A QUICK ENERGY PERFORMANCE SIMULATION OF TYPICAL BHUTANESE RESIDENTIAL BUILDING USING BUILDING INFORMATION MODELLING

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ABSTRACT

Bhutan is a tiny nation located in the Himalayan Mountain between India and China, with scarce natural resources and energy. So, this study aims to examine the energy performance of typical Bhutanese residential buildings by applying building information modelling. The typical Bhutanese residential building uses traditionally plastered brick walls and concrete block walls without insulation, resulting in greater heat loss from the structure. The heat loss from the building has a direct impact on the energy consumption of the building. Throughout most districts, the weather is cold from September to February, and mild with humid temperatures in the summer. The models have been constructed and analyzed using software called 'Open Building Designer' and 'Energy Simulator' under 3 scenarios: concrete block wall/concrete slab, brick wall/concrete slab, and stone masonry wall/timber flooring. The study was carried out on these three scenarios to ascertain the energy consumption, heat loss, and heat gain on the designed period. According to the simulation results, the Bhutanese residential building had a high heat loss from building but less heat intake from outside. Timber flooring and stone masonry wall are preferred in colder region as it can retain more heat if no insulation walls are used. The result also revealed that most of the heat from the structure was dissipated through the walls. Following that, a few types of insulated walls were used for simulation reasons, mostly to improve the building's thermal performance. Heat loss from the structure was minimized up to 46–65% by adopting the insulated walls.
Keywords: buildings, building information modelling, consumption, energy, insulation simulation, slab, walls.

1 INTRODUCTION

In several nations, building information modelling (BIM) adoption has skyrocketed during the last 10 years [1], but in Bhutan, the application of the BIM concept in the construction sector is extremely limited due to a lack of resources. In Bhutan, the building sector utilizes 42% of the total energy consumption [2]. The majority of houses utilize electric heating systems to heat their spaces, whereas none of them use cooling systems and instead rely on ceiling fans to cool their spaces [3]. Therefore, it is important to prevent heat loss and relying on the artificial heating system especially during winter to minimize energy consumption. So, this study aims to examine the heat loss and heat gain in existing models and improve the thermal energy performance by choosing the appropriate materials. Although fundamental tests such as the concrete cube test, basic brick test, water absorption test, tensile test, and so on are performed, energy simulation in the design process is not done, which is critical for building sustainability. In this study, a quick energy simulation was performed to find out the energy consumption, heat gain, and heat loss of an existing residential building with different floors and walls attributes.

2 RELATED LITERATURE REVIEW

The rate of energy consumption in the construction sector, both industrial and residential, is one of the most significant difficulties we face globally [4]. The electricity consumption of Bhutan in the buildings sector is shown in Fig. 1. The household electricity consumption is

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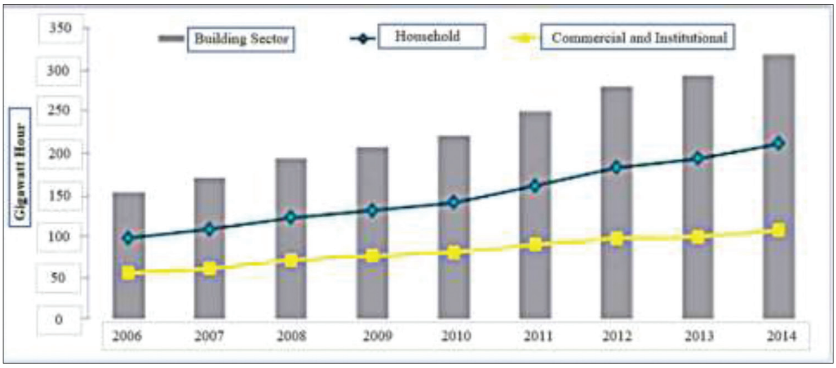


Figure 1: Electricity consumption split by consumer segments under buildings sector (in GWh) (*Source: Developed from power data handbook 2014, Bhutan*).

