heat flow. When the difference in air temperature on each side of the building is one Kelvin, the -value can be defined as the quantity of heat traveling through a unit area of the structure per time unit. The rate of heat transfer through a window due to conduction, convection, and radiation as a result of a temperature differential between the interior and outside is indicated by the U-value. In the winter, if the u-factor is large, more heat is lost through the window. To achieve great performance, the U coefficient of each aluminum frame single-glazed window varies from 1.3 to roughly 0.2. Under the same circumstances.

Table 6 Contrasting values of admittance and transmittance

Element	Y-value (W/m2 K)	U-value (W/m2 K)
A typical heavyweight wall (brick/blockwork with cavity insulation)	4.0	0.6
A typical heavyweight wall (brick/blockwork with cavity insulation)	1.0	0.6

As a result, a building element's heat flow (q) is:

$q = U \cdot (Ti - To)$ W/m2 (1)

The equation (Sandin 2011) is used to compute the heat transfer manually:

$Q = U \cdot A \cdot (T1 - T2\ )$ W/m2 (2)

Ashare standard

The ASHRAE Standard 55-2004 states that a temperature range of 20°C to 24°C in the winter and 24°C to 26°C in the summer, with an indoor air relative humidity of 50%, is thermally comfortable for humans. Relative humidity should not exceed 65 percent and should not go below 30 percent, according to ASHRAE (ASHRAE, Atlanta, 2004). The main goal of ASHARE standard is to define the combinations of thermal elements of environmental area of indoor and personal determinants which will result in thermal environmental thermal circumstances that are tolerable to the the vast majority of the occupants in various locations.

Tc = 0.31To + 17.8

2.7. Method for determining acceptable thermal comfort

2.7.1. Graphic Comfort Zone Method

This method is suitable for areas where the user's activity level results in a metabolic rate between 1.0-1.3m, and areas where clothing that can provide insulation between 0.5-1.0C.

2.7.2. The adaptive approach

Nicol and Humphreys created the adaptive comfort model approach. This thermal adaptive model is based on the ability of humans to adapt. The adaptive approach (ASHRAE, 2017) is also recognized as a PMV-PPD method under the ASHRAE-55 Standard. Unlike Fanger's concept, the adaptive approach model describes the comfort zone in terms of thermal experiences, garment changes, and activities. Thermal comfort will be affected by age, gender, and physical impairments in this model. There are three types of thermal adaptation. Psychologically, they are derived from the state of mind of prior experiences; physiologically, they are related to the body's reaction to temperature changes; and psychologically, they are formulated by the state of mind from previous experience.

Tcomf = 0.31 × Tout+17.8 (Desired room temperature is about 20˚ C, ±2 ˚ C, i.e. 18 ˚ C, to 22˚C)

Predicted Mean Vote (PMV)

While talking about the seven point thermal sensation scale , PMV is a measure that predicts the average sound of a group of inhabitants. Occupant’s internal heat production is the same as its heat loss when the thermal equilibrium is obtained. The thermal insulation, physical activity, and thermal environment parameters of clothing are all affected by personal thermal balance. For example, when the residents of the room control the indoor temperature, they usually feel warmer, which also helps to reduce the residents' high thermal expectations for the mechanical ventilation system. Six key factors for thermal are related using the predicted mean vote (PMV) model.

The following is the definition of the ASHRAE thermal sensation scale, which was created to quantify people's thermal feeling:

+3 hot +2

warm +1

slightly warm 0

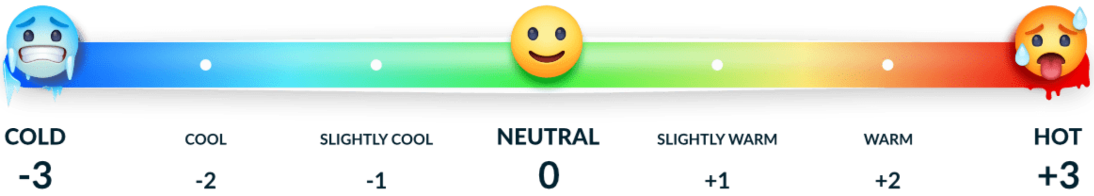
neutral –1

slightly cool –2

cool –3 cold

The predicted mean vote (PMV) model relates the six important thermal parameters using heat balance principles. When defining thermal comfort conditions, there are six primary aspects to consider. Comfort can be influenced by a variety of other things. The following are the six most important factors:

- Metabolic rate
- Radiant temperature
- Air speed
- Air temperature
- Clothing insulation



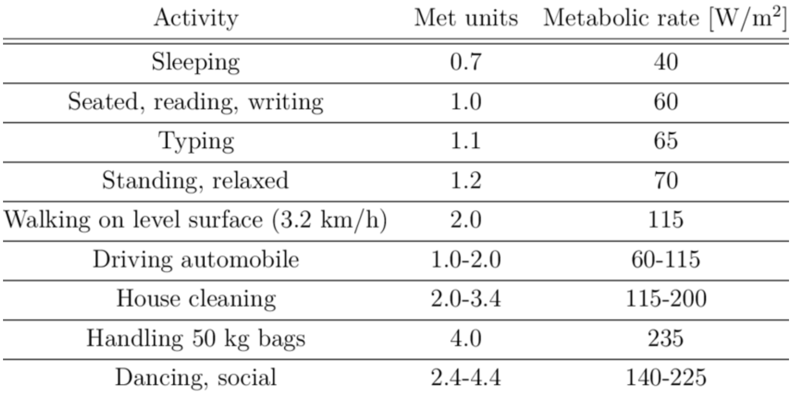
The PMV is linked to the PPD (predicted proportion of dissatisfied) indicator. It's based on the assumption that those who vote +2, +3, –2, or –3 on the thermal sensation scale are unhappy, as well as the assumption that PPD is symmetric around a neutral PMV.

Predicted Percentage Dissatisfied (PPD)

We can anticipate a population's thermal experience using PMV, but this isn't the complete picture. We also need to consider the satisfaction of the occupants in the room in order to have a more comprehensive understanding of whether and how to achieve thermal comfort. To this end, Fanger developed another equation that relates PMV to the predicted percentage of dissatisfaction (PPD). PDD essentially expresses the percentage of people who are predicted to have a localized disease. The PPD is the percentage of persons who are predicted to feel uneasy, or who rate.

Metabolic rate

Table 7 Metabolic rate



Activity	Met units	Metabolic rate [W/m^2]
Sleeping	0.7	40
Seated, reading, writing	1.0	60
Typing	1.1	65
Standing, relaxed	1.2	70
Walking on level surface (3.2 km/h)	2.0	115
Driving automobile	1.0-2.0	60-115
House cleaning	2.0-3.4	115-200
Handling 50 kg bags	4.0	235
Dancing, social	2.4-4.4	140-225

The number of calories required to keep your body operating at rest is known as your basal metabolic rate. BMR stands for body metabolic rate, and any increase in metabolic weight, such as exercise, will raise your BMR.

2.8. Estimation of comfort temperature

2.8.1. Comfort temperature from polynomial regression analysis

In all aspects, thermal sensation and interior globe temperature assist in determining the range of comfortable temperature levels. Students' responses can be classified into two kinds. Uncomfortable responses are characterized as very cold, cold, very cold, hot, and very hot. The remaining reactions (slightly cold, neutral, and slightly warm) are deemed "comfortable." The center zone (neutral, slightly chilly, and slightly hot) is considered comfortable by the ASHRAE -55 if 80 percent of responses lies in this range. For three districts, below is the quadratic regression equation for the proportion of pleasant and indoor globe temperature:

$$P_{comfortable} = -0.009T_g^2 + 0.521T_g - 6.436$$
$$\begin{pmatrix} \mathrm{N} = 2454, \mathrm{R}_2 = 0.02, \mathrm{S.E.}_1 = 0.001, \\ \mathrm{S.E.}_2 = 0.077, \mathrm{p} < 0.001 \end{pmatrix}$$

2.8.2. The comfort temperature equation by Nicol formula

Tcomf = 0.54 Tom + 12.9.......(i)

The equation shown above helps for the calculation of Adaptive thermal comfort from monthly mean max (Tmax), monthly mean outdoor temperature (Tom) and monthly comfort temperature of 12 months using Nichol adoptive thermal comfort model.

2.8.3. Griffiths method for Comfort temperature

The regression approach predicts a regression because of the adaptive behavior of pupils inside the classroom over time, the regression coefficient is low during regression analysis, resulting in a superfluous comfort temperature value. The Griffiths formula is used to compute the comfort temperatures.

$Tc = Tg + (4 - TSV/a)$

Where Tc is the comfort temperature in degrees Celsius, Tg is the indoor globe temperature in degrees Celsius, TSV is the thermal sensation vote, and an is the Griffiths constant.

2.9. Climate-responsive design strategies for Nepal

The temperature of Nepal's moderate temperate environment does not decrease much during the winter months. The combination of solar radiation and the building's thermal mass can keep the indoor temperature at a very pleasant level. The building should face south, with a long façade and medium openings, so that solar heat may be provided in the winter (when the sun is low) and overheating can be reduced in the summer.The shading of windows is very important in summer (Bodach, 2014). The opening should be medium in size (20-40% of the external wall surface) and shaded in the summer to protect it from direct sunlight. Thermal comfort could be achieved by combining high thermal mass with ventilation, especially during the hot and dry summer months. During the hot and humid monsoon season, however, light building materials are preferred. For this environment, light, well-insulated roofs are recommended. (Bodach, 2014)

2.10. Ecotect simulation

Autodesk Ecotect is a popular and extensively used tool for predicting building energy performance. Autodesk Ecotect Assessment is an environmental device that allows designers and developers to model performance of the building right from the start. The study's conclusions are exhibited alongside the architectural model, and it blends analysis functions with integrated platform. Thermal simulation analysis will be performed in school classrooms using the Ecotect program to evaluate and enhance the interior thermal performance of schools based on passive design principles and learning satisfaction with thermal comfort. To assess this information and the level of thermal comfort Ecotect is used as an environmental design tool.

Key Autodesk Ecotect analysis features

- Solar Analysis
- Sun and Shadow Studies
- Day lighting and Lighting
- Thermal performance
- Whole building energy analysis
- Weather data visualization

2.11. Previous studies related to thermal comfort in school

Shrestha(2019), performed study on adaptive thermal comfort in naturally ventilated Secondary School Buildings. (Shrestha, et al., 2019). The pupils' perceptions of indoor thermal in naturally ventilated schools were calculated during the autumn season of 2017 in several climatic regions (Nuwakot, Dhading and Kathmandu districts) of Nepal. The findings of the study raise awareness among school building teachers, designers, and students about the importance of employing mechanical systems to ensure thermal comfort in school buildings.

Manandhar(2015), conducted a study on passive cooling techniques for buildings in Nepal's hot, humid climate (Manandhar & Yoon, 2015). The study mainly focus on cooling strategies in the building. Simple passive design techniques can assist lower the building's cooling load, resulting in a 20% reduction in energy consumption, but thermal conductivity has a 10 times greater impact on energy consumption than other building design strategies.

Gurung(2003), performed thermal performance of Tharu house and its improvement techniques - A case of Dang-Deukhuri (Gurung, 2003). The research has been carried out on the basis of literature on Tharu house and their settlement pattern of Dang-Deukhuri district, adaptive thermal comfort, thermal performance and their improvement techniques. From the Nicol adaptive thermal comfort model the winter and summer comfort temperature of Dang was calculated, and it has been also compared with the temperature of investigated Tharu house of that area. From the finding based on calculations the investigated traditional Tharu house maintain 3.5°C less temperature other investigated houses in summer and 2.13 °C more temperature in winter .

Hamzah(2018), performed Analyses of Secondary School Students' Thermal Comfort in the Tropics (Hamzah, et al., 2018). The experiment was performed using data collected from eight different high schools. In 48 classrooms 1594 no of students were involved for the research. The calculation has been carried out with the use of several instruments. From the study we came to know that in the tropical Indonesian city, the secondary school students are able to acclimatize themselves with respect to thermal environments, they are beyond the comfort zone defined by the national and international standards.

Rijal (2015),who studied the impact of humidity on room temperatures in Japanese homes in the summer season, performed adaptive thermal comfort in Japanese homes. (Rijal, et al., 2015). The study examines the thermal performance of historic and modern residential buildings in the valley's traditional communities. The thermal environment of modern residential structures and various old buildings with various characteristics was studied using regression analysis. In comparison to the contemporary buildings in the research region, the thermal performance of historic residential buildings, adapted by changing thermal design for thermal comfort, is extremely good.

Ali (2019), performed the indoor thermal environment of various prototype school buildings in Jordan was evaluated (Ali & Al-Hashlamun, 2019). This research mainly focuses on evaluating and comparing the enclosure effect of non-insulated prototype public schools with the effect of insulated schools built before 2003. To assess the indoor temperature conditions of old and new school classrooms, two methodologies were used.

Zhang(2007), performed study in a subtropical climate, conducted a thermal comfort evaluation of naturally ventilated classrooms (Zhang, et al., 2007). From March 24 to April 23, 2005, the research was conducted at Hunan University in China. Thermal comfort of naturally ventilated school was calculated with ceiling fans. Each classroom was visited 2 to 3 times. A total of 4,444 were visited in 25 classrooms, and 1,273 students completed the questionnaire.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Study area and building

The Kapilvastu area is located at an altitude of 93 to 1,491 meters (305 to 4,892 feet) above sea level. This area is divided into two parts geographically one Terai plain and another hilly hills. Its climate is as hot as 41°C, with humid summers and cold and humid winters. The boundaries of Kapilvastu are defined by Rupandehi District inside the east, Dang Deukhuri District with in Rapti zone inside the northwest, Arghakhanchi District in the north, Balrampur district with in Awadh region of Uttar Pradesh, India in the west, and Siddharthnagar district in the Purvanchal region of Uttar Pradesh, India in the south.

Figure 3: Location of Kapilvastu on the map of Nepal (Department of hydrology and meterology GON,2020)

