THERMAL PERFORMANCE OF DIFFERENT BUILDING TYPOLOGIES IN THIMPHU

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Abstract— *The building sector in Bhutan is responsible for 42% of total energy and consumes 242,916 TOE of thermal energy. The maximum thermal energy was used for space heating. As per the studies conducted on the energy efficiency of the buildings in Bhutan, the buildings are found to be the worst performance in terms of thermal and airtightness. Without the proper insulation, lack of choice of the building materials as per the climatic conditions and lacks of awareness in the society about the green building practices has led to poor indoor quality of life. Buildings located inthe high region are found to be uncomfortably cold during winter months. This research focuses on studying the thermal performance of different building typologies. The main findings of this research were on enhancing indoor thermal comfort and reducing heating energy demand by the incorporation of passive measures. The results were achieved by simulating the buildings in EnergyPlus software using the data collected from questionnaires and field surveys. The simulation results showed that among the investigated buildings, a concrete hollow block wall located at Kabesa has the less comfort hour of 15% at the existing condition. When passive interventions were incorporated into the building, the thermal comfort hours were achievable up to 32% with the load reduction potential of 65%.As for the traditional house with the adobe brick wall and timber wall at Changdagang, had more comfort hours than the building located at Kabesa. With the different set of passive intervention, it was found that comfort hour of 38% to 41% and load reduction of 25.9% can be achieved for the building with adobe brick wall and timber wall respectively. Whereas for stone masonry with cement mortar and RCC framed structure located at Begana and Langdru had a thermal comfort hour of more that 30%. However, RCC framed structure was reported to have huge demand for heating energy compared to stone masonry with cement mortar. The passive intervention prepared for RCC and stone masonry had the potential to achieve 41%-57% of thermal comfort hours. The results from all the investigated buildings revealed that the inclusion of passive design could improve indoor thermal comfort and can achieve a reduction in heating energy demand.*

Keywords—thermal performance, passive intervention, building energy simulations.

1. INTRODUCTION

Globally, the buildings and construction sector contribute 36% of the total energy consumption and 39% of carbon dioxide (CO2) emissions [1]. The building sector in Bhutan is categorised into two segments: residential segment and commercial and institutional segment. The building sector consumed 42% of the total energy in 2014 [2]. The energy consumption in the building sector is in the form of electricity, biomass and liquefied petroleum gas. In 2014, 86% of biomass and 8% of electricity were consumed in the residential segments for heating, cooking and lighting [2].

As for thermal energy consumption, the building sector accounts for 242,916 TOE, which is equivalent to 52% of the total energy consumption. Traditional houses in Bhutan are mainly constructed with locally available materials such as rammed earth being the sustainable and energy efficient material and timber, and modern houses are dominated by reinforced concrete cement (RCC) construction with steel frames and bricks. Corrugated iron sheets are used for roofs and single glass aluminium is provided for most of the windows, but in general, the buildings in Bhutan are found to be the worst performance in terms of thermal and air tightness. The buildings are not adequately insulated, and the heat loss through doors, windows and roofs accounts for about 20 to 25% of total heat loss [3].

The rammed earth wall, with its thick thermal mass absorbs and retains solar energy and keeps the room warm. However, the cracks and gaps between the walls, window frames and floorboards are the significant causes of air leaks. Due to this, external sources like electric heaters are needed to make the spaces thermally comfortable.

With the urbanization and introduction of new building materials in the construction sector, there has been a decline in the construction of buildings with traditional methods. Especially in a fast growing city such as Thimphu, most buildings are dominated by reinforced concrete cement (RCC) with steel frames and bricks. As the modern construction designs and technologies are imported from India, it is found to be formalised pattern rather than a contextual scenario with the local environment [3]. The modern construction practice lacks green building design, materials and construction methods, which lead to poor indoor quality of life. Particularly at the higher elevations, the homes are uncomfortably cold during the winter months [3].

To improve the indoor quality of life and make the spaces thermally comfortable, energy consumption in the building sector continues to rise. Thimphu, with population of around 104,200, consumes the highest quantity of energy compared to the rest of the district in Bhutan. As per the study conducted on household energy consumption in Thimphu, 8,378.27 TOE (59.69%) was found to be the primary source of energy. Out of which, 34.47% has been consumed for space heating [4]. Therefore, retrofitting and incorporating passive measures to the existing buildings, especially in Thimphu, can reduce heat loss and save the heating energy demand. This research will focus in five buildings with different wall materials located in Thimphudue to the increase in energy consumption;

population density and different construction types expected to be found in Thimphu.