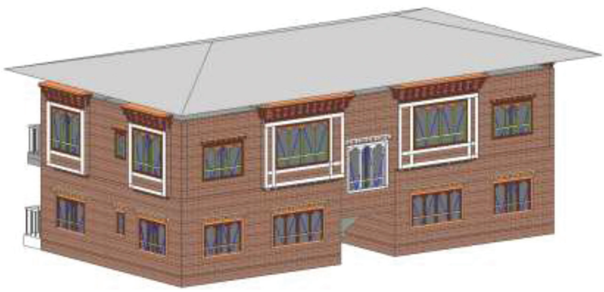


Figure 2: Building model.

much higher than the commercial and institutional buildings. Moreover, the electricity consumption for both sectors is increasing from the year 2006 to 2014. This indicates that more amount of electricity is required in the future in the building sector of Bhutan [2].

Thermal insulation thicknesses of 0.05 m in walls and roofs can save up to 40% of the energy used by air conditioners [5]. The study also found that by upgrading the building envelope, energy consumption can be lowered by up to 15.92% [6]. In hotter climates, shade devices are ideal because they limit solar heat intake and aid cooling [7]. One of the most important aspects of the indoor environment is the room's temperature. When the temperature in the office rises to 21–22°C, people's productivity rises [8].

3 BUILDING MODELS AND ITS SCENARIOS

The building model (Fig. 2) selected was a typical Bhutanese residential apartment building in Bhutan. To conduct energy analysis, the simplified BIM model is created in Open Building Designer. The model consists of multi-family units of the two-storied house. One family unit consists of two bedrooms, one sitting room, two toilets, and a kitchen. The ground floor plan is shown in Fig. 3 which is for the two-family units.

The model consists of windows on all sides of room spaces. The window is made up of 6 mm thick plain glass with an aluminum frame embedded in a wall. The three scenarios of building models were classified as shown in Table 1.

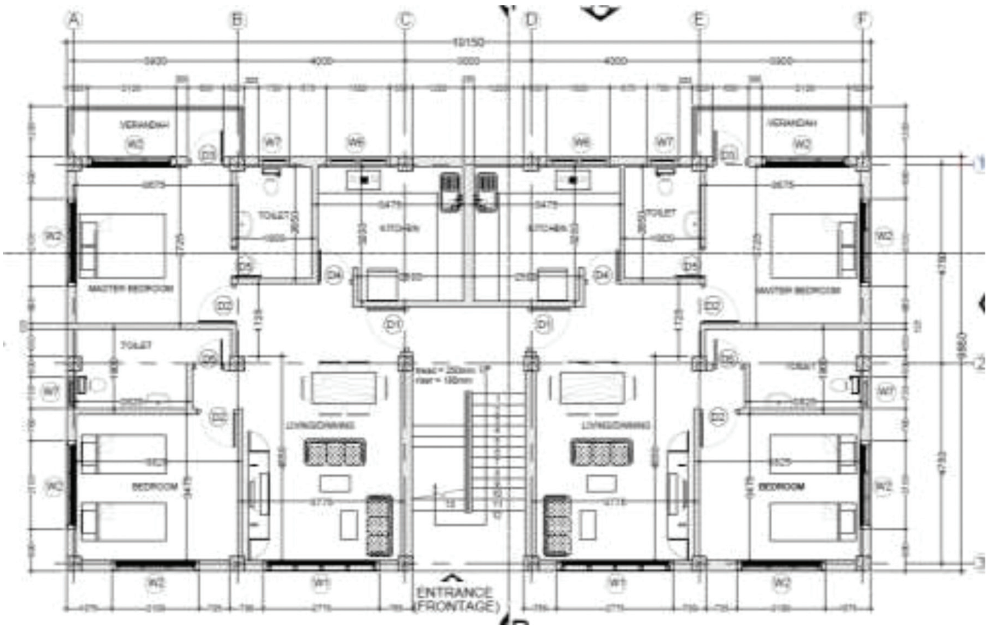


Figure 3: Plan view of ground floor.