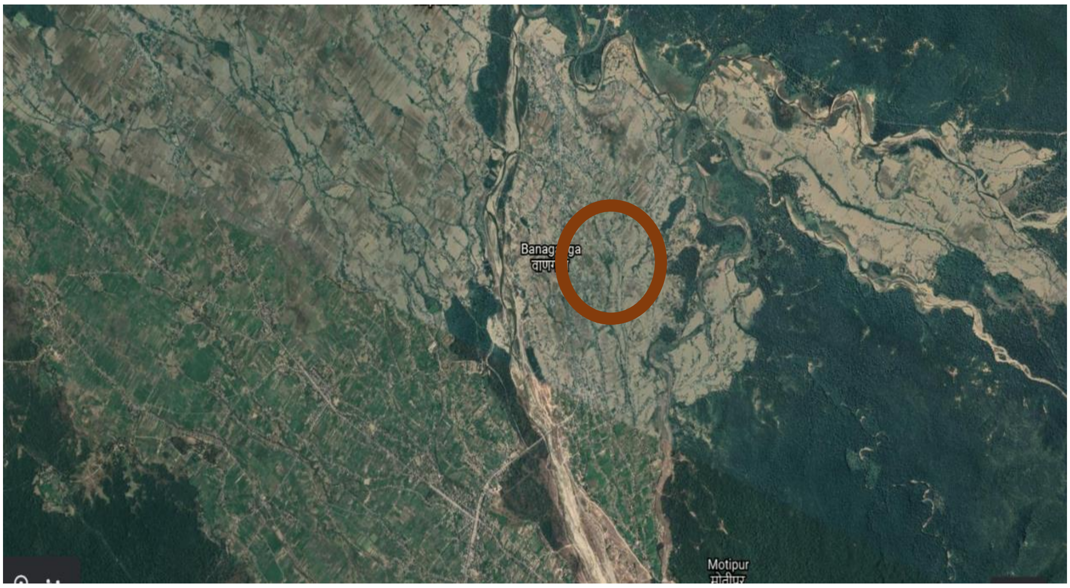


Figure 4: Boadgaun area Fig:https://earth.google.com

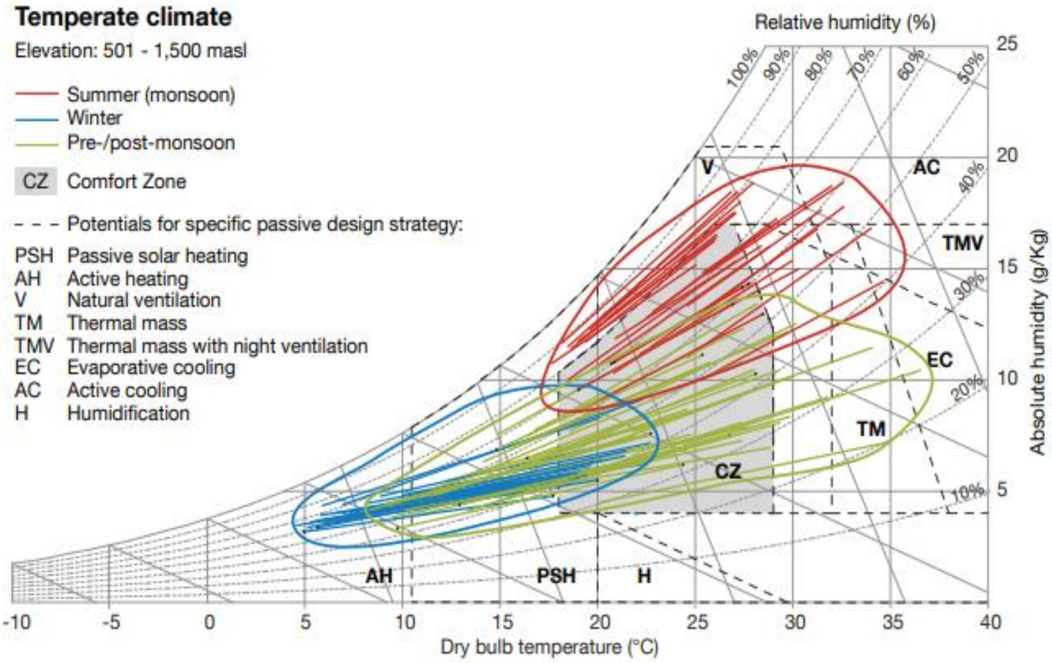


Figure 5 Bioclimatic Chart for temperate climatic zone

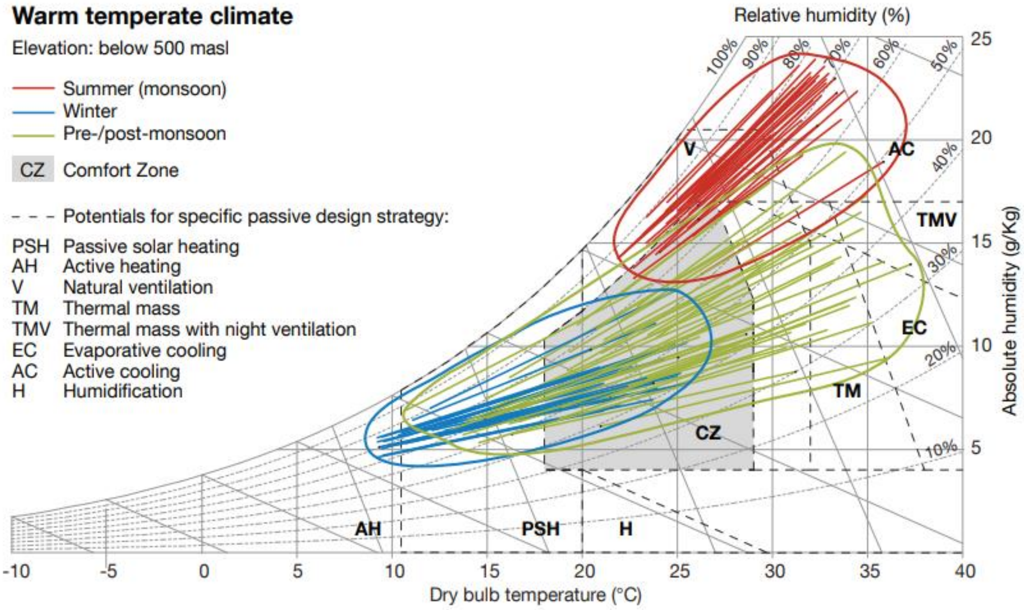


Figure 7 Bioclimatic Chart for temperate climatic zone

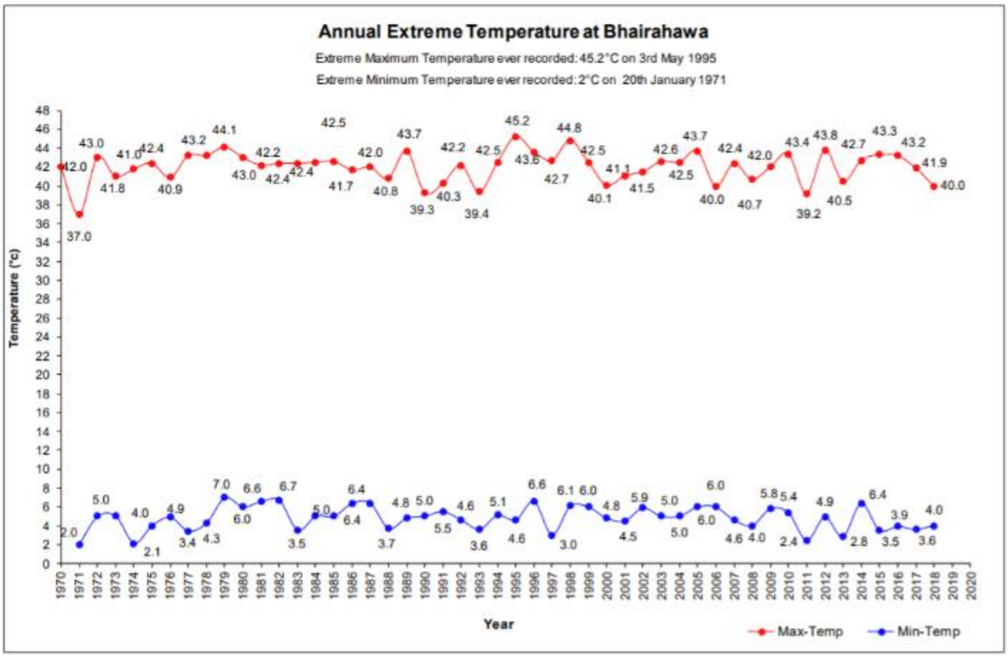


Figure 6 Annual extreme temperature at Bhairahawa(Department of hydrology and meterology)

Figure above shows the annual extreme temperature at Bhairahawa from the year 1970 to 2020.

3.2. Conceptual framework of study

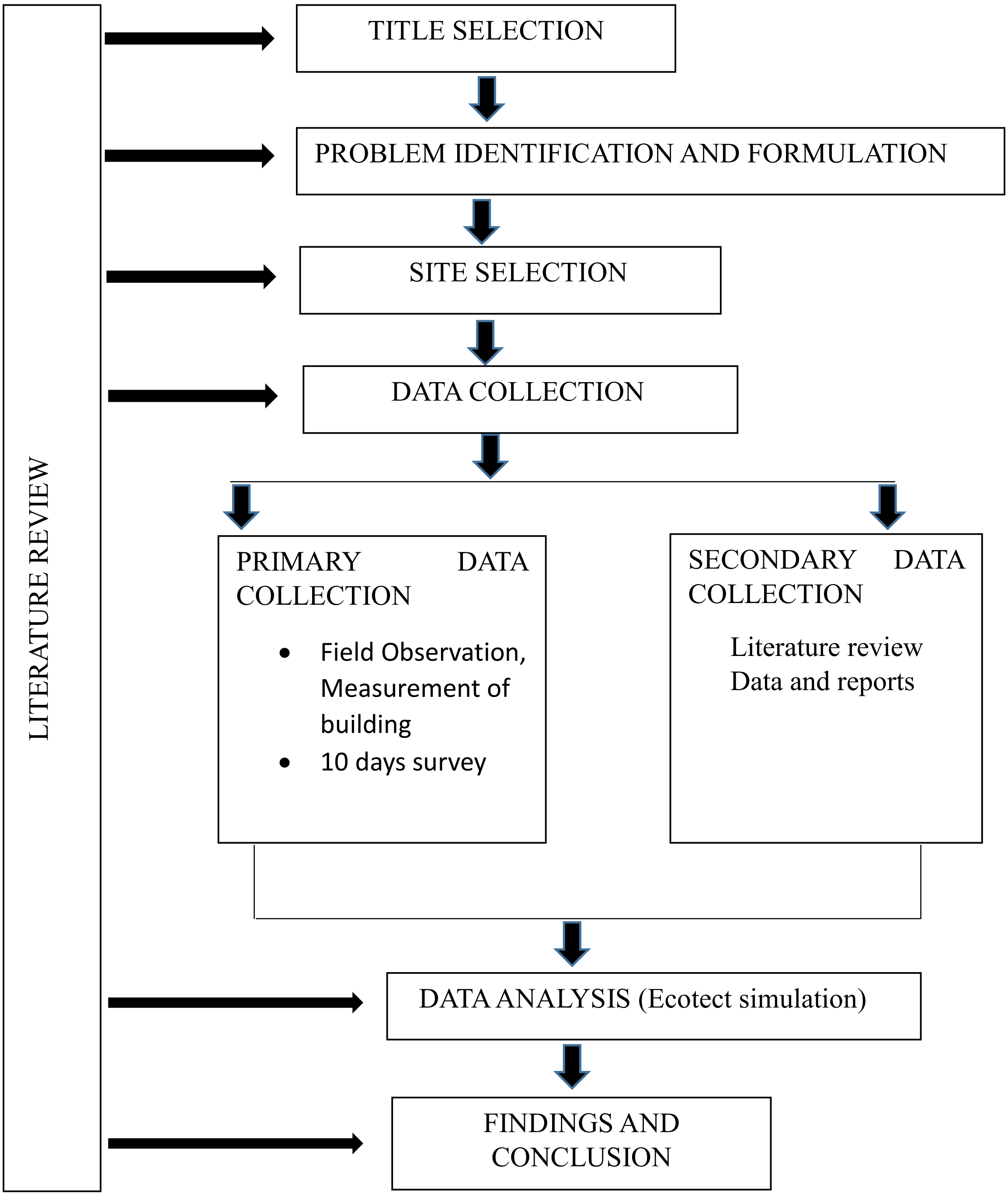


Figure 8 Conceptual framework of study

This study uses both quantitative and qualitative methods of data collection for the study. Field data and analysis are included in the evaluation of a building's thermal environment. Field study was done by monitoring thermal observation of different school building. The comfort temperature is estimated using the Nichol equation. Analysis of the data will be done using Autodesk Ecotect tool.

3.3. Data collection and data types

Primary data will be collected through school surveys and case studies, while secondary data will be collected through various literature.

3.4. Data analysis techniques

Autodesk Ecotect tools is used to analyze the data. Autodesk Ecotect software is used for building energy modeling. It includes a graphical application for creating and editing models, running simulations, and viewing results

3.5. Air temperature measurement and data presentation

For the measurement of ambient temperature the thermometer (Simple room thermometer HTC-1) were placed at 3 different school. The thermometer was put in the center of the room at the classroom desk to measure the indoor air temperature.

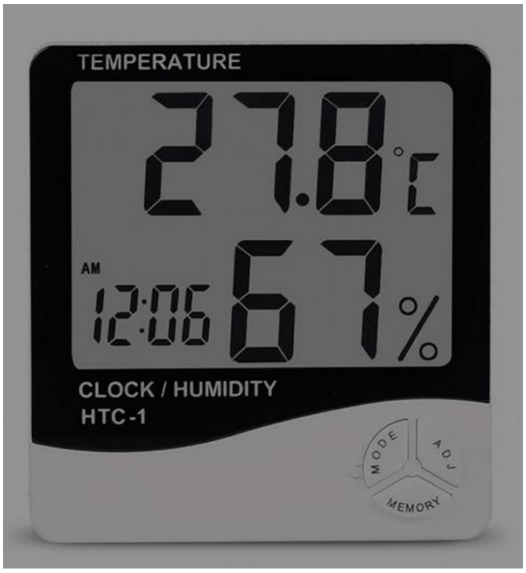


Figure 9 Room thermometer HTC-1

Figure 10 Photo of Class Room While measuring temperature

CHAPTER 4: CASESTUDY

4.1. Selection of schools to be studied

The study uses a survey-based method to describe and collect data on current school classrooms in school buildings around the Boadgaun area of Kapilvastu district. The research is carried out in three schools. The schools are Kapilvastu Vidhya Mandir secondary school (KVM), Udayapur School and Shainik shining English schoolWe measured three buildings in each area because to the homogeneity of the school building types in these regions and the limited availability of instruments. All of these school structures were constructed in the style of prior generations by local craftsmen utilizing locally available materials.

4.1.1. Case 1

Kapilvastu vidhya mandir secondary school (KVM)

Figure 11 Kapilvastu Vidhya mandir secondary school

Among three school buildings Kapilvastu Vidhya mandir is one which is chosen from Boadgaun area located in kapilvastu district as shown above. This two storey building has altogether 14 room. The school consists of 12 class room, one office room and one account room. The building is facing south direction. During the summer season from 5 to 15 july, 2021, mean indoor temperature is around 29.3 degree Celsius and daily maximum typically reaches to 32.7 degree Celsius. Brick and stone walls, as well as mortar plaster, are used to construct the structures. The structure of the building is built of reinforced concrete (RCC). The types of buildings and classrooms are depicted in the diagram below. The building is elongated towards south and west direction. There is large open ground in front of the building. Detail of the rooms are given below with the different dimension as measured in the fild. The building is surrounded with different types of trees. Because the buildings are not effectively insulated, students must accept a wide range of indoor thermal conditions. The building is two storey with 12 no of class rooms.

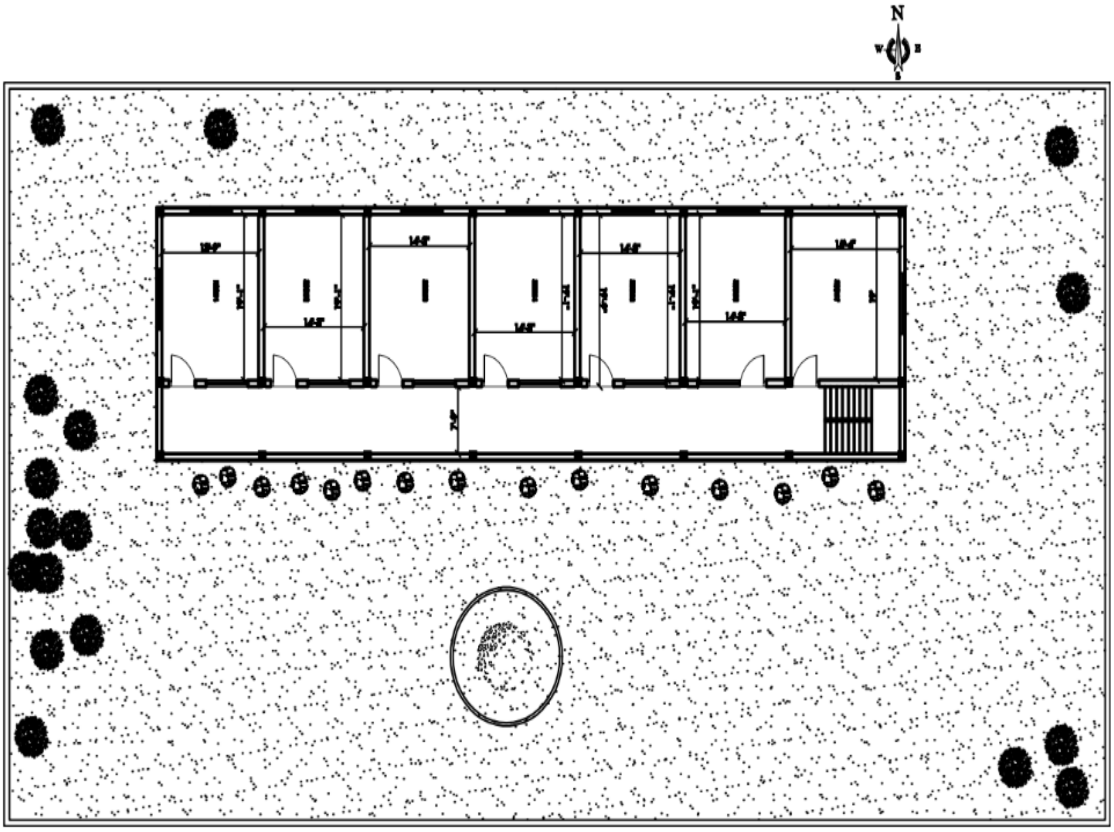


Figure 12 plan of school building

Detail of school building

Element	Description	Details
External walls	Total area: -3088 sq.ft Wall thickness: 9” Insulation: no	9"brick wall + 15 mm cement plaster
Roof	Total area:4004 sq.ft Insulation: no	125 mm reinforced concrete slab
Floor	Ground floor area: 3088 sq.ft Firstfloorarea:3088 sq.ft	Heavy concrete slab of 125mm
Windows	Total window area = 648 sq.ft No of Classroom windows=24 no	Single-glazed 6 mm windows + wooden frame
Room Height	10'	

Thermal comfort survey

Digital devices were used to measure physical factors relative humidity, temperature, globe temperature, air movement, surface temperature, and lighting level are all factors to consider.

Date	Time	Temperature(°C)	Average Temperature((°C)	Humidity	Average Humidity
2021,july5	12pm	29.5	29.16	85	78
	1 pm	29		76	
	2 pm	29		75	
2021,july6	12pm	29	28	89	84.4
	1 pm	28		86	

Date	Time	Temperature(°C)	Average Temperature((°C)	Humidity	Average Humidity
	2 pm	27		78	
2021,july7	12pm 1 pm 2 pm	26.3 (Rainiing) 27.5 27.7	27.16	99 99 91	94
2021,july8	12pm 1 pm 2 pm	24.1 (Rainiing) 25 25.7	25	93 93 89	91.6
2021,july9	12pm 1 pm 2 pm	27.5 28.1 28.9	28.2	84 80 79	81
2021,july10	12pm 1 pm 2 pm	26 28.5 29.9	28.2	93 82 68	84
702021,july11	12pm 1 pm 2 pm	27(Light Rainiing) 29.5 30.1	28.9	83 80 67	77
2021,july12	12pm 1 pm 2 pm	30 31.3 32.2	31.2	78 68 65	70
2021,july13	12pm 1 pm 2 pm	31 31.6 32.3	31.6	79 66 65	70

Date	Time	Temperature(°C)	Average Temperature((°C)	Humidity	Average Humidity
2021,july14	12pm 1 pm 2 pm	31.2 31.8 32.5	31.9	80 65 62	69
2021,july15	12pm 1 pm 2 pm	31.3 31.9 32.7	32	80 66 65	70
			Mean =29.3	Mean =79	

4.1.2. Case 2

Udayapur school

Figure 13: Udayapur school

Udayapur school is located in the kapilvastu district. It is primary school. The school building has two blocks. This one storey building has altogether 8 room . The school consists of 6 class room, one teacher's room and one administrative room. Brick and stone walls, as well as mortar plaster, are used to construct the structures. Tr the time of summer season from 5to 15 july,2021, mean indoor temperature is around 29.3 degree Celsius and daily maximum typically reaches to 32 degeree Celsius. Brick and mortar plaster are used to construct the structures. The building's roof structure is represented by a CGI sheet. Figure 14 depicts the general types of structures and classrooms. Because the buildings are not effectively insulated, students must accept a wide range of indoor thermal conditions.

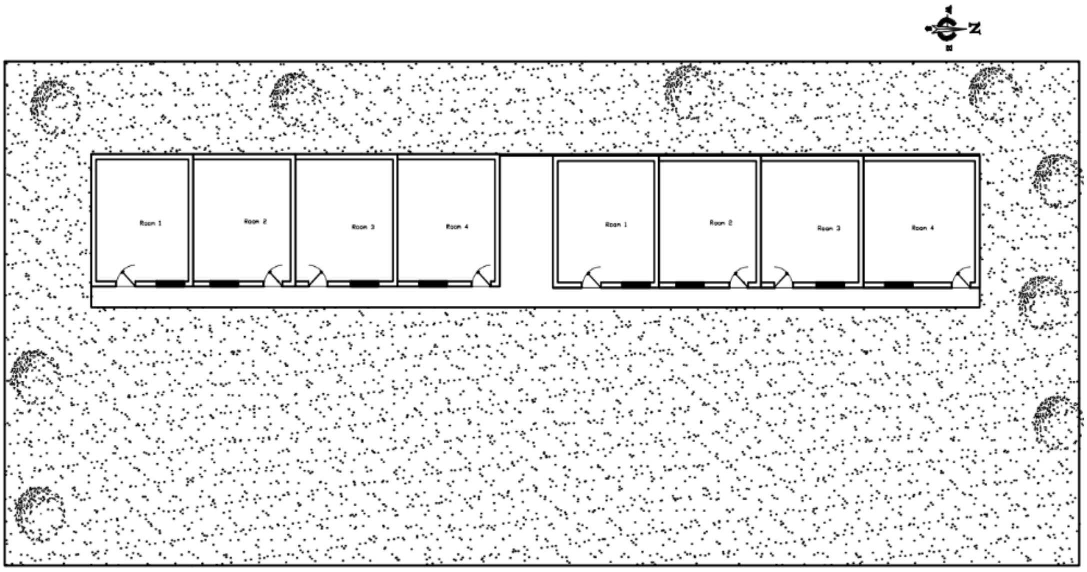


Figure 14 Plan of school building

Detail of school building

Element	Description	Details
External walls	Total area: -3055 sq.ft Wall thickness: 4” Insulation: no	4"brick wall + 15 mm cement plaster

Element	Description	Details
Roof	Total area3187 sq.ft tiles Insulation: no	CGI roof 1 mm Roof thickness
Floor	Ground floor area: 3055 sq.ft	M15 Concerete for DPC of 100mm thick
Windows	Total window area = 240sq.ft No of Classroom windows=12 no	Wooden windows + wooden frame
Room Height	10'	

Thermal comfort survey

Digital devices were used to measure physical factors relative humidity, temperature, globe temperature, air movement, surface temperature, and lighting level are all factors to consider.