2. METHODOLOGY

This research work focuses on the heating energy demand and the indoor temperature of the selected sites. For the each investigated building, simulations are performed based on the data collection, questionnaire survey and blower door test. The flow chart below shows the detailed research approach.

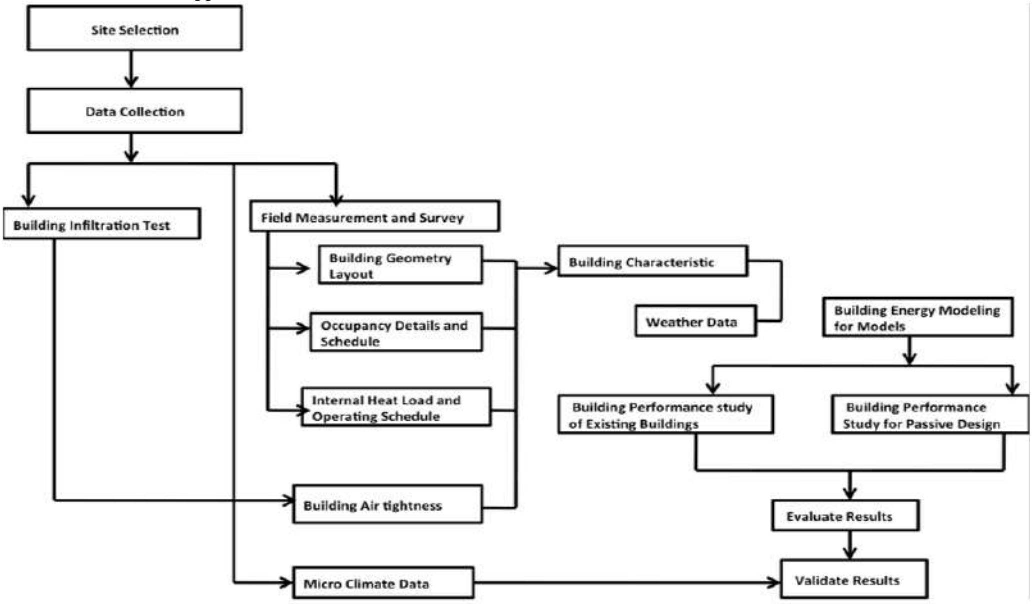


Fig. 1. Research Methodology Flow Chart

2.1. Identification of Study Location and Site Selection

Thimphu being the capital city of Bhutan with a population of 104,200 is considered one of the most energy consuming districts of Bhutan [5]. The construction of buildings of different types is expected to rise in the coming years. Therefore, the identification of study location was made based on population density, increasing demand of energy consumption, and different buildings typology found in Thimphu. A total of five buildings with different wall materials are selected. As all the case study buildings are located in Thimphu, the weather data are identical and only minimum variation in altitude was found. The descriptions of study locations are given in the table 1 below.

TABLE 1. Description of Study Location

Location (Thimphu)	Building Type	Altitude in Meters	Floor Area (m^2)
Kabesa	RCC Framed with Concrete Hollow Block	2455	109
Changdagang	Traditional House with Adobe Brick Wall	2524	87.5
Changdagang	Traditional House with Timber Wall	2524	50.2
Begana	Traditional House with Stone Masonry	2485	59.4
Langdru	RCC Framed with Red Brick Wall	2713	69

2.2. Data Collection

The building energy performance for the selected sites were investigated using questionnaire survey regarding the occupancy schedule and operating schedule for the electric load, micro indoor and outdoors climate data, electricity consumption, and building airtightness was carried out. In the following paragraph, each of the data collected is explained in detail.

2.2.1. Questionnaire Survey

The questionnaire survey was conducted on all the five sites selected for this research work. The survey questions contained the types of construction materials used, number of occupants and their schedule, totalkitchen appliances in the households, operation pattern, and lighting load. Along with the questionnaire, the measurements of the building dimensions were carried out using the measuring tape.