Tabel 1: The three scenarios of building models.

Model scenarios	Scenario 1	Scenario 2	Scenario 3
Description	The model was constructed with a concrete block wall and concrete slab flooring.	The model was constructed with brick wall and concrete slab flooring.	The model was constructed with stone wall and timber flooring

4 RESEARCH METHODOLOGY

In this study, the Open Building Designer was used to create the building models. Once the model was created, then space was assigned to individual rooms with names. Space must be created because spaces help to generate the energy model before the simulation. The different scenarios of building models are constructed based on wall and floor attributes that can be directly altered from the wall and floor catalogue once the model is created. The attributes of materials can be changed during energy simulation. The analytical space model can be directly exported from Open Building Designer to simulate and calculate the electricity consumption, heat loss, and heat gain.

4.1 Energy model

Unlike AECOsim Building Designer, the Open Building Designer can directly create and export energy models in Energy Simulator. After exporting the energy model in the energy simulator, the project site and site properties are set in the project tree. In this phase, the building data is defined in the project by setting building location, building type, and climate zone. Or it can also be created separately in Energy Simulator without exporting directly from the Open Building designer. Once the room is created the exposed surfaces like external walls, partition walls, floors, windows, and doors are automatically generated graphically in the project tree. The properties of each room can be changed by clicking on room properties. Window and doors can be also added directly by using add tools from the energy simulator. Windows and doors can be also modified with the project tree as per the requirement. The roof was added to the energy model by exporting the roof layout from the design drawing.

4.2 Simulation

The energy simulator has got various tools that can be used to simulate the building as per the users' requirements. Energy simulators can be used for daylighting study, calculating heat loss and gain, calculating summer heat, and simulating energy usage. After the energy model has been developed, a simulation tap can be used to calculate the building's entire electricity consumption. Similarly, heat gain and heat loss can be also calculated from the CIBSE heat gain tool and CIBSE heat loss tool. Here, CIBSE stands for Chartered Institution of Building Services Engineers. In this study, the CIBSE energy standard was used because the building type was low-rise building. The Heating Ventilation, and Air Conditioning (HVAC) system was not included in the simulation because it is not used in Bhutanese homes [3].

5 RESULTS AND DISCUSSION

The simulation was carried out on all three scenarios to find out the energy consumption of the building. The inside temperature was set to 22°C in all three scenarios. The simulation was set for one year from January 1, 2020, to December 31, 2020. The annual energy consumption was 15301.43 kWh per year that was the same for all scenarios. Thus, each family unit consumes 319 kWh per month. The study also revealed that the average monthly power consumption of the sample households was 300 kWh in Bhutan [3]. Since, only difference of 19 kWh was observed, it is therefore, Open Building designer can be reliable to calculate the energy consumption of buildings.

5.1 CIBSE heat loss calculation

The design day was set on January 21, and the CIBSE heat loss tool was used to simulate the heat loss of the three different model scenarios. The Fig. 4 depicts the total amount of heat lost by each model in percentage. It was evident from the charts that scenario 3 (the model constructed with stone wall and timber flooring) can lose less heat compared to scenario 1 (model constructed with concrete block wall and concrete slab flooring) and scenario 2 (model constructed with brick wall and concrete slab floorings). The major portion of heat is lost through walls followed by glazing and minimum heat loss through roofs. The concrete block wall and brick wall lose more heat than the stone wall.