Date	Time	Temperature(°C)	Average Temperature(°C)	Humidity	Average Humidity
2021,july5	12.15pm	30	29.5	85	78
	1.15pm	29		76	
	2.15 pm	29.5		75	
2021,july6	12.15pm	28.8	28.8	80	79
	1.15pm	29		86	
	2.15 pm	28.6		73	
2021,july7	12.15pm	27.3 (Rainiing)	27.6	98	94
	1.15pm	28		94	
	2.15 pm	27.5		91	

Date	Time	Temperature(°C)	Average Temperature(°C)	Humidity	Average Humidity
2021,july8	12.15pm 1.15pm 2.15 pm	24.1 (Rainiing) 25.5 25.8	25.13	94 93 90	93
2021,july9	12.15pm 1.15pm 2.15 pm	32 32.5 33	32.5	83 79 65	75
2021,july10	12.15pm 1.15pm 2.15 pm	26 28.7 30	28.2	88 74 68	76
2021,july11	12.15pm 1.15pm 2.15 pm	27.6(Light Rainiing) 29.8 31.5	29.7	83 80 67	76
2021,july12	12.15pm 1.15pm 2.15 pm	30.3 32 33.1	31.8	76 69 68	71
2021,july13	12.15pm 1.15pm 2.15 pm	31.5 32.3 33	32.2	78 64 63	68
2021,july14	12.15pm 1.15pm 2.15 pm	31.8 32.8 33.2	32.6	77 66 64	68
2021,july15	12.15pm 1.15pm	31.9 32.8	32.7	78 67	70

Date	Time	Temperature(°C)	Average Temperature(°C)	Humidity	Average Humidity
	2.15 pm	33.1		66	
			Mean 30.1	Mean 77.6	

4.1.3. Case 3

Shainik shining English school

Figure 15 photo of school 3

Among three school buildings Shainik shining English school is one which is chosen from Boadgaun area located in kapilvastu district as shown above. Shainik shining

English school is located in the kapilvastu district. This one storey building has altogether 9 room . The school consists of 7 class room, one office room and one account room. The building is facing east direction.

During the summer season from 5to 15 july, 2021, mean indoor temperature is around 29.6 degree Celsius and daily maximum typically reaches to32 degree Celsius according to data survey. Brick and stone walls, as well as mortar plaster, are used to construct the structures. The building's construction is made of reinforced concrete (RCC). Figure 9 depicts the general types of buildings and classrooms. Because the buildings are not effectively insulated, students must accept a wide range of indoor thermal conditions. The structure is two stories tall and has a total of 12 classrooms.

Detail of school building

Element	Description	Details
External walls	Total area: -3132 sq.ft Wall thickness: 9” Insulation: no	9"brick wall + 15 mm cement plaster
Roof	Total area3150 sq.ft tiles Insulation: no	125 mm reinforced concrete slab
Floor	Ground floor area: 3132 sq.ft	Concerete slab of 125mm
Windows	Total window area = 360sq.ft No of Classroom windows=18 no	Wooden windows + wooden frame
Room Height	10'	

Thermal comfort survey

Digital devices were used to measure physical factors relative humidity, temperature, globe temperature, air movement, surface temperature, and lighting level are all factors to consider.

Date	Time	Temperature(°C)	Average Temperature(°C)	Humidity	Average Humidity
2021,july5	12.30pm 1.30pm 2.30 pm	29.9 28.5 30	29.4	85 76 75	78
2021,july6	12.30pm 1.30pm 2.30 pm	26.8 28.6 28.9	28.1	80 85 73	79
2021,july7	12.30pm 1.30pm 2.30 pm	26.3 (Rainiing) 27 27.5	27	97 93 90	93
2021,july8	12.30pm 1.30pm 2.30 pm	24.1 (Rainiing) 24.5 25.6	24.8	95 92 88	81
2021,july9	12.30pm 1.30pm 2.30 pm	28 30.5 32	30.2	83 78 63	74
2021,july10	12.30pm 1.30pm 2.30 pm	25.8 28.6 30	28.2	88 75 67	76

Date	Time	Temperature(°C)	Average Temperature(°C)	Humidity	Average Humidity
2021,july11	12.30pm 1.30pm 2.30 pm	27.6(Light Rainiing) 29.8 31.5	30	83 80 67	76
2021,july12	12.30pm 1.30pm 2.30 pm	30.6 32 32.8	31.8	77 66 63	69
2021,july13	12.30pm 1.30pm 2.30 pm	31.0 32.0 32.5	31.9	79 64 64	69
2021,july14	12.30pm 1.30pm 2.30 pm	31.4 32.8 32.9	32.4	78 65 63	69
2021,july15	12.30pm 1.30pm 2.30 pm	31.4 32.6 33	32.4	79 68 66	71
			Mean 29.6	Mean 78	

CHAPTER 5: ANALYSIS, DISCUSSION AND RESULT

5.1. Air temperature measurement and data presentation

According to ASHARE standard 55-2004 suggests a thermally acceptable range for humans of 20°C to 24°C in the winter and 24°C to 26°C in the summer, with an indoor air relative humidity of 50%. Relative humidity should not exceed 65 percent and should not go below 30 percent, according to ASHRAE (Olesen,et al., 2006).

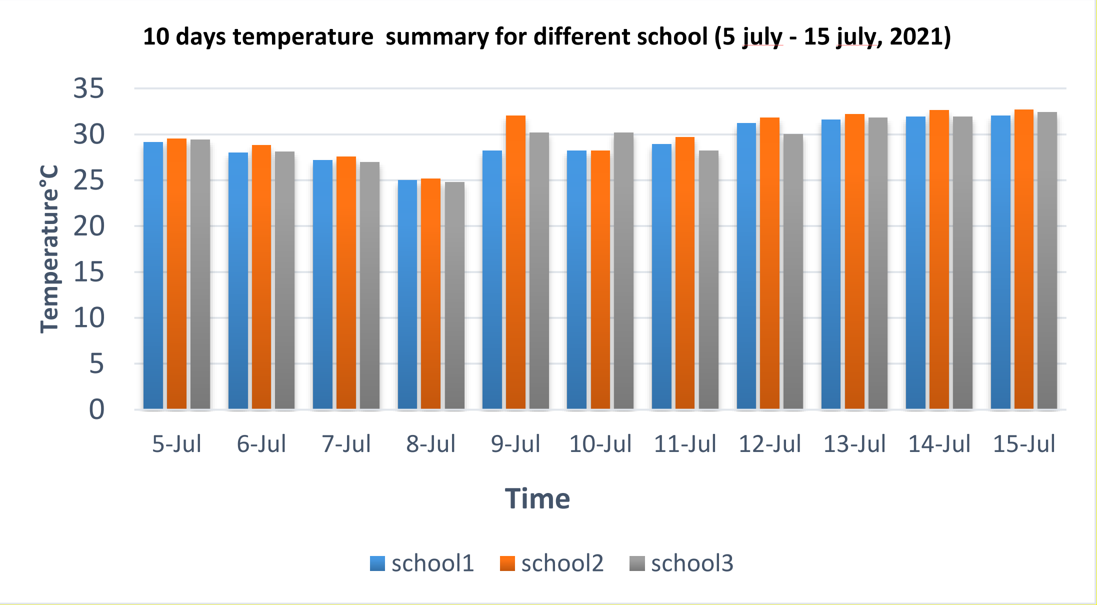


Figure 16 10 days temperature summary for diffrent school

The average indoor temperature is monitored in different schools, during the peak hour from(12pm-2am).The maximum average temperature recorded in the Kapilvastu vidhya mandir secondary school (KVM) was 32c, in the Udayapur school was 32.7 °C, and in Shainik shining English school was 32.4°C. Here we can see the maximum temperature recorded was 32.7°C in Udayapur school, this shows that the Udayapur school's envelope had low thermal performance. The reason for the maximum air temperature variation in Udayapur school may be due to the use of the use of CGI in roof, which have high U-value.

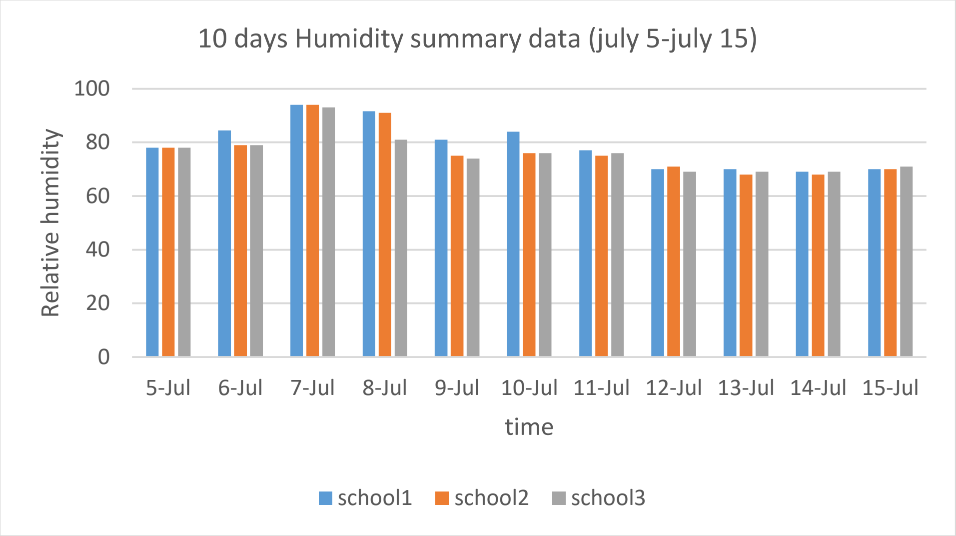


Figure 17 10 days humidity summary data for diffrent schools

The average humidity is also monitored in different schools, during the peak hour from(12pm-2am).The average humidity recorded from july 5 to july 15 in the Kapilvastu vidhya mandir secondary school (KVM) was 79%, in the Udayapur school was 77.6%, and in Shainik shining English school was 78%.

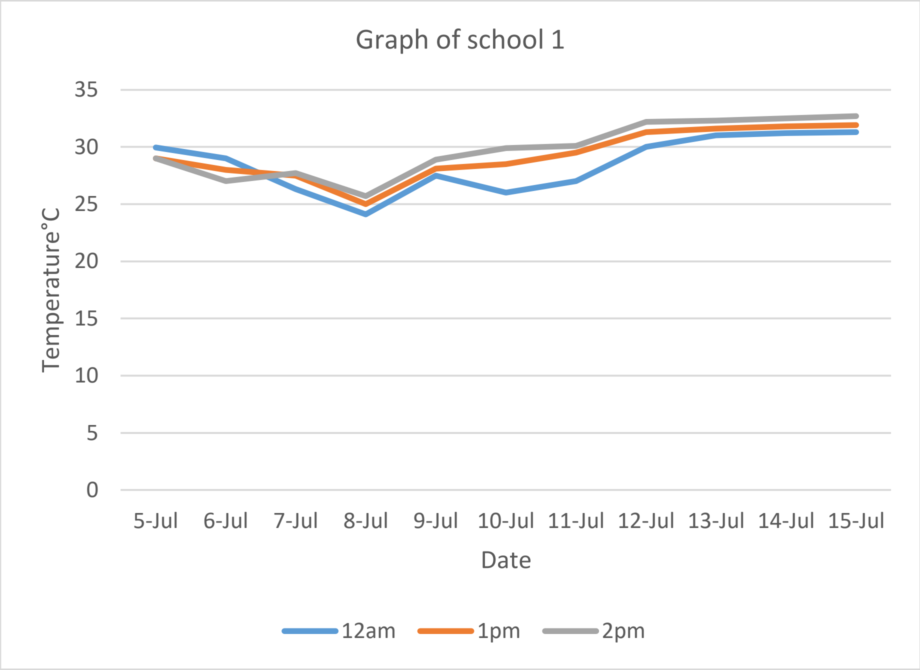


Figure 18 Temperature graph of school 1

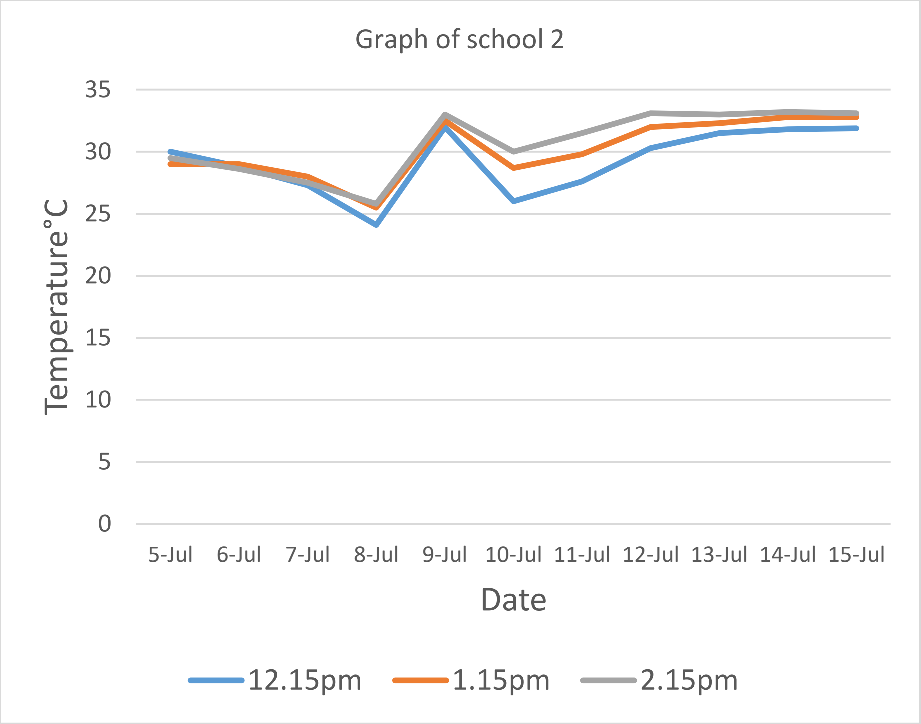


Figure 19 Temperature graph of school 2

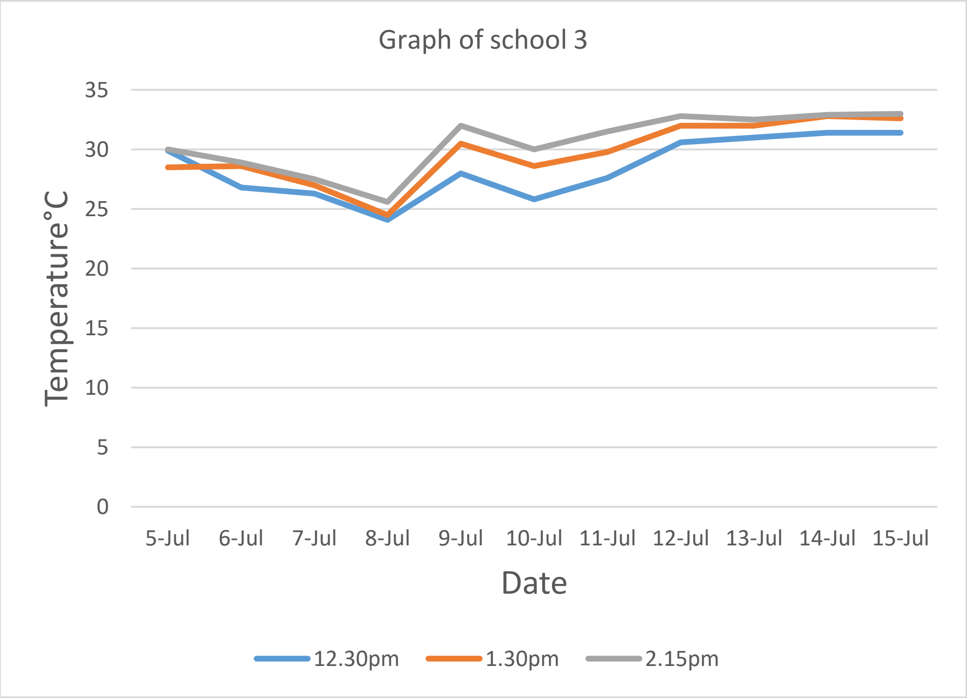


Figure 20 Temperature graph of school 3

Figure20, 21 and 22 shows temperature of three investigated buildings in 3 different locations at three different times of the day in summer which was measured in the field. As seen in the figure 20, the difference in air temperature was seen maximum in 10 july about 4°C. If we compare it with other investigated school the difference of nearly 3°C is seen in summer condition. The reason for the maximum air temperature variation may be due to the use of the use of CGI roof in school 2, with high U-value.

5.2. Comfort Temperature for Kapilvastu

Figure below shows Nicol graph for Kapilvastu which start finding the temperature in which people find comfortable to live, in which indoor air temperature varies with mean outdoor air temperature of outdoor temperature . It has been calculated from recent climatic data (1980-2010) of Kapilvastu assessed from Department of hydrology and Metrology, Gorvenment of Nepal. The comfort temperature varies according to the geographical location. The comfort temperature of Kapilvastu has been calculated using the Nicol formula shown in equation (i)

Tcomf = 0.54 Tom + 12.9.......(i)

The equation shown above helps for the calculation of Adaptive thermal comfort from monthly mean max (Tmax), monthly mean min (Tmin), monthly mean outdoor temperature (Tom) and monthly comfort temperature of 12 months

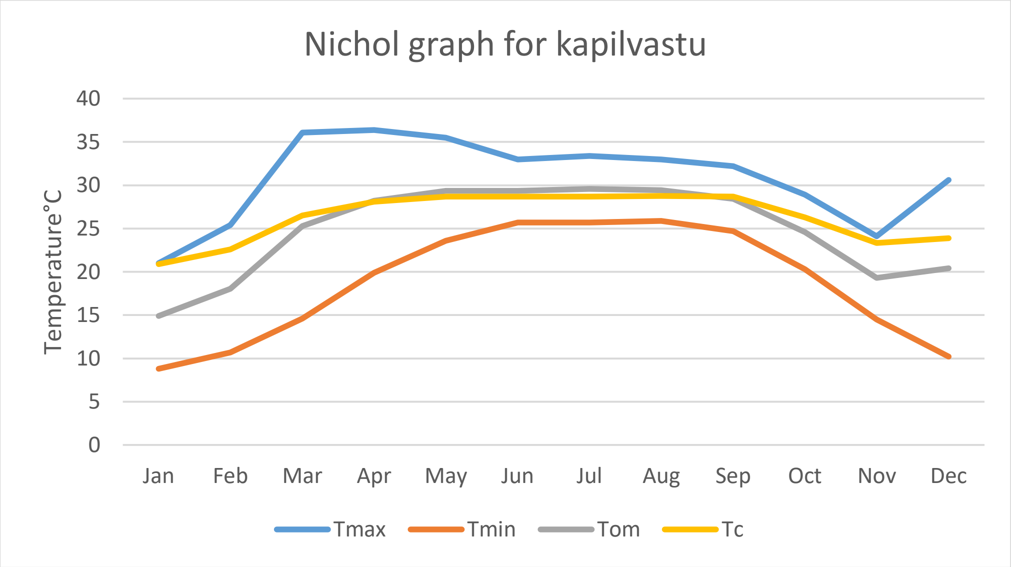


Figure 21Nichol graph for kapilvastu

As shown in fig , the lowest temperature in which the people of Kapilvastu feel comfortable is 20.3°C during, whereas the highest temperature in which the people of Kapilvastu feel comfortable is 28.6°.