2.2.2 Blower Door Test

To determine the thermal performance of the building, it is important to consider the building's airtightness and the insulation. The unintentional flow of air from the outside leads to an increase in heating energy demand, especially for the buildings located in cold climates. The building's airtightness test indicates how leaky the building is. To determine the leakage of case study buildings, a blower door test was conducted following the blower door operation manual [6]. Before the actual test was conducted, the building dimensions were measured. The indoor and outdoor temperatures were measured using the temperature sensor required for the test.

Fig. 2. Blower Door Test

As shown in above figure 2, the speed variable fan was mounted in the temporary adjustable panel frame setup on the exterior door. The manometer was connected to the fan and the outside through the small pressure tube. The pressure difference between the inside and outside of the buildings was created where to measure the rate of airflow through the fan. The measured valued was then normalized into the air change rate. To find the air leaks in the buildings, the buildings were depressurized to a constant pressure difference of 50 Pa. Usually, the test pressure difference ranges from 40 and 60 Pa and the results at higher pressure differences are considered to be accurate. The blower test results are standardized at 50 pa and are considered to be the preferred value for blower door testing. For this research work, the blower door test result was used for the building energy simulation.

2.2.3. Micro Climate Data

The thermal performance of the buildings is greatly influenced by the climatic conditions of the regions [7]. A region where the temperature is hot needs an air cooler to keep the room cool and an electric heater for the cold places. Climate plays a vital role in the determination of building energy consumption. Buildings designed regarding the region's climatic conditions are considered energy efficient, environmentally friendly and achieve the highest degree of thermal comfort [8]. The real-time indoor and outdoor temperature and humidity of case study buildings were monitored using the UT330 USB data loggers. To study the outdoor temperature, two data loggers were placed at the case study building located south and north of Thimphu. The data loggers were placed in an area where it was exposed to the outdoor weather condition without exposing to direct solar radiation.

Fig. 3. UT330 USB Data Logger [9]

For the measurement of indoor temperature and humidity, the data loggers were placed only at one case study building (Kabesa). It was placed inside the bedrooms and living room to study the indoor operative temperature. The measured indoor temperature was later used to calibrate the computer model.

2.4 Building Energy Modelling

The building energy modelling of the case study buildings was done using the energy plus software through OpenStudio graphical user interface (GUI). The OpenStudio plugin Sketchup was used to draw the models for the selected buildings. Some of the steps used for the building's energy modelling are discussed below.

2.4.1. SketchUp

For all five selected sites, CAD models were drawn using SketchUp Make 2017. After the dimensions of the building were measured, the model geometry was created using SketchUP. After the model geometry, the surface matching for the models was done. The surface matching was necessary so that the internal walls were considered as interior surfaces and external walls as exterior surfaces by the software. Figure 3.5 shows the surface matching done for Changdagang (timber) case study building, where the green colour indicates the interior wall and the blue colour as the external wall. Then the space types and thermal zones were assigned to the models, as shown in Figure 4.

2.4.2. OpenStudio and EnergyPlus

Once the model geometry with thermal zones and space types were done in SketchUp, OpenStudio was used to create the materials, assign the construction materials, create occupancy schedules, assign internal loads and their plans and display the results. The occupancy and internal load schedules were done based on the survey conducted. The construction materials were created as the actual materials used in the selected sites. After all the construction materials and schedules were assigned, the EnergyPlus simulation engine was used to estimate the energy consumption of the case study buildings. The simulation results were displayed both in OpenStudio and EnergyPlus.

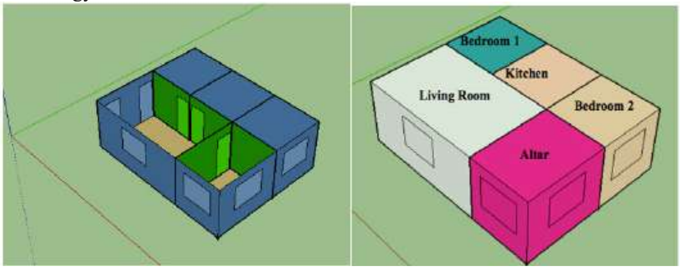
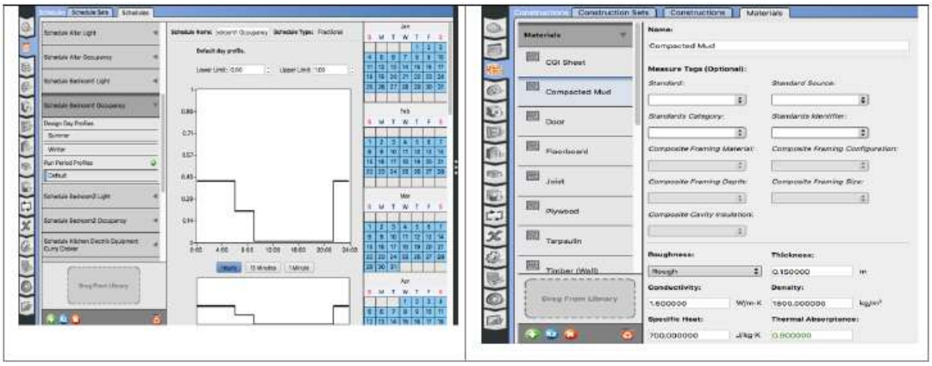