5.2 CIBSE heat gain calculation

The design day was set on July 21, and the heat gain simulation of three different scenarios of models was carried out using the CIBSE heat gain tool. Figure 5 shows the total heat

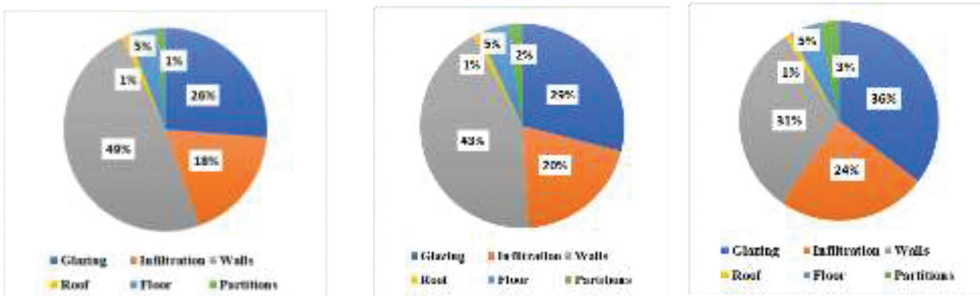
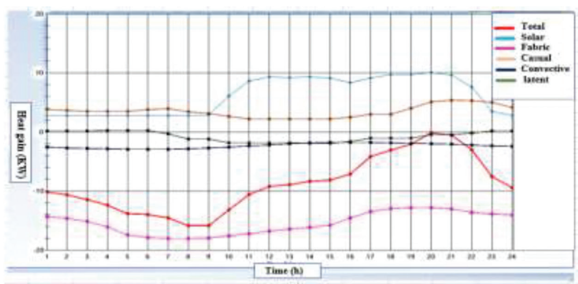
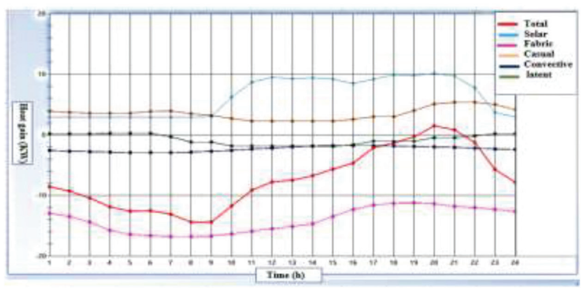


Figure 4: The charts showing heat losses from three scenarios. (a) Scenario 1; (b) Scenario 2; (c) Scenario 3.



(a)



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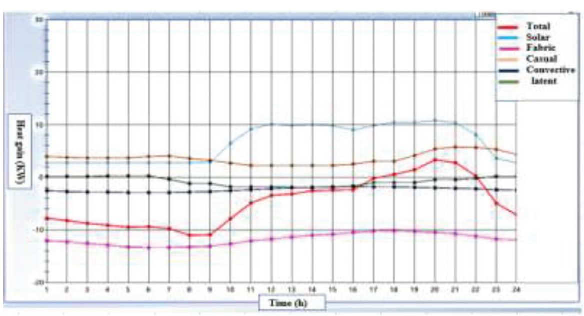


(c)

Figure 5: The graphs showing heat gain from three scenarios plotted across 24 hours. (a) Scenario 1; (b) Scenario 2; (c) Scenario 3.

gained by individual models in 24 hours. Each graph in each model reflects the heat gain in terms of solar, fabric, casual, convective, and latent heat gain. The total heat gain graph in red was plotted across 24 hours, and in all three circumstances, the total heat gain graph shows unsatisfactory outcomes.

The heat enters the room for only a few hours, while most of the time the heat was lost outside from the structure. According to the heat gain results, scenario 3 (the model with stone walls and timber flooring) can allow more heat than scenario 1 (the model with concrete block walls and concrete slab flooring) and scenario 2 (model constructed with brick wall and concrete slab flooring). Thus, indicating stone wall and timber flooring can retain more heat comparing to brick walls, concrete block walls, and slab flooring.