5.3. Data simulation, findings and analysis through modelling : Ecotect

To compare the effect of envelopes in uninsulated prototype classrooms with thermally insulated schools, energy modeling was done using a simulation tool. To attain this objective, various necessary features of a school building at Kapilvastu was studied. For the simulation two different structure building such as Kapilvastu vidjya Mandir school (RCC frame building) and Udayapur School (CGI roof building) were selected. The collected documents and drawings were drafted according to site conditions. The software adopted for simulation of the building is Autodesk Ecotect 2011. After combining the weather file in Ecotect, thermal analysis was the major concern to study the comfort level of the building. Parameters such as the monthly load of the building, heat loss and heat gain were calculated for thermal analysis. Also, the building is simulated creating different building envelopes as scenario cases. The focus of the simulation was an investigation of building envelope elements. Different four scenario were created. The results are mainly represented through monthly loads and heat gain and heat loss for a better understanding of the performance of building materials and its subsequent energy requirements. The U-value of Brick wall (1.8 W/m2K) which is higher than other 8” AAC block (0.71 W/m2K) , 3”Eco panel (0.315 W/m2K) and double brick cavity wall (1.780 W/m2K). (Latif, 2010)

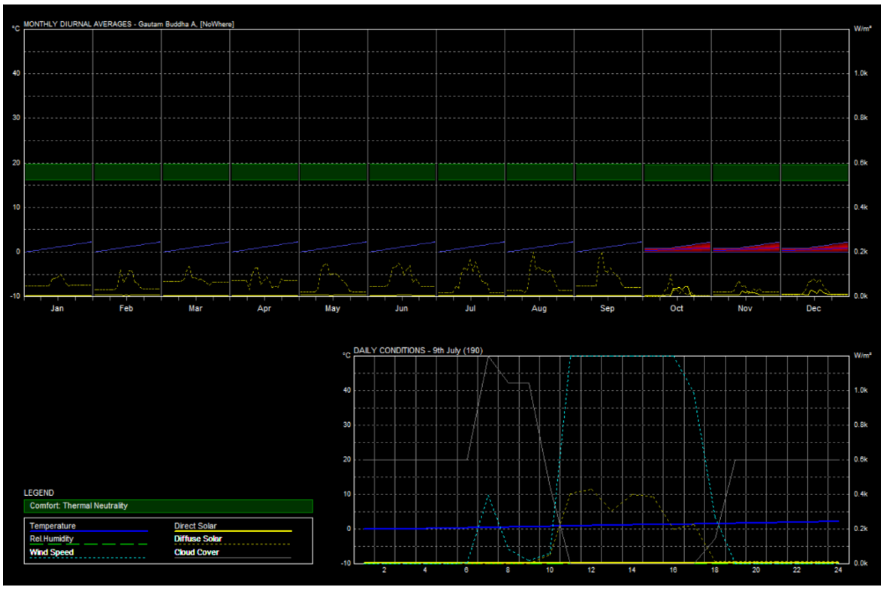


Figure 22 Ecotect model

Table 8 The Material Properties Used in the Ecotect Analyses.

Materials for construction	Materials detail	U-value (W/m2 K)
1 AAC block	Lining made of plaster (3 cm) AAC stumbling block (20 cm) Mortar made of sand and cement (3 cm) Finishing exterior stone (2 cm)	0.71 (Mohammad & Shea, 2013)
2 AAC block	Lining made of plaster (3 cm) AAC stumbling block (10 cm) Expanded polystyrene (EPS) is used to fill the cavity (5 cm) AAC stumbling block (10 cm) Mortar made of sand and cement (3 cm) Finishing exterior stone (2 cm)	0.37 (Mohammad & Shea, 2013)
Double brick cavity wall	10mm plaster on the inside, as well as a 110mm double brick and a 50mm cavity.	1.780 (Charde, 2014)
Eco panel	Eco panel 30mm	0.727
	Eco panel 40mm	0.563
	Eco panel 50mm	0.460
	Eco panel 60mm	0.388
	Eco panel 75mm	0.315
	Eco panel100mm	0.240

5.3.1. Results of Simulation

Kapilvastu Vidhya Mandir secondary school (KVM

Kapilvastu Vidhya mandir is two storey building which has altogether 14 room. The building is facing south direction. The building is built with brick and stone walls and mortar plaster. The building's construction is made of reinforced concrete (RCC). The insulation of this building is not good, and the students have to accept different thermal conditions inside.

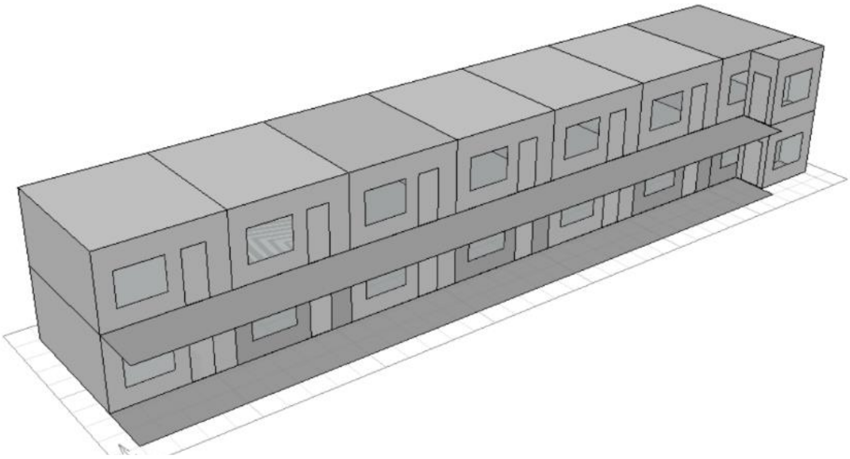


Figure 23 3D model Ecotect

Table 9 Diffrent scenario for different material

Criteria	(Base) scenario 1	Scenario 2	Scenario 3	Scenario 4
Wall	Wall 9 inch brick wall +inner plaster 15mm	Eco panel 80mm	AAC block 8 inch	Double brick cavity wall
Floor	Floor Rcc125 mm +40mm screed	Floor concrete Rcc125 mm +40mm screed	Floor Rcc125 mm +40mm screed	Floor Rcc125 mm +40mm screed
Roof	Concrete slab 125mm	Green roofing	Green roofing	Green roofing

Openings	Single-glazed 6 mm windows +wooden door	Wooden windows +Hollow core ply wood door	Wooden windows +Hollow core ply wood door	Wooden windows +Hollow +wooden door

Scenario 1 is base line scenario was modelled as an existing scenario. All specification were as per site data collection and conditions. This scenario was modelled with the best possible way to represent the actual finding in the site. Other three different scenarios are created using different material. The material used are AAC block, EPS sandwich panel and double brick cavity wall and Green roofing. Ecotect use known thermal values of the various layers of building material to calculate overall thermal resistance of the system

Table 10 Monthly heating/cooling loads base scenario

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	7467	215	7682
Feb	28577	82282	110858
Mar	41737	391029	432767
Apr	52041	577324	629365
May	65248	639483	704731
Jun	66486	632998	699483
Jul	64367	626024	690391
Aug	55331	623975	679306
Sep	66751	647317	714068
Oct	49016	528816	577832
Nov	36505	347214	383719
Dec	16713	4797	21510
TOTAL	550238	5101474	5651712

Scenario 1:

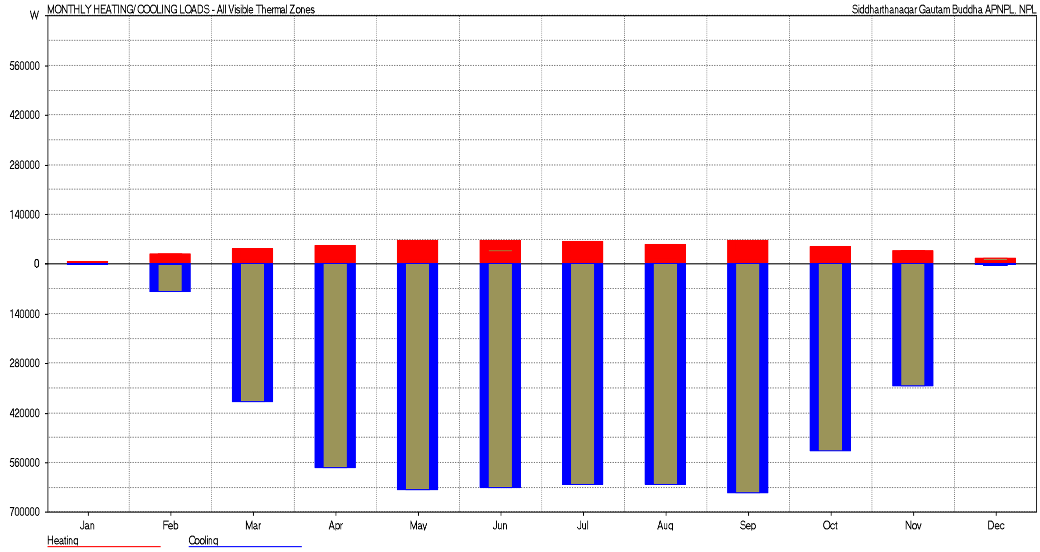


Figure 24 Monthly heating/cooling loads (scenario 1)

Heating load required is 550238Wh, Cooling load required is 5101474Wh and total load required throughout the building is 5651712Wh. Max Heating load required is 637W at 05:00 on 3rd February Max Cooling load required is 2415W at 13:00 on 8th October The graph depicts the monthly heating and cooling load requirements based on data collected from Siddarthanagar station, and clearly demonstrates the need for cooling during the majority of the months.

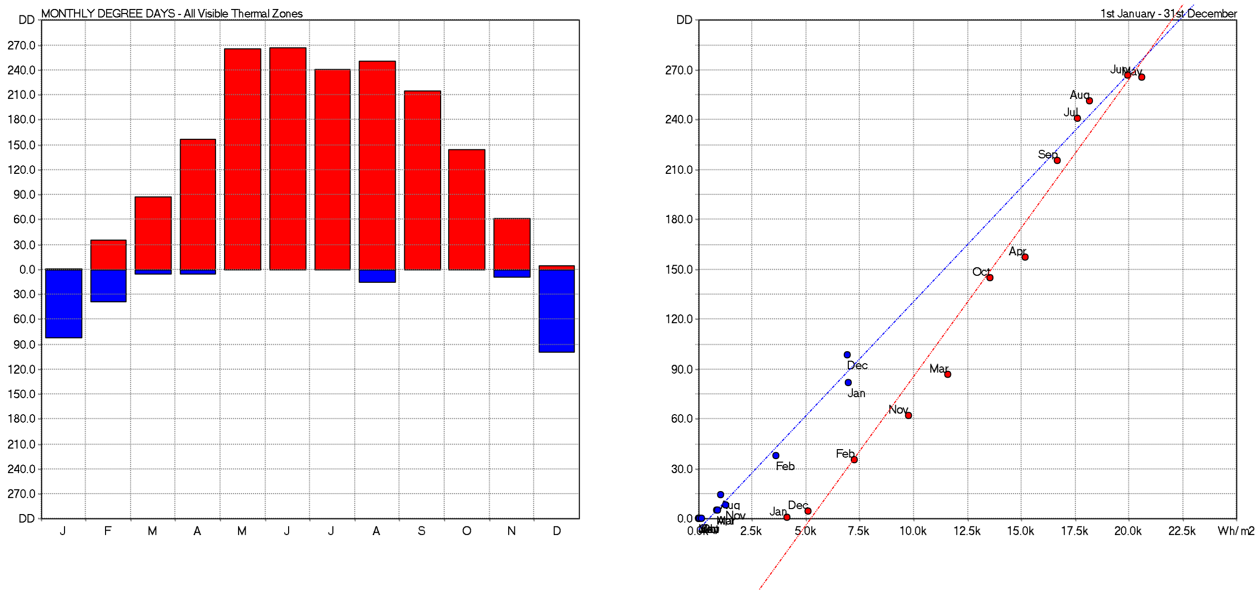


Figure 25 Monthly degree days-all visible Thermal zone (scenario 1)

Total heat loss is 21796Wh, and heat gain 159579 Wh throughout the building for one year for scenario 1.

Scenario 2:

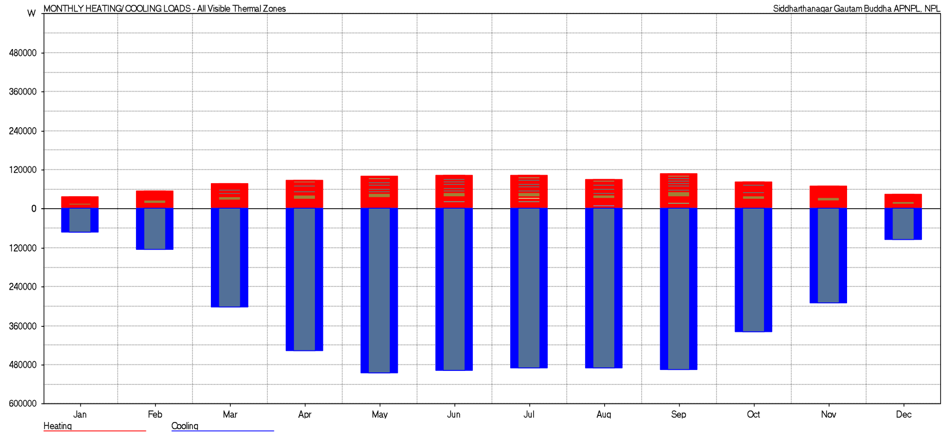


Figure 26 Monthly heating/cooling loads (scenario 2)

Fig above shows the Monthly cooling and heating loads requirement from the data recorded in Siddarthanagar station and requirement of cooling load is seen clearly most of the months.

Heating load required is 955809Wh, Cooling load required is 4204190Wh and total load required throughout the building is 5159999Wh. Max Cooling load required is 1836 W at 13:00 on 21st May.

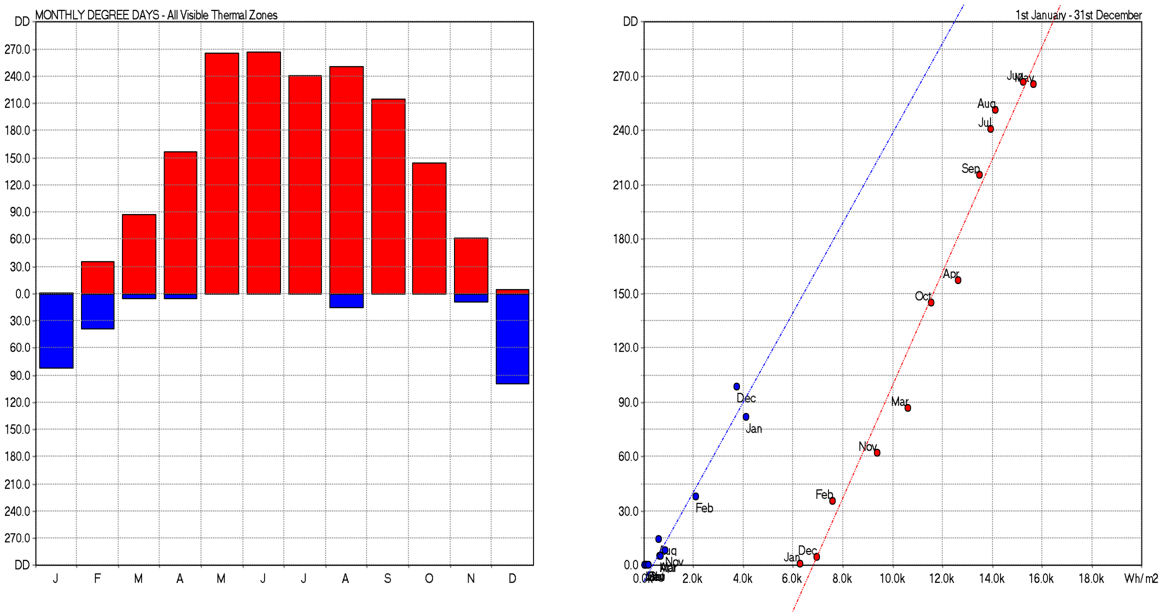


Figure 27 Monthly degree days-all visible Thermal zone (scenario 2)

Total heat loss is 13249Wh, and heat gain 137465Wh throughout the building for one year for scenario 2.

Scenario 3:

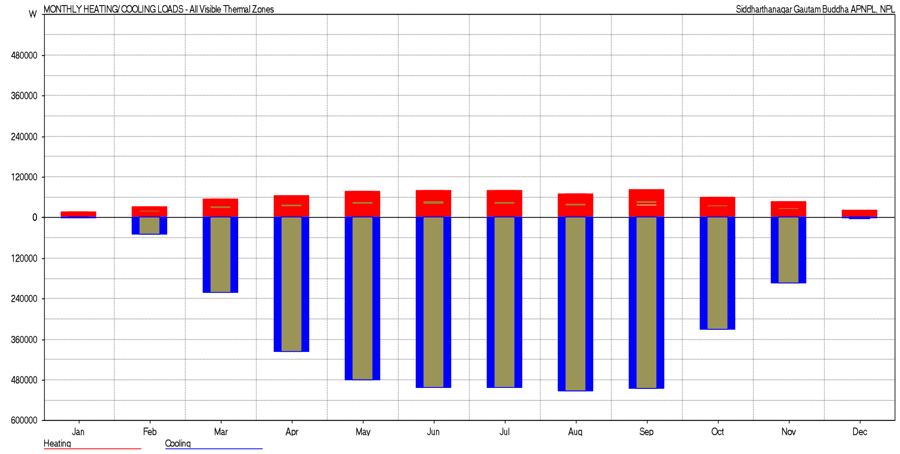


Figure 28 Monthly heating/cooling loads (scenario 3)

Fig above shows the Monthly cooling and heating loads requirement from the data recorded in Siddarthanagar station and clearly demonstrates the need for cooling during the majority of the monthsHeating load required 686249Wh, Cooling load required is 3721450Wh and total load required throughout the building is 4407699Wh. Max Cooling load required is 1793 Wat 16:00 on 31st May.