Fig.4. Surface Matching and Space Types

Fig. 5. Occupancy Schedules and Construction materials in openStudio



3. RESULT AND DISCUSSION

All the important results such as blower door results, indoor temperature of the case study buildings and heating energy demand are discussed here. The heating set point is defined as 18°C and 24°C as cooling set point to calculate the heating and cooling energy demand. However, for this research cooling energy demand is not considered as all the selected site are located at Thimphu. The schedules are prepared based on the survey response of the occupants. To find out whether there is an increase in indoor temperature and reduction in thermal load, various passive interventions are incorporated into the models of the existing buildings.

3.1 Blower Door Test Results

The blower door test was conducted on all the five sites selected for this research work. It determines how leaky the buildings are. The table below shows the blower door test result of sites in ACH (n50). From the results, it can be concluded that the traditional house with timber wall at Changdagang with 14.90 ACH/h was found to be the worst performance in terms of air tightness. The leakage was visually identified between the window, doorframe, and the spaces between floorboards.

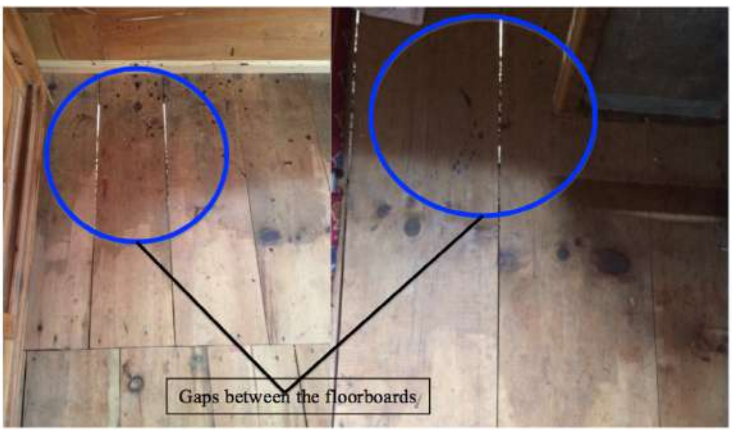


Fig. 6. Spaces Between the Floorboards at Changdatang (Timber)

As shown in Figure 6, the unintentional airflow was observed from the spaces between the floorboards at Changdagang. The floorboard was directly placed on the joist and the space between the ground and floorboard were about 50cm. Due to this, the ACH value for the Chandagang (timber) was found to be higher than the other selected sites. The RCC framed with a red brick wall at Langdru with 5.54 ACH/h was found airtight among the investigated buildings.

The results value from the blower door test is the air change rate at 50 Pa pressure differences, which represents the mean value of depressurize measured at 50 Pa. As per the research done on the "field study of the building physics properties of common building types in the inner Himalayan valleys of Bhutan," by Mark F. Jentsch and the team, from the n_{50} data, the mean air infiltration (n_{inf}) into the buildings was considered with the wind-shielding coefficient (e).

$$n_{inf} = n_{50} e$$

The wind shielding coefficient (e) value as assumed to be e=0.07 as per the ISO 13789:2007 [10]. Therefore for this research, the same method has been adopted and the value of mean air infiltration was considered as deemed representative of all the investigated buildings. The reduced value or (n_{inf}) was used in the energy simulation of the building.