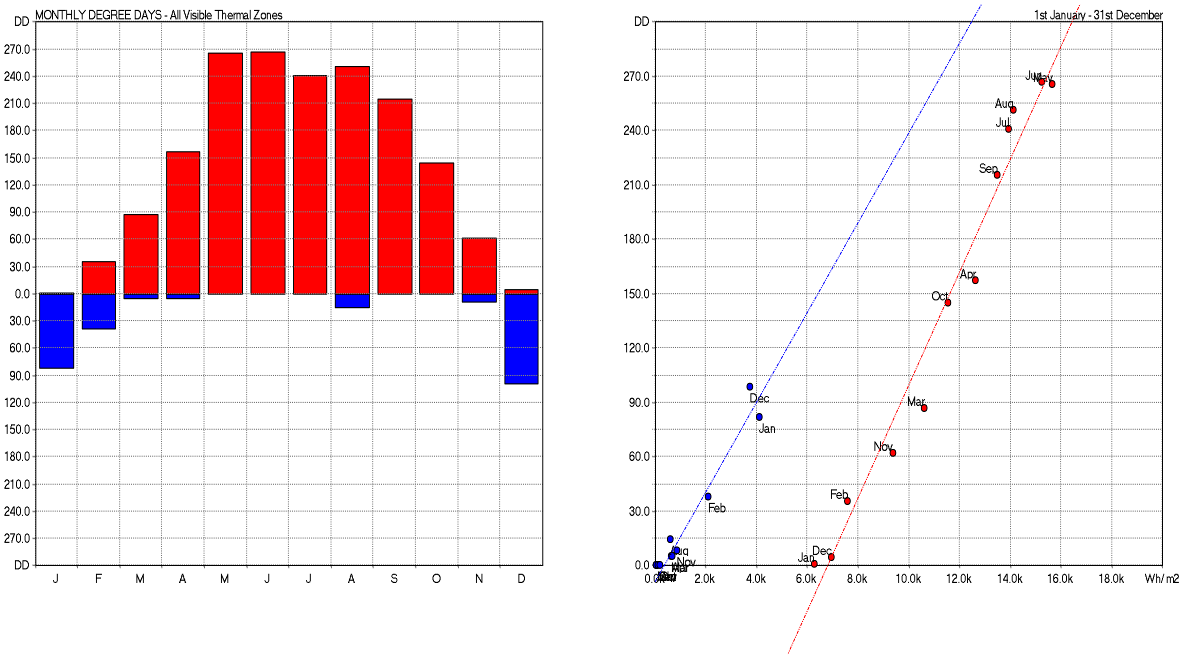


Figure 29Monthly degree days-all visible Thermal zone (scenario 3)

Total heat loss is 14312 Wh, and heat gain 140125 Wh throughout the building for one year for scenario 3.

Scenario 4:

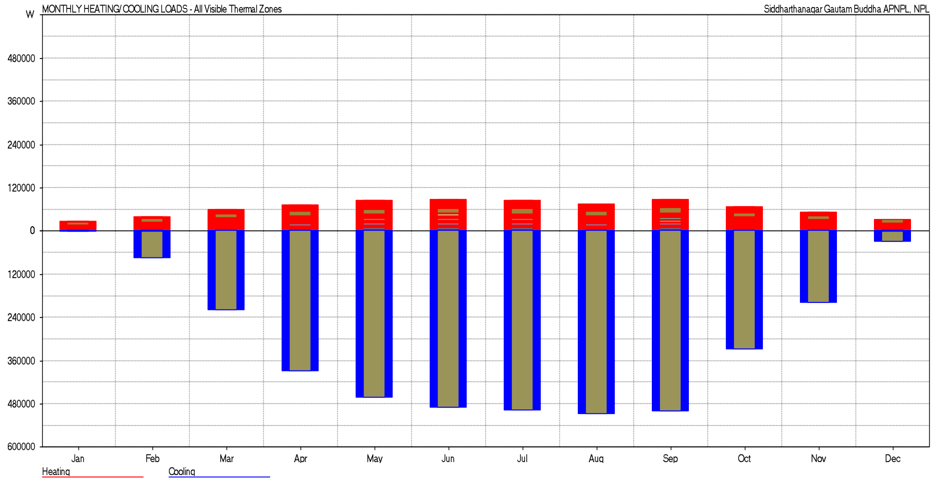


Figure 30 Monthly heating/cooling loads (scenario 4)

Fig above shows the Monthly cooling and heating loads requirement from the databrecorded in Siddarthanagar station and clearly demonstrates the need for cooling for the majority of the year. Heating load required 764310Wh, Cooling load required is 3722449Wh and total load required throughout the building is 4486759Wh. Max Cooling load required is 1679 W at 16:00 on 30th June.

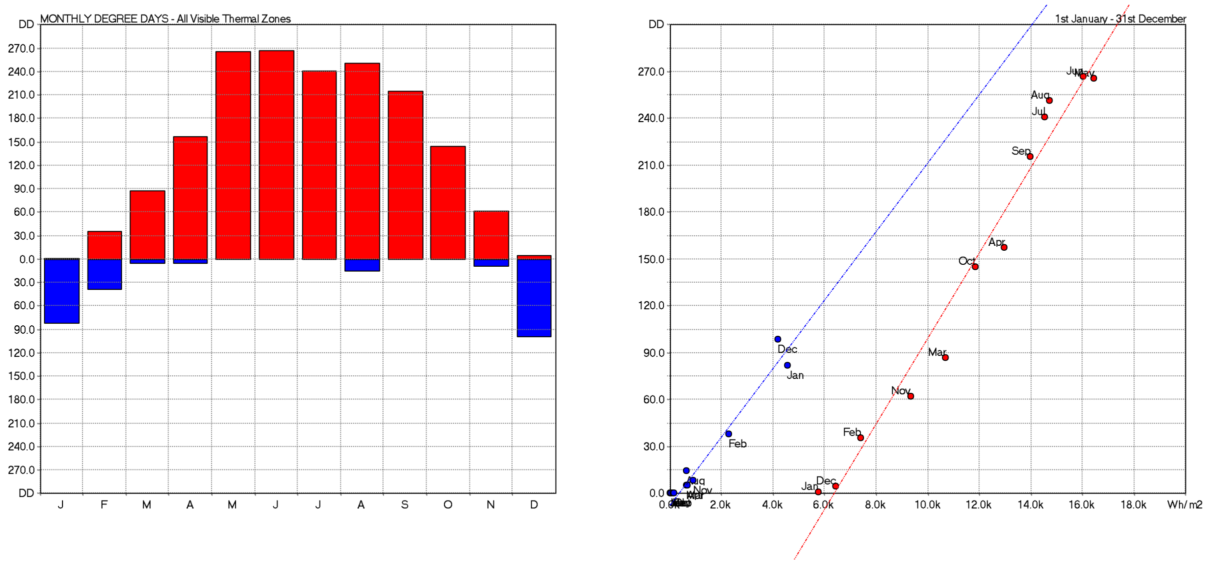


Figure 31Monthly degree days-all visible Thermal zone (scenario 4)

Total heat loss is 13961Wh, and heat gain 151017Wh throughout the building for one year for scenario 4.

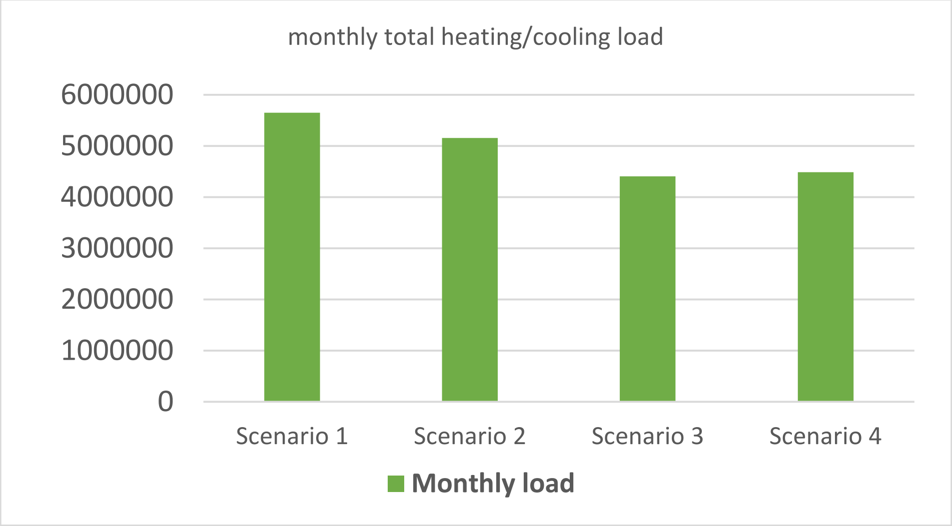


Figure 32 Comparison of monthly total heating/cooling load of different scenario (KVM School)

Fig above shows the Comparison of monthly total heating/cooling load of different scenario in KVM school. Total monthly load required for scenario 1 is 5651712Wh, for scenario 2 is 5159999Wh, Scenario 3 is 4407699Wh and scenario 4 is 4486759Wh.

Udayapur School

The school building has two blocks. This one storey building has altogether 8 rooms. Brick and mortar plaster are used to construct the structures. The building's roof structure is represented by a CGI sheet. Because the buildings are not effectively insulated, students must accept a wide range of indoor thermal conditions.

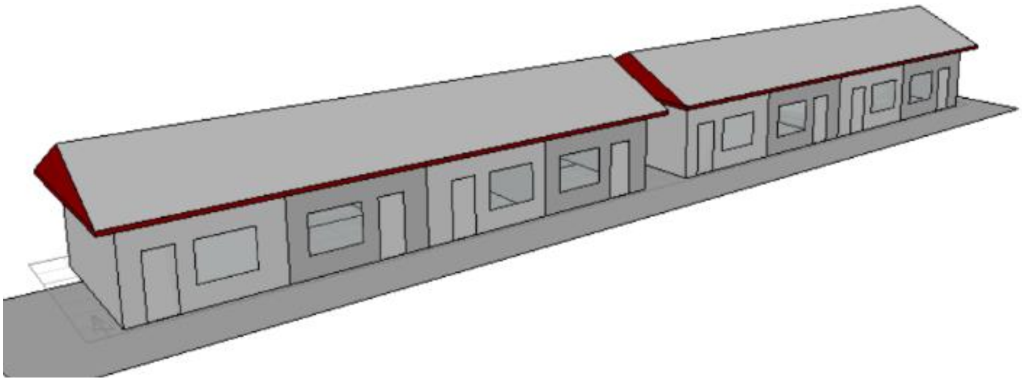


Figure 33 model Ecotect

Table 11 Diffrent scenario for different material

Criteria	(Base) scenario 1	Scenario 2	Scenario 3	Scenario 4
Wall	Wall 9 inch brick wall +inner plaster 15mm	Eco panel 80mm	AAC block 8 inch	Double brick cavity wall
Floor	Floor rcc125 mm +40mm screed	Floor rcc125 mm +40mm screed	Floor rcc125 mm +40mm screed	Floor rcc125 mm +40mm screed
Roof	CGI roof 10mm	Upvc roof	Upvc roof	Upvc roof
Openings	Single-glazed 6 mm windows +wooden door	Wooden windows +hollow core ply wood door	Wooden windows +hollow core ply wood door	Wooden windows +hollow core ply wood door

Scenario 1 is base line scenario was modelled as an existing scenario. All specification were as per site data collection and conditions. Other three different scenarios are created using different material. The material used are AAC block, EPS sandwich panel and double brick cavity wall and UPVC roofing. Ecotect use known thermal values of the various layers of building material to calculate overall thermal resistance of the system. For the second third and fourth scenario Eco panel board, AAC blocks and double brick cavity wall are used. For the roofing material UPVC is used.

Table 12 Monthly heating/cooling loads base scenario

MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	881440	18683	900123
Feb	327998	652685	980683
Mar	4991	3835512	3840503
Apr	0	7456884	7456884
May	0	9969482	9969482
Jun	0	9659174	9659174
Jul	0	9111987	9111987
Aug	19831	8324052	8343883
Sep	0	8761830	8761830
Oct	0	5888282	5888282
Nov	11098	2862003	2873100
Dec	965432	201077	1166510
TOTAL	2210791	66741648	68952440

Scenario 1:

Fig above shows the Monthly heating and cooling loads requirement. Heating load required is 2210791Wh, Cooling load required is 66741648Wh and total load required throughout the building is 68952440Wh.

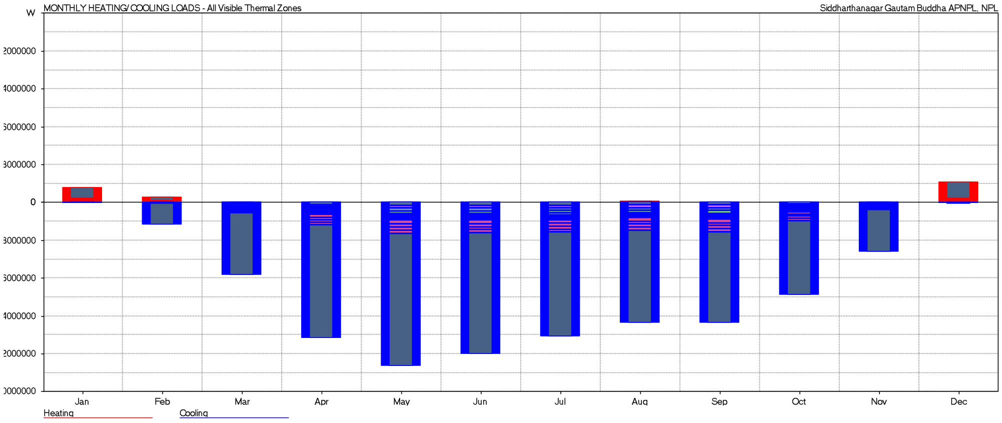


Figure 34 Monthly heating/cooling loads (scenario 1)

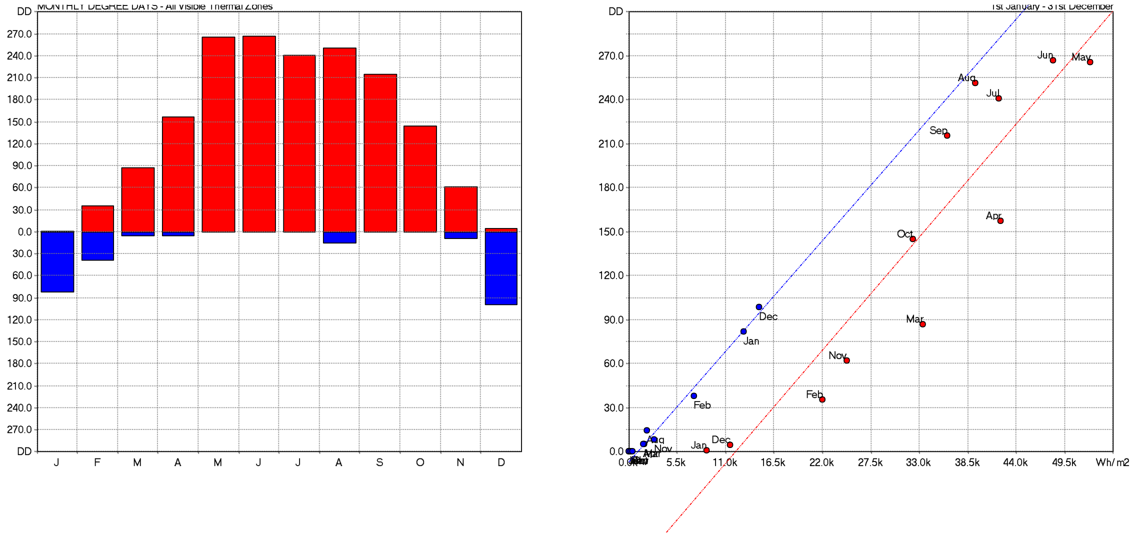


Figure 35 Monthly degree days-all visible Thermal zone (scenario 1)

Total heat loss is103235Wh, and heat gain 866219Wh throughout the building for one year for scenario 1.

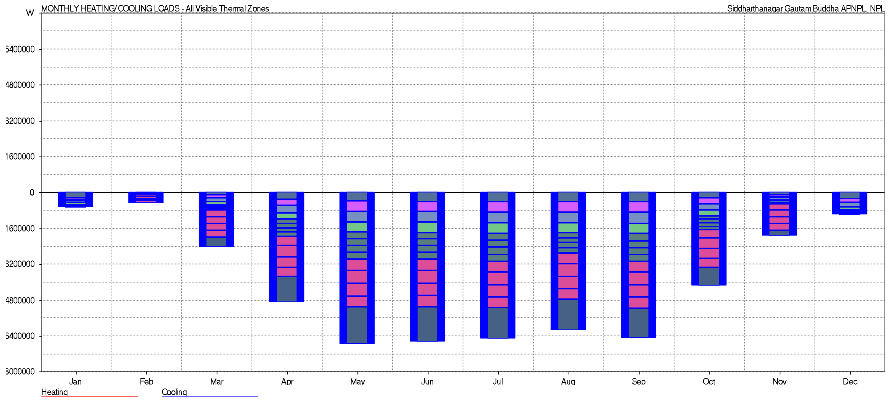


Figure 36 monthly heating/cooling loads (scenario 2)

Scenario 2:

Fig above shows the Monthly heating and cooling loads requirement. Heating load required is 66505Wh, Cooling load required is 48190340Wh and total load required throughout the building is 48256844Wh.

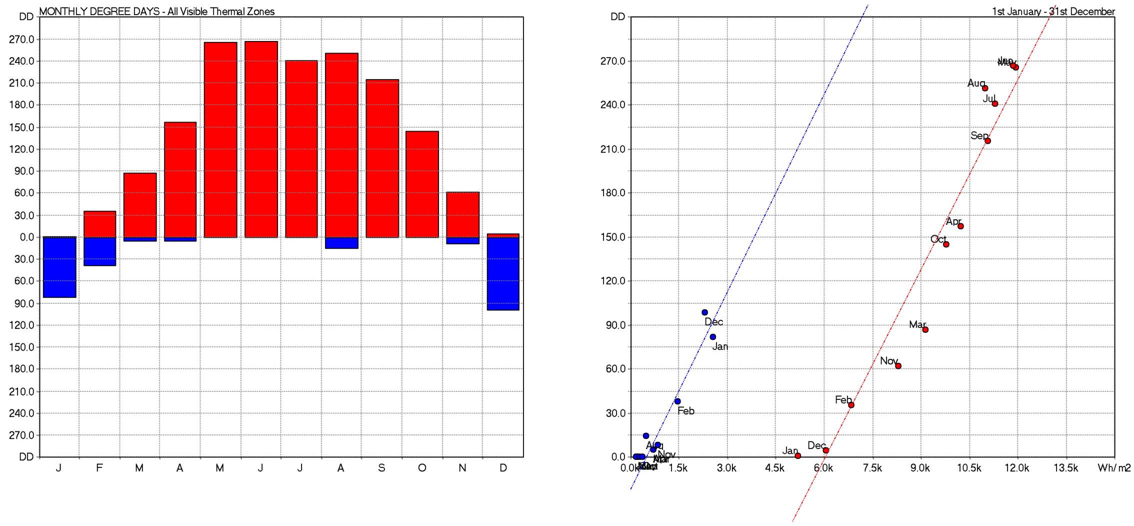


Figure 37 Monthly degree days-all visible Thermal zone (scenario 2)

Total heat loss is 10386Wh, and heat gain 111495Wh throughout the building for one year for scenario 2.