TABLE 2. Blower Test Results

Building Types	Building Location	ACH at 50 Pa (n_{50})	(n_{inf})
RCC Framed with Hollow Block Wall	Kabesa	6.56	0.45
Traditional House with Adobe Brick Wall	Changdagang	6.64	0.46
Traditional House with Timber Wall	Changdagang	14.90	1.04
Traditional House with Stone Masonry	Begana	8.90	0.62
RCC Framed with Red Brick Wall	Langdru	5.54	0.38

3.2. Building Thermal Performance Study

For the building energy simulation, weather data is one of the most important parameters, which determines the energy consumption of the selected sites. For this research work weather data from photovoltaic geographical information system (PV GIS) software has been used. The building thermal performance has been conducted on all the five investigated sites with different typologies in the OpenStudio software.The table below shows the buildings description of individual selected sites. As per the descriptions such as type of wall materials used, orientation, floor size and window and door construction, the energy simulation is performed.

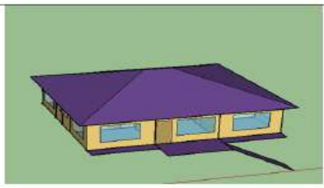
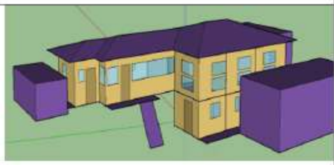
TABLE 3. Building Description of Selected Sites

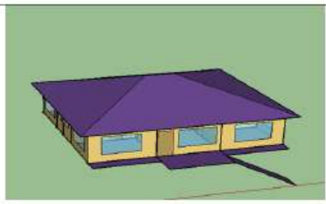
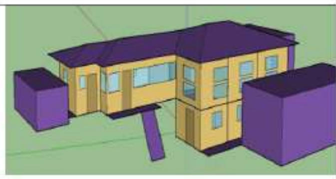
Building Types	Building Descriptions	
Kabesa (Bldg-1)		Constructed with reinforcement cement concrete 200 mm thick concrete hollow block wall Floor, door and window made up of timber Building Façade oriented towards southwest
ChangdagangAdobe Block (Bldg-2)		Two-storied traditional house where the walls are made from local earth bricks/adobe blocks. The upper floor is partially in a timber-framed structure known as *rabsel.* The inner walls are constructed with wood. For the flooring, wooden joists are provided and above these joists, wooden planks are placed.
Changdagang Timber (Bldg-3)		One storied residential house with an external wall made up of timber and an internal wall with 4mm plywood board. The façade of the house is oriented towards the East direction. Ceiling is made up of a 40 mm joist and wooden plank, where mud is compacted over it.
Begana (Bldg-4)		Two-storied residential building constructed with stone masonry and cement mortar thickness 525 mm. The ceiling of the building is built with joist, wooden plank and soil. The window frames for both ground and first floor are constructed with timber and 6mm single glaze. The façade of the building is oriented towards the southeast direction and has a floor area of 59.41 m^2.
Langdru (Bldg-5)		One storied residential building, constructed with reinforcement cement concrete (R.C.C) and brick wall of thickness 200 mm. The ceiling of the building is constructed with plywood, and a corrugated iron sheet is used as a roofing material. The internal wall is also constructed with 200mm thick brick and cement plaster on both sides of the wall.

3.2.1. Existing Conditions of the Buildings

Along with the building parameters, the number of occupancy, electrical appliances and the measured indoor temperature are also used in the simulation. The Cad model created using the SketchUp and OpenStudio and the detailed existing conditions of the buildings are given in the table below.

TABLE 4. Existing Conditions of Buildings

Building Types	Existing Conditions of Buildings	
Kabesa (Bldg-1)		It has a floor area of 109m2 Weather data from PV GIS software Reduced infiltration value of 0.45 ACH/h Six thermal zones, living, kitchen, altar and three bedrooms 5 peoples occupy for most of the time in a year 1 set of television and 40W tube light Indoor temperature of living room ranges from 5.08°C to 12.7°C
Changdagang Adobe Block (Bldg-2)		Floor area of 87.51 m^2 Reduced infiltration value of 0.46 ACH/h The building façade is oriented towards Southwest Six thermal zone living room, kitchen, altar and three bedrooms Indoor temperature varies from 5.6°C to 20.8°C

Building Types	Existing Conditions of Buildings	
Kabesa (Bldg-1)		It has a floor area of 109m2 Weather data from PV GIS software Reduced infiltration value of 0.45 ACH/h Six thermal zones, living, kitchen, altar and three bedrooms 5 peoples occupy for most of the time in a year 1 set of television and 40W tube light Indoor temperature of living room ranges from 5.08°C to 12.7°C
Changdagang Adobe Block (Bldg-2)		Floor area of 87.51 m^2 Reduced infiltration value of 0.46 ACH/h The building façade is oriented towards Southwest Six thermal zone living room, kitchen, altar and three bedrooms Indoor temperature varies from 5.6°C to 20.8°C

3.2.2. Thermal Comfort Hours and Heating Energy Demand of Buildings at Existing Condition

For the investigated buildings, the simulated result determines, how thermally the buildings are comfortable for the occupants. As the heating and cooling set point is 18°C and 24°C, respectively, the temperature below 18°C is counted as heating degree-days and temperature above the 24°C is counted as cooling degree-days. As the indoor temperature is below 24°C for all the selected buildings, the cooling degree-days is 0. The simulated results shows that the total comfort hours spent are less than 50% at the exiting condition of the buildings and the heating energy demand is very high with 549.58 MJ/m2 for Kabesa (Bldg-1) as given in the table below.

TABLE 5. Simulated Results at Existing Condition

Building Types	Locations	Thermal Comfort Hours (18°C to 24°C)	% Of Total Hours	Heating Energy Demand (MJ/m^2)
Bldg-1	Kabesa	983	11.2	549.58
Bldg-2	Changdagang	2670	30.4	343.51
Bldg-3	Changdagang	2670	30.4	532.1
Bldg-4	Begana	2764	31.6	186.64
Bldg-5	Langdru	3630	41.43	520

3.2.3. Passive Intervention to the Case study Buildings

To improve the thermal comfort hours and reduce the thermal load of the zones, passive measures are intervened in the wall, floor, ceiling, and windows of all the case study buildings. The passive measures such as using insulation,double glazing and making the rooms more airtight by sealing the gaps can be adopted by every one and its less expensive compare to use of electrical appliances. As given in the table below, as the means of passive measure, two types of insulations namely expended polystyrene and mineral wool are considered on the wall, ceiling and floors.

TABLE 6. Passive Measures For the Buildings

Buildings	Locations	Double Glazing	ACH Value	Insulation	
				Expended Polystyrene	Mineral Wool
Bldg-1	Kabesa	12mm	0.45	25mm thick considered on both side of the wall	100mm considered for ceiling
Bldg-2	Changdagang	12mm	0.46		100mm considered for the external wall and ceiling
Bldg-3	Changdagang	12mm	1.04	25mm considered between timber and plywood of external wall	100mm considered for ceiling and floor
Bldg-4	Begana	12mm	0.5	25 mm considered on the inner side of the wall	50mm mineral wool considered for the ceiling
Bldg-5	Langdru	12mm	0.38	25mm considered for both side of the wall	8mm for the floor and 100mm for the ceiling

3.2.4. Thermal Comfort Hours and Heating Energy Demand of Buildings with Passive Intervention

With the passive intervention into the buildings, the simulated results shows that there is an increase in thermal comfort hours and reduction of heating energy demand. The percentage of total thermal comfort hours is more than 50% and there is drastic reduction of 191.81 MJ/m2 heating energy demand at Kabesa (Bldg-1).

TABLE 7. Simulated Results with Passive Intervention

Building	Location	Thermal Comfort Hours (18°C to 24°C)	% of Total Hours	Heating Energy Demand (MJ/m^2)
Bldg-1	Kabesa	2884	32	191.81
Bldg-2	Changdagang	3357	38	254.46
Bldg-3	Changdagang	3619	41	249.02
Bldg-4	Begana	3508	40	153.92
Bldg-5	Langdru	5025	57	123.04

3.3. Comparative Study on Heating Energy Demand of Investigated Buildings

Due to the different orientation of the buildings, a number of occupants and their schedules, electrical load and operating schedules, infiltration rate, and various construction materials, the heating energy required for the buildings are found to be different.

Among the Five different typologies, Begana (Bldg-4) with stone masonry required less heating energy demand of 186.64 MJ/m^2. The building's façade was oriented towards southeast and most of the windows were faced towards the south where the maximum sunlight was received. The external wall was constructed with stone masonry bonded with cement mortar of thickness 525mm. The internal wall was wood-panelled, which served as the insulation material. Due to the high thermal mass, the solar gain received during the day was not lost immediately whereby keeping the room temperature high and heating energy demands less. With the infiltration rate of 8.90 ACH (reduced to 0.62 ACH), Bldg-4 was found to be airtight compared to Changdgang timber (Bldg-3). Only one person occupies the Bldg-4 most of the year with minimum usage of electrical appliances.