Scenario 3:

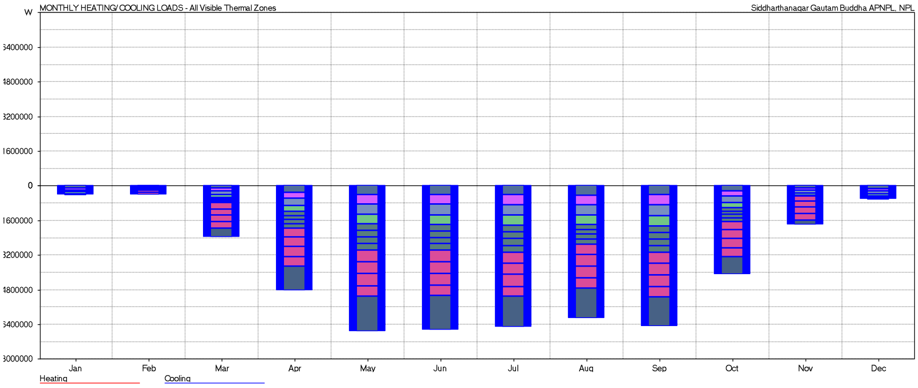


Figure 38 monthly heating/cooling loads (scenario 3)

Fig above shows the Monthly heating and cooling loads requirement. Heating load required is 47219Wh, Cooling load required is 47190720Wh and total load required throughout the building is 47237940Wh.

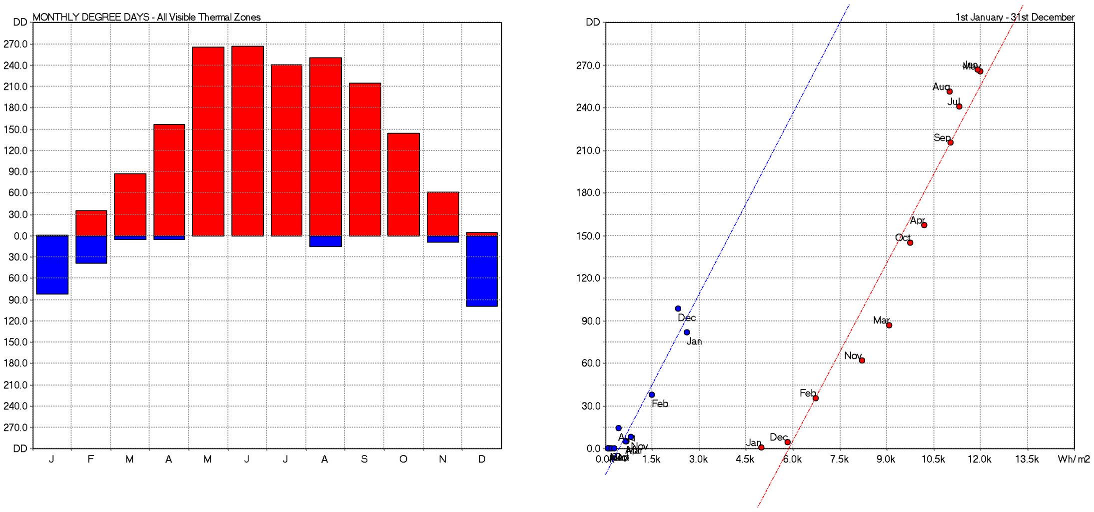


Figure 39 Monthly degree days-all visible Thermal zone (scenario 3)

Total heat loss is9795 Wh, and heat gain 112077Wh throughout the building for one year for scenario 3.

Scenario 4:

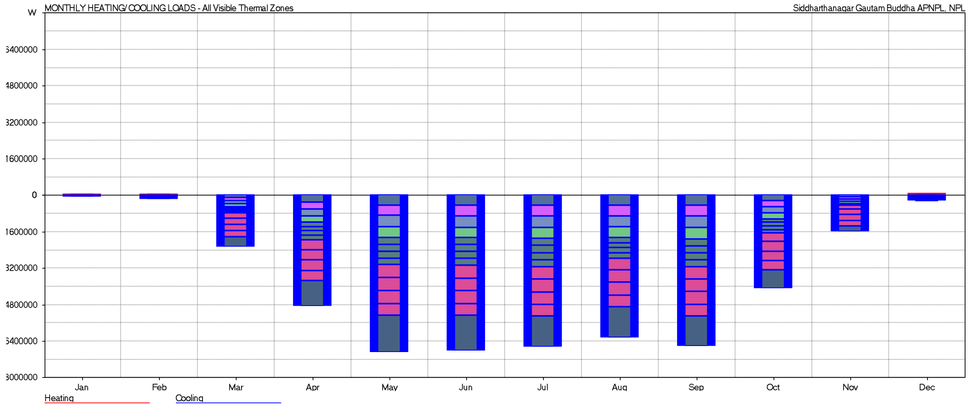


Figure 40Monthly heating/cooling loads (scenario 4)

Fig above shows the Monthly heating and cooling loads requirement. Heating load required is 170604Wh, Cooling load required is 46693280Wh and total load required throughout the building is 46863884Wh

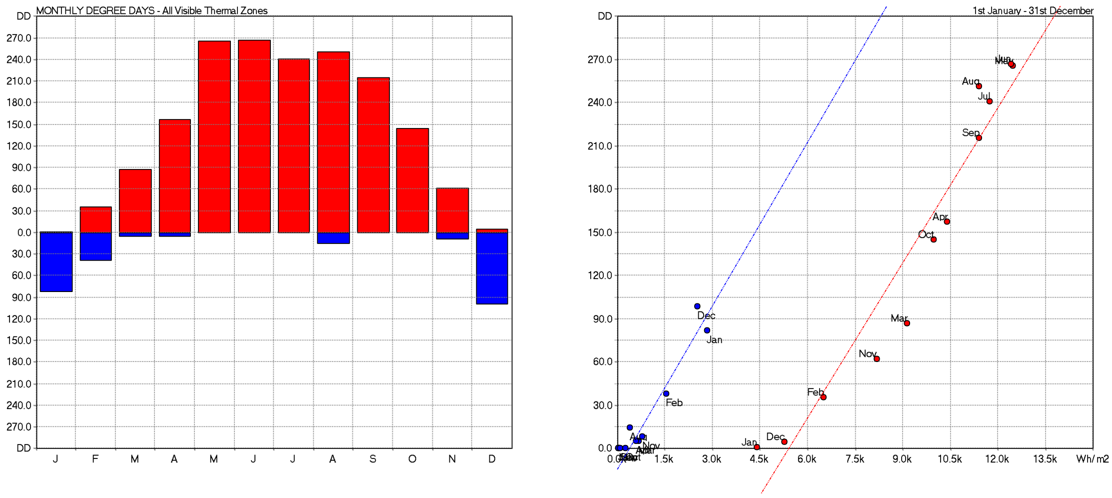


Figure 41Monthly degree days-all visible Thermal zone (scenario 4)

Total heat loss is 15834Wh, and heat gain 186055Wh throughout the building for one year for scenario 4.

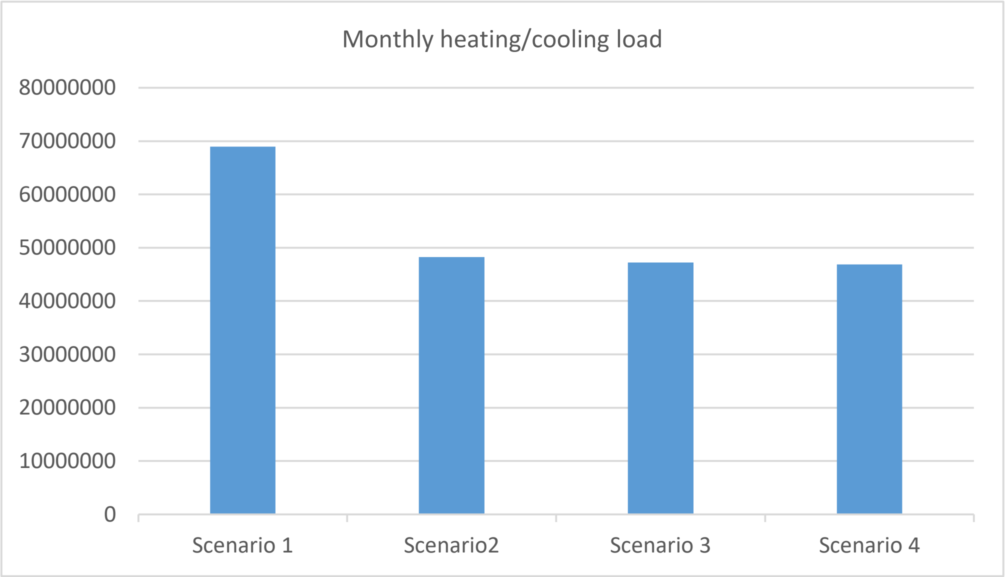


Figure 42 Fig: Comparison of monthly total heating/cooling load of different scenario Udayapur School).

Fig above shows the Comparison of monthly total heating/cooling load of different scenario in Udayapur School. Total monthly load required for scenario 1 is

68952440Wh,for scenario 2 is is 48256844Wh, Scenario 3 is 47237940Wh and scenario 4 is46863884Wh.

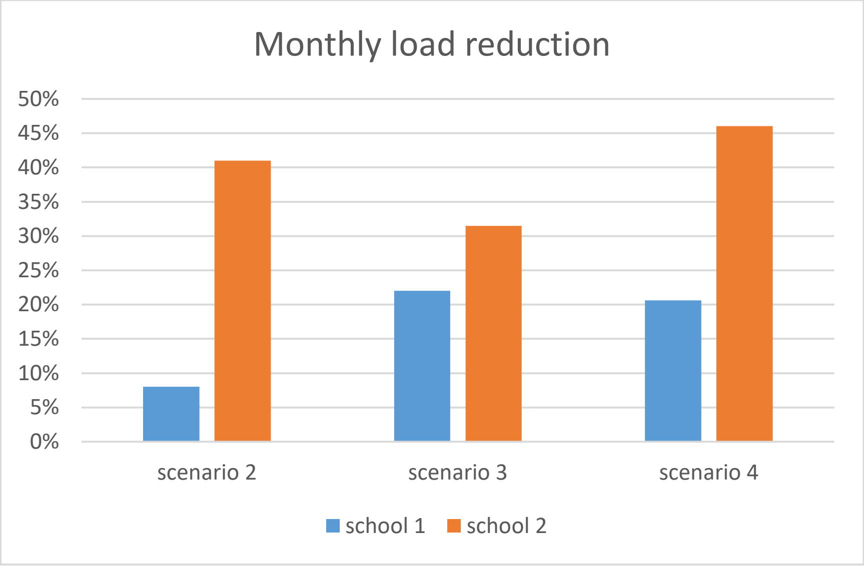


Figure 43 Comparision of Monthly load reduction in diffrent schools.

Fig above shows the Comparison of monthly total heating/cooling reduction load of different two school. For KVM School reduction in monthly load is 8% for scenario 2, 22% for scenario 3 and 20.6% for scenario 4. . For Udayapur School reduction in monthly load is 30.01% for scenario 2, 31.5% for scenario 3 and 32.03% for scenario 4.

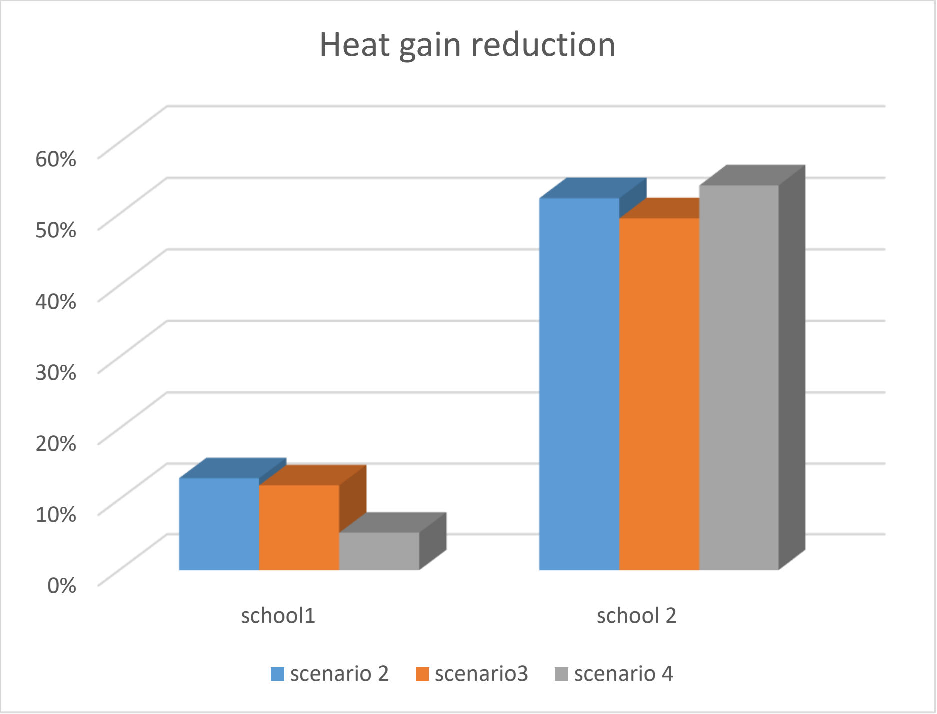


Figure 44 Heat gain reduction

Fig above shows the Comparison of heat gain reduction load of different two school. For KVM School reduction in heat gain is 13% for scenario 2, 12% for scenario 3 and 6% for scenario 4. For Udayapur School reduction in heat gain is 52.2% for scenario 2, 49.5% for scenario 3 and 54% for scenario 4.

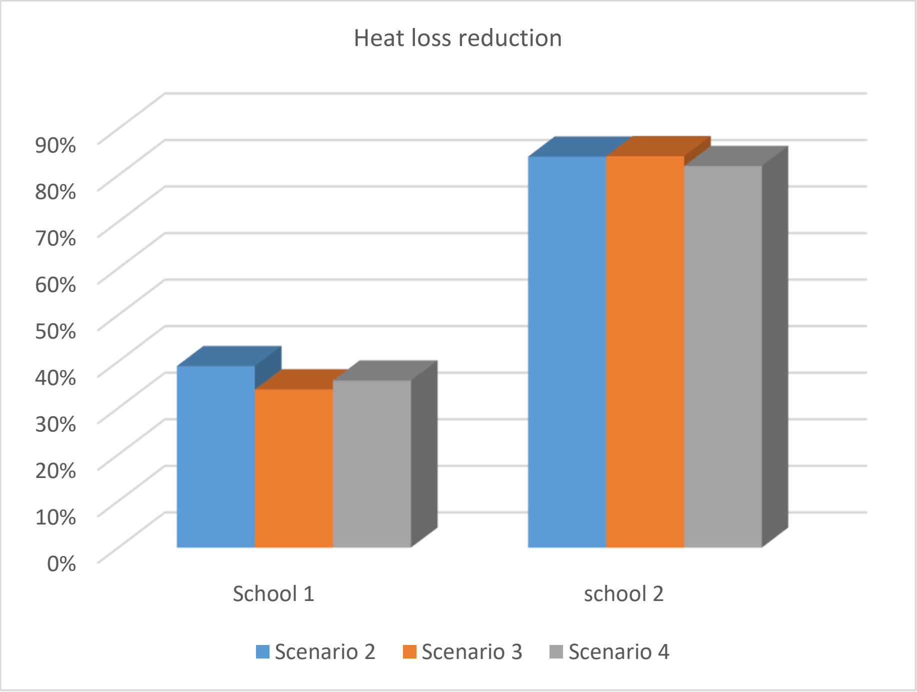


Figure 45 Heat loss reduction

Fig above shows the Comparison of heat loss reduction load of different two school. For KVM School reduction in heat loss is 39% for scenario 2, 34% for scenario 3 and 35.9% for scenario 4. . For Udayapur School reduction in heat loss is 75.4% for scenario 2, 75.6% for scenario 3 and 74% for scenario 4.

In the summer, the table below illustrates an assessment of the comfort temperature with existing research. The diagram depicts a summary of thermal comfort studies conducted in various regions to assess student comfort in the school building. The study was conducted in several countries, including Japan and Pakistan, as well as various locations in Nepal. Adaptive thermal performance in schools has been emphasized in a number of studies. According to the Nichol thermal adaptive comfort model, the comfort temperature for Nepal is between 21.1 and 30 degrees Celsius. Thermal comfort was determined to be the same in both studies, ranging from 20.3°C to 28.6°C.

Table 13 Comparison of comfort temperature for diffrent area

Area	Reference	Tc (°C)
Japan(Gifu)	Rijal et al.	26.1
Japan (Kanto)	Japan (Kanto)	27.6
Nepal	Rijal et al.	21~30
Pakistan	Nicol & Roaf	26.7~29.9
Nepal(Dang)	Bajracharya, S. B.	17~27.6
Nepal(kathmandu)	Bajracharya, S. B.	18~26
Nepal(Kapilvastu)	This study	20.3~28.6*

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1. Conclusion

This report describes the results of thermal comfort assessment of school buildings in Nepal's Kapilvastu district for the summer season.

- The first objective was to remark on the thermal environmental conditions of classrooms in kapilvastu schools.The maximum average indoor temperature recorded in the Kapilvastu Vidhya Mandir secondary school (KVM) was 32°C, in the Udayapur school was 32.7 °C, and in Shainik shining English school was 32.4 °C. From this 10 days survey data the variation of 0.7°C in indoor temperature between two schools was carried out. The reason for the maximum air temperature variation in Udayapur school may be due to the use of CGI in roof, which have high U-value.
- The second objective was to find the comfort temperature of the study area. The comfort temperature of Kapilvastu has been calculated using the Nicol formla, the lowest temperature in which the people of Kapilvastu feel comfortable is 20.3°C , whereas the highest temperature in which the people of Kapilvastu feel comfortable is 28.6°.
- The third goal was to examine the impact of envelopes in thermally insulated and uninsulated prototype classrooms. The discomfort of being too hot or too cold was recorded during the Ecotect simulation, and the data clearly demonstrates that cooling is required during the majority of the months. In order to attain a better outcome for the thermal comfort in the school building, insulation and materials with a lower U-value can be beneficial. The outcome of a building simulation for the Terai region is that cooling loads are higher and heating loads are substantially lower (Heidari, 2009). According to the study, each degree reduction in heating/cooling loads saves 7% of energy. Lessening material with lesser U-value can save 10-40% monthly heating or cooling load in summer than uninsulated buildings of Kapilvastu. Insulations and material with lesser u-value are good in order to achieve the thermal comfort in the school building.