As for the maximum heating energy demand, Kabesa (Bldg-1), constructed with a hollow block wall, required 549.58 MJ/m2 of heating energy. Five people occupy Bldg-1 with maximum usage of electrical appliances. The building façade is oriented towards Southwest. Even though the full sunlight was received through the south facing windows, due to the less thermal mass of the wall with a thickness 200mm, the inability of the wall to retain heat and infiltration rate of 6.56 ACH (reduced to 0.45), more heating energy was required to make the spaces thermally comfortable.

The heating energy demand of Changdagang timber (Bldg-2) and Langdru (Bldg-5) was 532.1 MJ/m^2 and 520 MJ/m^2, respectively. The Bldg-2 constructed with the timber wall material of thickness 25mm and 4mm plywood has the highest infiltration rate of 14.90 ACH/h among the investigated buildings. The Bldg-2 is orientated towards East. Even though the maximum sunlight is received through the living room windows facing south, the high ACH value and less thermal mass of the wall to retain heat makes the room cold and increases the heating energy demand. For most of the year, only five people occupy Bldg-2 with minimum usage of electrical appliances.

Langdru (Bldg-5) with the red brick wall material was found to be more airtight compared to other investigated buildings. The front façade of the buildings is oriented towards the southwest. The closed corridor and laundry room located in front of the living room and altar room shaded any sunlight received through the windows, which made the room cold and increased the heating energy demand.

Compared to Bldg-2 and Bldg-5, Changdagang with adobe block wall (Bldg-2) has less heating energy demand of 343.51MJ/m^2. The façade of the building is oriented towards the Southwest and all the solar gainfrom the building envelope such as (windows, walls, and doors) are retained for a longer duration due to high thermal mass of the wall where by making the room warm with less heating energy demand.

To the above investigate buildings, the passive measures such as adding insulation to the wall, ceiling, and floor and considering double-glazing for the windows, the heating energy demand reduces. For the buildings, Bldg-1, Bldg-3, and Bldg-5, the wall, ceiling and floor insulation and double-glazing window, the heating energy demand reduces to above 50%. As for the Bldg-2 and Bldg-4, considering the high thermal mass of the wall and incorporating the insulation to the ceiling, external wall and floor, the heating energy demand was reduced to 25% and 17% respectively.

4. CONCLUSION

The concept of energy efficient buildings is new to Bhutanese society. As almost all the modern buildings designs are adopted from the neighbouring countries like India, there are hardly any attentions given to the performance of the building especially the thermal performance. As buildings are very cold during the winter and hot in summer, this research work has been carried out to study the indoor temperature and thermal load. The five buildings of different typologies from Thimphu have been selected as the case study buildings. The questionnaire survey, airtightness test, indoor operative temperature, type of building construction and the building energy modelling analysis are done for the selected site.

From the blower door test conducted for the selected site, it was found that the Bldg-3 located at Changdagang has the highest infiltration rate of 14.90 ACH /h and Bldg-5 at Langdru with the lowest infiltration rate of 5.5 ACH/h. It can be concluded that, with the increase of ACH value from 1 to 3, the heating energy demand of the buildings increases. The Bldg-1 at Kabesa at the existing condition has the highest heating energy demand of 549.58 MJ/m² conditioned floor area followed by the Bldg-3 with 532 MJ/m² conditioned floor area. The Bldg-4 required the least heating energy demand of 186.64 MJ/m² conditioned floor area.

When the passive measures such as incorporation of the insulation to the ceiling, wall and floor are considered with the double glazing of the windows, the heating energy demand of Bldg-1 reduces to 191 MJ/m² which is equivalent to the 65% and as for the heating energy demand of Bldg-4 with the passive measures, it reduces to 153.92 MJ/m². Therefore, from the building energy modelling results, it can be concluded that the existing building stocks, especially in Thimphu, demands the maximum heating energy and with the minimum passive intervention like providing insulation to ceiling, floor and wall can result in drastic reduction of heating energy demand. Along with the insulation, making the building airtight and sealing the leakage can make the occupants thermally comfortable.

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