6.2. Recommendation

- In order to promote thermal comfort in the school building, insulation and materials with a lower u-value are beneficial.
- We should install building envelope insulation material to reduce energy consumption for cooling and heating by enhancing thermal resistance. Mechanical cooling systems should be avoided by including passive and low-energy cooling options during the design phase.
- It is suggested that designers utilize environmentally friendly materials to improve the building's thermal condition. The best approach to save energy is to insulate your building.
- It is recommended to researchers to incorporate temperature of all season for the more accurate results.
- Research can be extended in other climatic zones.
- We should consider the comfort of the residents and the building's suitability to the local climate when designing.
- To achieve indoor thermal comfort, policymakers must develop more climate adaptation policies, programs, and a set of rules for the indoor environment.

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APPENDICES

Appendix 1: Monthly heating/cooling loads calculation

Monthly heating/cooling loads base scenario 2(KVM school)

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	35723	73503	109226
Feb	54082	126654	180736
Mar	78037	305366	383403
Apr	87719	439295	527013
May	99491	508022	607513
Jun	103478	498753	602231
Jul	102128	492895	595023
Aug	90140	491723	581863
Sep	106690	497671	604361
Oct	83198	380236	463434
Nov	69745	291599	361345
Dec	45378	98473	143851
TOTAL	955809	4204190	5159999

Monthly heating/cooling loads base scenario 3(KVM school)

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	17414	55	17470
Feb	32533	51162	83694
Mar	53964	223932	277896
Apr	64690	398880	463570
May	78018	482123	560141

Jun	80520	506085	586606
Jul	78710	505744	584454
Aug	68542	514382	582924
Sep	81689	506625	588314
Oct	60699	333027	393726
Nov	47007	195491	242499
Dec	22461	3944	26405
TOTAL	686249	3721450	4407699

Monthly heating/cooling loads base scenario 4(KVM school)

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	26119	519	26638
Feb	39280	76779	116059
Mar	60116	220670	280786
Apr	71060	390899	461958
May	83576	463664	547240
Jun	86285	493056	579341
Jul	84385	500273	584658
Aug	74097	510612	584709
Sep	87830	502448	590278
Oct	66181	331259	397440
Nov	52573	201333	253906
Dec	32810	30937	63747
TOTAL	764310	3722449	4486759

Monthly heating/cooling loads base scenario 2(Udayapur school)

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	24831	655987	680818
Feb	18729	478555	497283
Mar	0	2438824	2438824
Apr	0	4894932	4894932
May	0	6760430	6760430
Jun	0	6660566	6660566
Jul	0	6531182	6531182
Aug	0	6167620	6167620
Sep	0	6512464	6512464
Oct	0	4153251	4153251
Nov	0	1925799	1925799
Dec	22946	1010729	1033674
TOTAL	66505	48190340	48256844

Monthly heating/cooling loads base scenario 3(Udayapur school)

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	16074	431420	447494
Feb	20004	412624	432628
Mar	0	2395286	2395286
Apr	0	4848790	4848790
May	0	6746054	6746054
Jun	0	6652150	6652150

Jul	0	6515958	6515958
Aug	0	6137186	6137186
Sep	0	6492416	6492416
Oct	0	4101933	4101933
Nov	0	1815897	1815897
Dec	11140	641008	652149
TOTAL	47219	47190720	47237940

Monthly heating/cooling loads base scenario 4 (Udayapur school)

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	58527	86322	144849
Feb	43107	179601	222708
Mar	0	2274756	2274756
Apr	0	4872254	4872254
May	0	6917903	6917903
Jun	0	6839606	6839606
Jul	0	6677178	6677178
Aug	0	6267340	6267340
Sep	0	6637758	6637758
Oct	0	4100880	4100880
Nov	0	1593619	1593619
Dec	68970	246060	315029
TOTAL	170604	46693280	46863884

Appendix 2: Site photos

Figure 47 Inerior view of classroom

Figure 46 Udayapur school building

Figure 48 Shainik Shining School

Figure 49 Kapilvastu Vidhya Mandir school

Appendix 3: Article –accepted in 10th IOE-GC in Pulchowk campous

Study of thermal comfort in Terai region Nepal – A case of school building in Kapilvastu district

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Abstract

The global average surface temperature has increased by more than 1.6 degrees Fahrenheit (0.9 degrees Celsius). Similarly the temperature of Nepal is warming at the rate faster rate than that of the global average temperature. Thermally discomfort creates the negative impact in the academic performance, so there should be serious attention to improve the indoor thermal environment of classroom. Adaptation to climate change is a functional requirement and best way of insulating is to have well-defined thermal boundary in building.All of the existing schools in Nepal have been constructed without any concern for the comfort of the occupants and the adaptation of the buildings to the local climate. This research focuses on evaluating and comparing effect of envelopes in uninsulated prototypical school with thermally insulated in Kapilvastu district. This study will help to report the thermal environmental conditions of classrooms in the schools of Kapilvastu. Primary data would be collected through school survey and case studies while secondary data would be collected through various literatures. The comfort temperature of Kapilvastu has been calculated using the Nicol formla, the lowest temperature in which the people of Kapilvastu feel comfortable is 20.3°C, whereas the highest temperature in which the people of Kapilvastu feel comfortable is 28.6°. For KVM School reduction in monthly load is 8% for scenario 2, 22% for scenario 3 and 20.6% for scenario 4.For Udayapur School reduction in monthly load is 41.49% for scenario 2, 31.5% for scenario 3 and 46% for scenario 4.The findings based on calculations Material with lesser U-value can save 10-40% monthly cooling or heating load in summer than uninsulated buildings of Kapilvastu.

Keywords: Adaptive thermal comfort, Comfort Temperature, Adaptive thermal comfort

1. Introduction

Advancement in addressing climate factors in building help to reduce the energy consumption of the building and help to improve the thermal comfort of the occupants according to [1], the correlation of the local climate with the shape and the thermal performance of the building is the major considerations of the passive design approaches to reduce the energy use of the building and increase the thermal comfort of the occupants. However, improving the indoor environment and reducing building's energy consumption is one of the conflicting criteria [2]. Buildings sector only consume up to 40 % of the total energy consumed in developed countries, whereas it is anticipated that developing nations will likely consume more energy than advanced nations by 2020 [2]. The students spend about their 30% of daily lives in school [3].Thermal comfort is one of the most important indicators for indoor quality and it is defined through [Ansi/Ashrae.] as the state of mind that expresses satisfaction with the thermal environment in which it is located. Thermal comfort is affected by different parameters like heat, conduction, radiation, convection and heat losses by evaporation. The building design code which has been issued by the Government of Nepal which does not address the issue of thermal comfort ,so it is major cause for the performance of poor indoor thermal comfort [4]. Schools are one of the building types necessarily of great interest when we consider the potential links between building performance, general sustainability, and the benefits of productive ,a healthy,and comfortable environment [5]. Thermal conditions in class- rooms have to be considered carefully mainly because of the high occupant density in classrooms and because thermal dissatisfaction cause negative effect on learning and performance of the students [6]. [7] Points out that the envelope of a building is not only a separator from the external environment but it acts as a prevention for climatic elements and protect the building directly. A building interacts with the environment through its external facades such as roof, walls, openings, floor and projections referred as building envelope. The envelope acts as a thermal envelope, which if thoughtlessly constructed, would result in energy leaks through every component. Therefore, each components of buildings needs to be properly chosen to ensure an energy efficient building. [8]. Most of the developed countries are conducting the thermal comfort survey in school buildings and other types of buildings. But in case of Nepal, study on thermal comfort in school building has not been studied. Few number of research has been conducted in a residential buildings [9] [10].

Need and Importance of research

In case of Nepal Most of the existing schools in have been constructed without any concern of the occupants thermal comfort and the adjustment of the buildings to the local climate, so there is necessary to provide thermal comfort for the occupants and maintain quality of construction of the school building. Exploring the thermal environmental comfort in school building is very important because children are very sensitive to temperature variations, in context of physical comfort there should be serious consideration it is a critical issue. [1] Study of thermal comfort in Terai region Nepal is very necessary in case of school building of Terai region. However light building material with less U value are recommended for the hot and humid monsoon season. Light weight and well insulated roofs are recommendable for this climate [11]. According to kathmandupost 135,427 students are studying in 431 community schools and other educational institutions in Kapilvastu. Many researches and experiences on the residential, office buildings and other commercial building has been done but almost nothing has been done in the passive school buildings [9].

Research objective

Main Objectives

- Main objectives of the study is to increase thermal condition of the school building by upgrading thermal comfort in the indoor area.

Specific objectives of the research

- To report the thermal environmental conditions of classrooms in the schools of Kapilvastu.
- To find out comfort temperature of the study area.
- To differentiate effect of envelope in the uninsulated school building with thermally insulated building material.

2. Materials and Methods

2.1Study Area

The research has been carried out in the schools of Boadgaun area of Kapilvastu district. Qualitative and exploratory research is carried out to gain in depth knowledge regarding the study of thermal environmental state of in the classroom of school building. The data collection was carried out in the field. The primary data collection included the measurement of air temperature, school detail measurement in the field whereas secondary data collection included climatic data of Kapilvastu from Department of Hydrology and Metrology.

Figure 1 Location of Kapilvastu on the map of Nepal (Department of hydrology and meteorology)

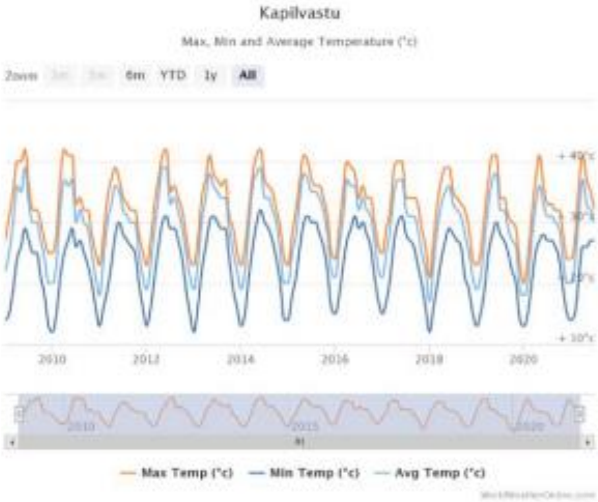
Climate of Kapilvastu

Kapilvastu district is located at a height of 93 to 1,491 meters (305 to 4,892 ft) above sea level, which lies in subtropical and warm temperate climatic region. In the summer season the temperature reaches above 27 °C and similarly in the winter temperature remains bebelow 15 °C .

Table 1Climatic zones in Nepal (Source: Borgkvist, I. 2017)

		Winter	Summer
Sub-tropical	0-1200	15	>30
Warm temperate	1200-2100	10	24-30
Cold temperate	2100-3300	<5	20
Alpine	3300-5000	<0	10-15
Tundra	Above 5000	<0	<0

Geographically, the Kapilvastu district has been divided into the low land plains of Terai and the low Chure hills. Its climate is extremely hot upto 41°C and humid in summer and very cold and fuggy in winter.



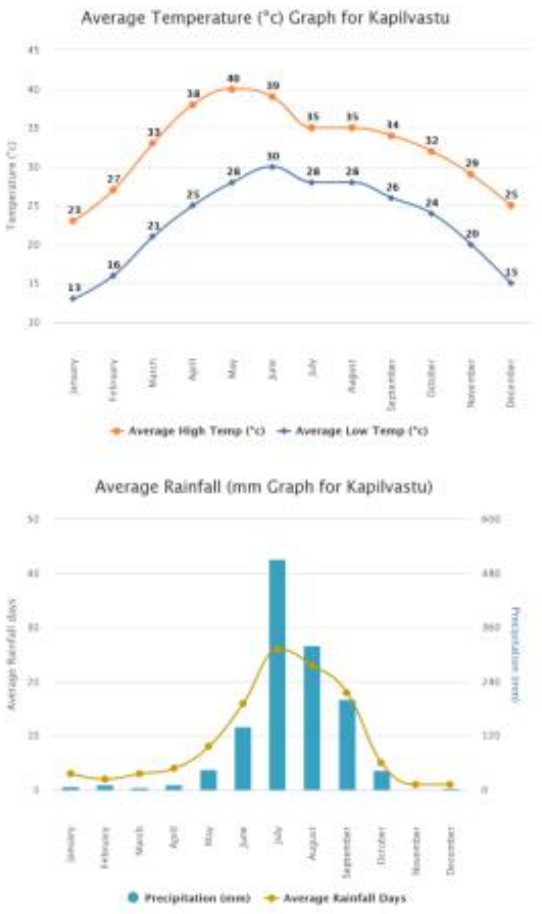


Figure 2Graphs showing max., min., average temperature (C); average rainfall (mm) (Source: Weather online.com)

2.2 Building Description

Three different types of school were selected for the measurement of air temperature in order to investigate the difference in indoor temperature and compare the temperature variation of investigated building. The schools are Kapilvastu Vidhya mandir (KVM), Udayapur School and Shainik Shining English School . The investigated School were based on the indicators like measurement of air temperature, size of openings and materials used in the house. On the basis of these parameters the findings has been formulated.

1. School 1: Kapilvastu Vidhya Mandir School: Two storied RCC modern frame structure building with brick wall and RCC roof.

Table 2 Detail of school 1

Element	Description	Details
External walls	Total area: -3088 sq.ft Wall thickness: 9" Insulation: no	9"brick wall + 15 mm cement plaster
Roof	Total area:4004 sq.ft Insulation: no	125 mm reinforced concrete slab
Floor	Ground floor area: 3088 sq.ft Firstfloorarea:3088 sq.ft	Heavy concrete slab of 125mm
Windows	Total window area = 648 sq.ft No of Classroom windows=24 no	Single-glazed 6 mm windows + wooden frame
Room Height	10'	

2. School 2: Udayapur School: One story building with CGI roof.

Table 3 Detail of school 2

Element	Description	Details
External walls	Total area: -3055 sq.ft Wall thickness: 4" Insulation: no	4"brick wall + 15 mm cement plaster
Roof	Total area3187 sq.ft tiles Insulation: no	CGI roof 1 mm Roof thickness
Floor	Ground floor area: 3055 sq.ft	M15 Concerete for DPC of 100mm thick
Windows	Total window area = 240sq.ft No of Classroom windows=12 no	Wooden windows + wooden frame
Room Height	10'	

3. School 3: Shainik Shining English school: Single storied RCC modern frame structure building with brick wall and RCC roof.

Table 4 Detail of school 3

Element	Description	Details
External walls	Total area: -3132 sq.ft Wall thickness: 9" Insulation: no	9"brick wall + 15 mm cement plaster
Roof	Total area3150 sq.ft tiles Insulation: no	125 mm reinforced concrete slab
Floor	Ground floor area: 3132 sq.ft	Concerete slab of 125mm
Windows	Total window area = 360sq.ft	Wooden windows +

	No of Classroom windows=18 no	wooden frame
Room Height	10'	

2.3Methods

The research has been carried out in the schools of Boadgaun area of Kapilvastu district. Qualitative and exploratory research is carried out to gain in depth knowledge regarding the study of thermal environmental conditions of classrooms in the school building of kapilvastu. The data collection was carried out in the field. In order to fulfill the defined objectives, different research indicators has been selected, on the basis of which thermal performance has been carried out. On the basis of literature review different research indicators like measurement of air temperature, building orientation, thermal transmittance (U-value) of materials used and size of the door windows, size of wall were considered. After selection of indicators the data collection was carried out in the field. The primary data collection included the measurement of air temperature, school detail measurement in the field whereas secondary data collection included climatic data of Kapilvastu from Department of Hydrology and Metrology. The thermal environmental conditions of classrooms in the schools of kapilvastu was measured and analyzed. By this we achieve our First objective of the study. The comfort temperature of Kapilvastu has been calculated using the Nicol adaptive thermal comfort model. By this we achieve our second objective of the study. To achieve our third objectives, the thermal behavior of different building materials are analyzed in Ecotect software. For the simulation two different structure building, Kapilvastu vidjya Mandir(RCC frame building) school and Udayapur School (CGI roof building) were selected. The effect of envelopes in uninsulated prototypical schools were compared with thermally insulated by Ecotect simulation.

Air temperature measurement and data presentation

For the measurement of ambient temperature the thermometer (Simple room thermometer of HTC-1) were placed at 3 different school. For the measurement of indoor air temperature the thermometer was placed on the desk of the classroom, desk was placed at the center of classroom. During the summer season from 5 to 15 july, the indoor air temperature of all the investigated building was recorded at three different times of the day i.e. nearly 12:00, 1:00 and 2:00 for ten continuous days.

3. Data Analysis

3.1 Air temperature measurement and data analysis

The ASHRAE Standard 55-2004 recommends a temperature range of 20°C to 24°C in winter season and 24°C to 26°C in summer season with indoor air relative humidity of 50% as thermally comfortable range for humans. ASHRAE also recommends relative humidity to not exceed 65% and fall below 30% ([12].

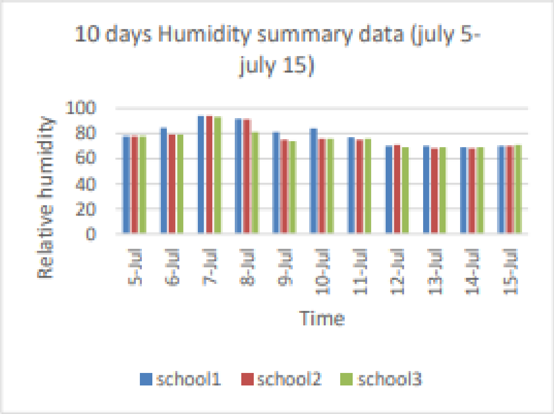


Figure 4: 10 days Humidity summary data

The average indoor temperature is monitored in different schools, during the peak hour from (12pm-2pm).The maximum average temperature recorded in

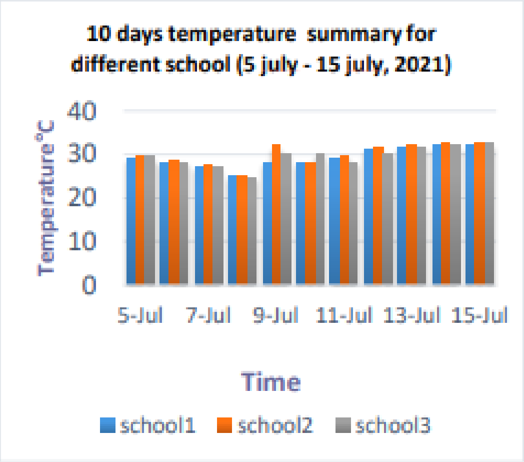


Figure 3:10 days Temperature summary data

the Kapilvastu Vidhya Mandir secondary school (KVM) was 32°C, in the Udayapur school was 32.7 °C, and in Shainik shining English school was 32.4°C. Here we can see the maximum temperature recorded was 32.7°C in Udayapur school,this indicates there was poor thermal performance of the envelope in the Udayapur school. The reason for the maximum air temperature variation in Udayapur school may be due to the use of the use of CGI in roof, which have high U-value.

The average humidity is also monitored in different schools, during the peak hour from (12pm-2pm).The average humidity recorded from july 5 to july 15 in the Kapilvastu vidhya mandir secondary school (KVM) was 79%, in the Udayapur school was 77.6%, and in Shainik shining English school was 78%.

3.2 Comfort Temperature for Kapilvastu

According to Nicol, the 'adaptive comfort temperature' is the temperature which people finds comfortable in a given situation.

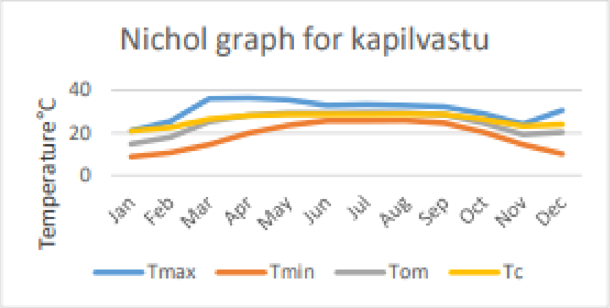


Figure 3 Nichol graph for Kapilvastu

Figure 5 shows Nicol graph for Kapilvastu which start finding the temperature in which people find comfortable to live, in which indoor air temperature varies with mean outdoor air temperature of outdoor temperature . It has been calculated from recent climatic data (1980-2010) of Kapilvastu assessed from Department of Hydrology and Metrology, Government of Nepal. The comfort temperature varies according to the geographical location. The comfort temperature of Kapilvastu has been calculated using the Nicol formula shown in equation.

$$\mathbf{Tcomf = 0.54\ Tom + 12.9 ....(i)}$$

The equation shown above helps for the calculation of Adaptive thermal comfort from monthly mean max (Tmax), monthly mean min (Tmin), monthly mean outdoor temperature (Tom) and monthly comfort temperature of 12 months

As shown in the table fig 5, the lowest temperature in which the people of Kapilvastu feel comfortable is 20.3°C during, whereas the highest temperature in which the people of Kapilvastu feel comfortable is 28.6°.

3.2 Ecotect Simulation

The energy modelling was performed through a simulation tool to compare the effect of envelopes in uninsulated prototypical schools with thermally insulated. To attain this objective, various necessary features of a school building at Kapilvastu was studied.

For the simulation two different structure building such as Kapilvastu vidjya Mandir school (RCC frame building) and Udayapur School (CGI roof building) were selected. The collected documents and drawings were drafted according to site conditions. The software adopted for simulation of the building is Autodesk Ecotect 2011. After combining the weather file in Ecotect, thermal analysis was the major concern to study the comfort level of the building. Parameters such as the monthly load of the building, heat loss and heat gain were calculated for thermal analysis. Also, the building is simulated creating different building envelopes as scenario cases. The focus of the simulation was an investigation of building envelope elements. Different four scenario were created. The results are mainly represented through monthly loads and heat gain and heat loss for a better understanding of the performance of building materials and its subsequent energy requirements. The U-value of Brick wall (1.8 W/m2K) which is higher than other 8" AAC block (0.71 W/m2K) , 3"Eco panel (0.315 W/m2K) and double brick cavity wall (1.780 W/m2K). [13].

Table 5U-value of diffrent materials

Materials for construction	**Materials detail**	**U-value (W/m2 K)**
AAC block	Plaster lining (3 cm) AAC block (20 cm) Sand & cement mortar (3 cm) Exterior stone finishing (2 cm)	0.71
A2 AAC block	Plaster lining (3 cm) AAC block (10 cm) Cavity filled with expanded polystyrene (EPS) (5 cm) AAC block (10 cm) Sand & cement mortar (3 cm) Exterior stone finishing (2 cm)	0.37
Double brick cavity wall	110mm double brick plus 50mm cavity, with 10mm plaster inside.	1.780
Eco panel	Eco panel 30mm Eco panel 40mm Eco panel 50mm Eco panel 60mm Eco panel 75mm Eco panel100mm	0.727 0.563 0.460 0.388 0.315 0.240

Kapilvastu Vidhya Mandir School

Kapilvastu Vidhya mandir is two storey building which has altogether 14 room. The building is facing south direction. The Kapilvastu Vidhya Mandir school is constructed using different construction material stone,brick, mortar plaster, wooden timber etc. The structure of the building is Reinforced Concrete Construction (RCC). The existing buildings is not well insulated and the students of the this area have to accept the variety of indoor thermal conditions.

Table 6 Diffrent scenario for different material

Criteria	Scenario 1(base)	Scenario 2	Scenario 3	Scenario 4
Wall	Wall 9 inch brick wall +inner plaster 15mm	Eco panel 80mm	AAC block 8 inch	Double brick cavity wall
Floor	Floor Rcc125 mm +40mm screed	Floor concrete Rcc125 mm +40mm screed	Floor Rcc125 mm +40mm screed	Floor Rcc125 mm +40mm screed
Roof	Concrete slab 125mm	Green roofing	Green roofing	Green roofing
Openings	Single-glazed 6 mm windows +wooden door	Wooden windows +Hollow core ply wood door	Wooden windows +Hollow core ply wood door	Wooden windows +Hollow +wooden door

Scenario 1 is base line scenario was modelled as an existing scenario. All specification were as per site data collection and conditions. This scenario was modelled with the best possible way to represent the actual finding in the site. Other three different scenarios are created using different material. The material used are AAC block, EPS sandwich panel and double brick cavity wall and Green roofing. Ecotect use known thermal values of the various layers of building material to calculate overall thermal resistance of the system.

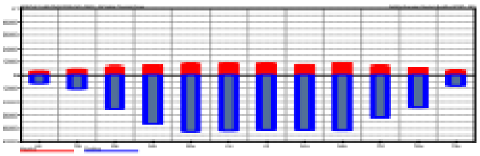
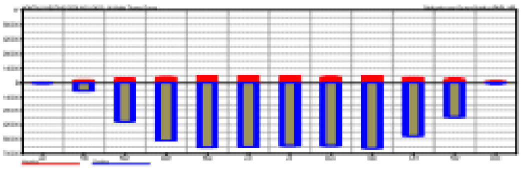


Table 7 Monthly heating/cooling loads base scenario

MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	7467	215	7682
Feb	28577	82282	110858
Mar	41737	391029	432767
Apr	52041	577324	629365
May	65248	639483	704731
Jun	66486	632998	699483
Jul	64367	626024	690391
Aug	55331	623975	679306
Sep	66751	647317	714068
Oct	49016	528816	577832
Nov	36505	347214	383719
Dec	16713	4797	21510
TOTAL	550238	5101474	5651712

Scenario 1:

Heating load required is 550238Wh, Cooling load required is 5101474Wh and total load required throughout the building is 5651712Wh. Max Heatingload required is 637W at 05:00 on 3rd FebruaryMax Cooling load required is 2415W at 13:00 on 8th October.

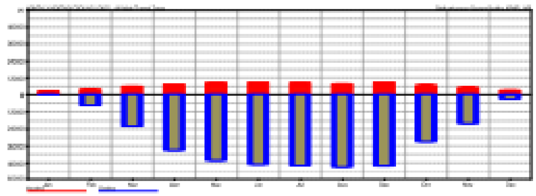


Scenario 2:

Heating load required is 955809Wh, Cooling load required is 4204190Wh and total load required throughout the building is 5159999Wh. Max Cooling load required is 1836 W at 13:00 on 21st May.

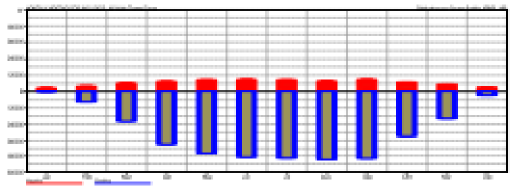
Scenario 3:

Heating load required 686249Wh, Cooling load required is 3721450Wh and total load required throughout the building is 4407699Wh. Max Cooling load required is 1793 W at 16:00 on 31st May.



Scenario 4:

Heating load required 764310Wh, Cooling load required is 3722449Wh and total load required throughout the building is 4486759Wh. Max Cooling load required is 1679 W at 16:00 on 30th June.



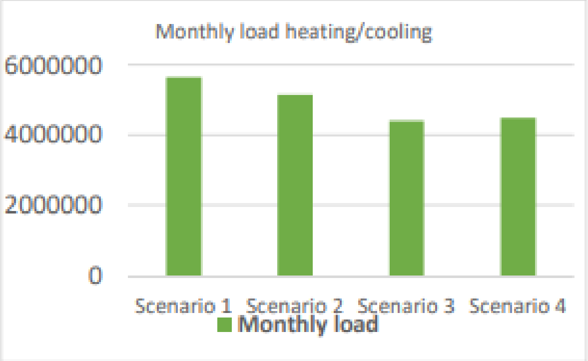
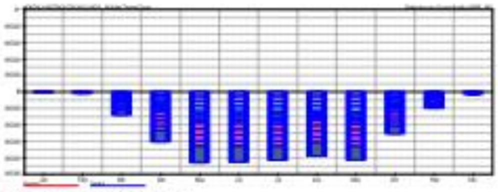


Figure 4 Comparison of monthly total heating/cooling load of different scenario.

Fig above shows the Comparison of monthly total heating/cooling load of different scenario in KVM school. Total monthly load required for scenario 1 is

5651712Wh, for scenario 2 is 5159999Wh, Scenario 3 is 4407699Wh and scenario 4 is 4486759Wh.



Udayapur School

The school building has two blocks. This one storey building has altogether 8 rooms. The buildings is constructed using brick and mortar plaster. The roof structure of the building CGI sheet. Buildings is not well insulated and the students have to accept the variety of indoor thermal conditions

Scenario 1 is base line scenario was modelled as an existing scenario. All specification were as per site data collection and conditions. Other three different scenarios are created using different material. The material used are AAC block, EPS sandwich panel and double brick cavity wall and UPVC roofing. Ecotect use known thermal values of the various layers of building material to calculate overall thermal resistance of the system.

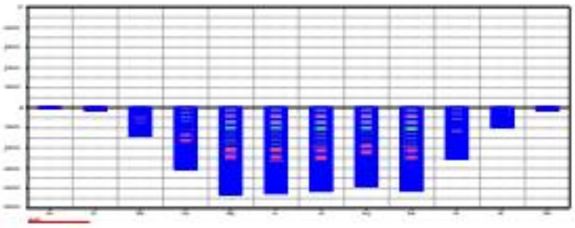
Table 8: Monthly heating/cooling loads base scenario

MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	881440	18683	900123
Feb	327998	652685	980683
Mar	4991	3835512	3840503
Apr	0	7456884	7456884
May	0	9969482	9969482
Jun	0	9659174	9659174
Jul	0	9111987	9111987
Aug	19831	8324052	8343883
Sep	0	8761830	8761830
Oct	0	5888282	5888282
Nov	11098	2862003	2873100
Dec	965432	201077	1166510
TOTAL	2210791	66741648	68952440

Scenario 1:

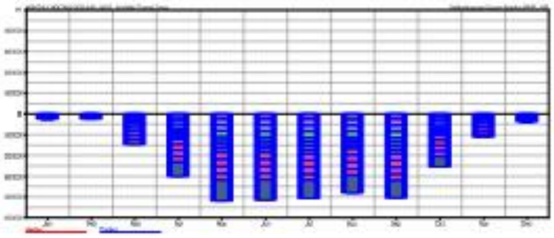
Heating load required is 2210791Wh, Cooling load required is 66741648Wh and total load required throughout the building is 68952440Wh.

Scenario 2: Heating load required is 57187Wh, Cooling load required is 40535120Wh and total load required throughout the building is 40592308Wh.



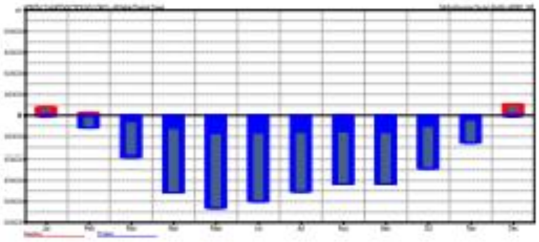
Scenario 3:

Heating load required is 47219Wh, Cooling load required is 47190720Wh and total load required throughout the building is 47237940Wh.



Scenario 4:

Heating load required is 161704Wh, Cooling load required is 37046396Wh and total load required throughout the building is 37208100Wh.



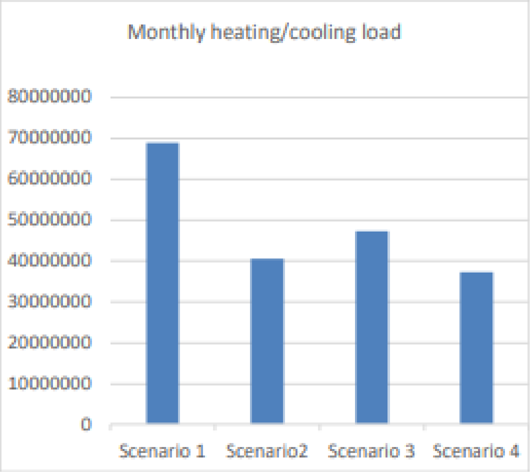


Figure 5Comparison of monthly total heating/cooling load of different scenario

Fig above shows the Comparison of monthly total heating/cooling load of different scenario in Udayapur School. Total monthly load required for scenario 1 is 68952440Wh, for scenario 2 is is 40592308Wh, Scenario 3 is 47237940Wh and scenario 4 is 37208100Wh.

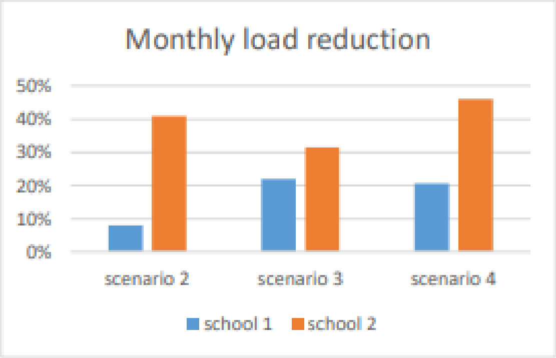


Figure 6 Monthly load reduction

Fig above shows the Comparison of monthly total heating/cooling reduction load of different two school. For KVM School reduction in monthly load is 8% for scenario 2, 22% for scenario 3 and 20.6% for scenario 4. . For Udayapur School reduction in monthly load is 41.49% for scenario 2, 31.5% for scenario 3 and 46% for scenario 4.Reduction in monthly total heating/cooling load is high in Udayapur School.

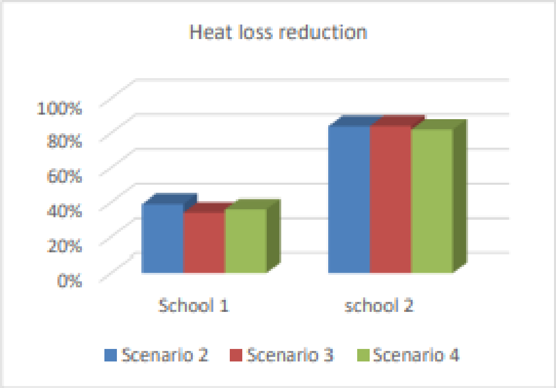


Figure 7Heat loss reduction

Fig above shows the Comparison of heat loss reduction load of different two school. For KVM School reduction in heat loss is 39% for scenario 2, 34% for scenario 3 and 35.9% for scenario 4. . For Udayapur School reduction in heat loss is 75.4% for scenario 2, 75.6% for scenario 3 and 74% for scenario 4.

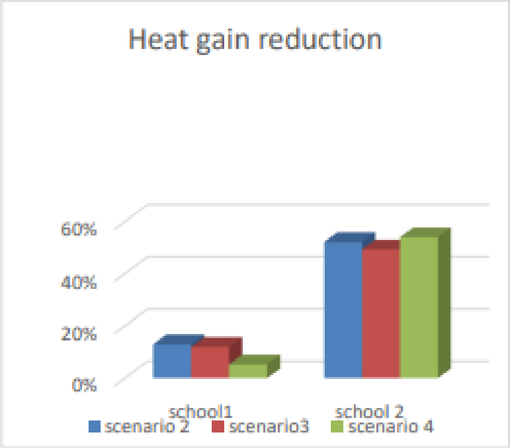


Figure 8Heat gain reduction

Fig above shows the Comparison of heat gain reduction load of different two school. For KVM School reduction in heat gain is 13% for scenario 2, 12% for scenario 3 and 6% for scenario 4. For Udayapur School reduction in heat gain is 52.2% for scenario 2, 49.5% for scenario 3 and 54% for scenario 4.

Table 8Comparison of comfort temperature for diffrent area

Area	Reference	Tc (°C)
Japan (Gifu)	Rijal et al.	26.1
Japan (Kanto)	Japan (Kanto)	27.6
Nepal	Rijal et al.	21.1~30.0
Pakistan	Nicol & Roaf	26.7~29.9
Nepal(Dang)	Bajracharya, S. B.	17~27.6
Nepal(kathmandu)	Bajracharya, S. B.	18~26
Nepal(Kapilvastu)	This study	20.3~28.6*

Table above shows comparison of comfort temperature with existing research in summer. Figure above shows summary of studies of thermal comfort conducted in the different areas to evaluate thermal comfort status of students in the different school buildings. The research has been carried out in the different regions like japan, Pakistan and different places of Nepal. From the several studies it is clear that adaptive thermal comfort is crucial in the school buildings. The comfort temperature for Nepal lies between 21.1(°C)-30 (°C) from the Nichol thermal adaptive comfort model. This study found the same value of thermal comfort i.e 20.3°C-28.6°C.

4. Conclusion

This paper represents thermal comfort study which was conducted for the first time in case of school buildings in Kapilvastu district Nepal for summer season. The first objective was to report the thermal environmental conditions of classrooms in the schools of kapilvastu. The maximum average indoor temperature recorded in the Kapilvastu Vidhya Mandir secondary school (KVM) was 32°C, in the Udayapur school was 32.7 °C, and in Shainik shining English school was 32.4 °C. The second objective was to find the comfort temperature of the study area. The comfort temperature which the people of Kapilvastu feel comfortable is 20.3°C , whereas the highest temperature in which the people of Kapilvastu feel comfortable is 28.6°.Third objective was to compare the effect of envelopes in uninsulated prototypical schools with thermally insulated. Insulations and material with lesser U-value can be good in order to achieve the better result for the thermal comfort in the school building. Heidari [14]. Estimates that each degree reduction in heating/cooling loads results in 7% energy saving. The heat gain data generated by the software were compared and analyzed. Material with lesser U-value can save 10-40% monthly heating or cooling load in summer than uninsulated buildings of Kapilvastu.

5. Recommendation

Insulations and material with lesser u-value are good in order to achieve the thermal comfort in the school building. While designing we should give concern for the comfort of the occupants and the adaptation of the buildings to the local climate. Passive and low-energy cooling solutions need to be incorporated in the design phase, in order to avoid mechanical cooling systems. It is recommended to designers to use the environment friendly materials to improve the thermal condition of the building.

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