5.3 Different alternative walls (with insulations)

The heat loss charts showed that the walls lose the most heat, followed by the glazing, while the roof and partition losses the least amount of heat. Thus, to minimize the heat loss through walls, other alternatives wall cases are chosen to improve the design over the existing wall. The cross-sectional views of different alternatives are showed in Fig. 6 (case 1, case 2, case 3). Brick walls and slab flooring are often used because it is available and easy to construct,

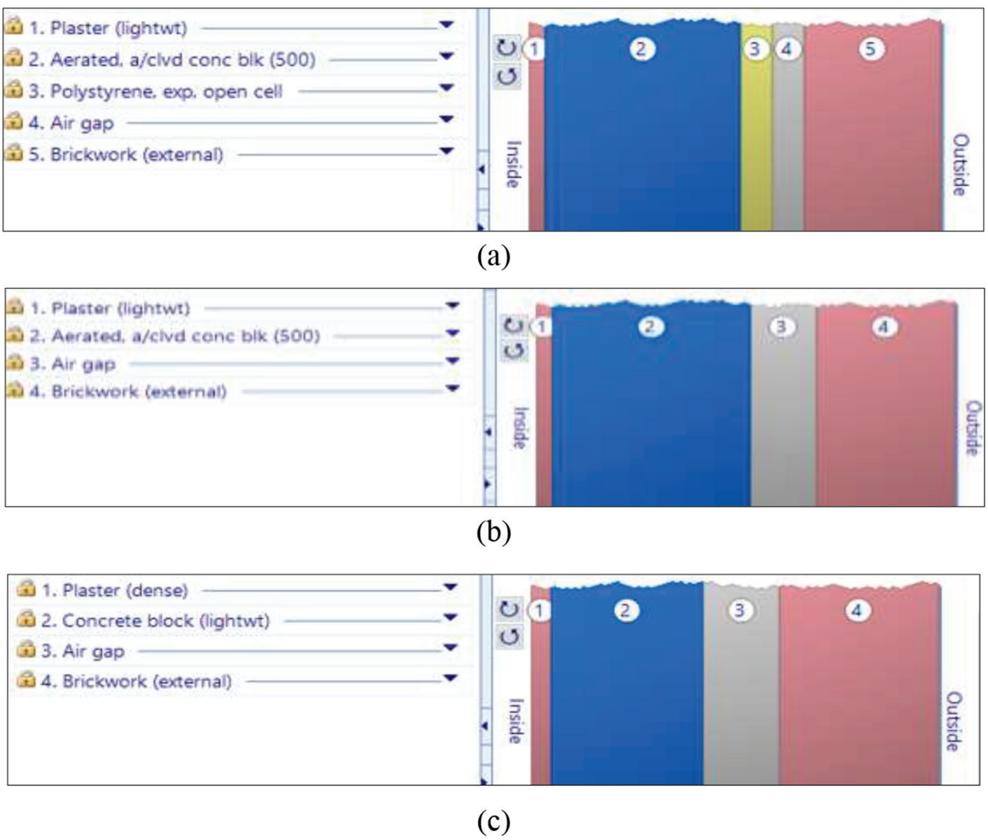
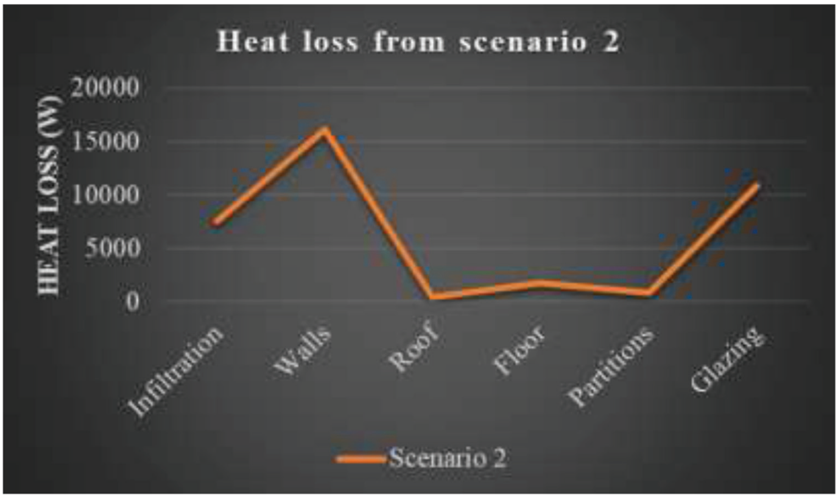
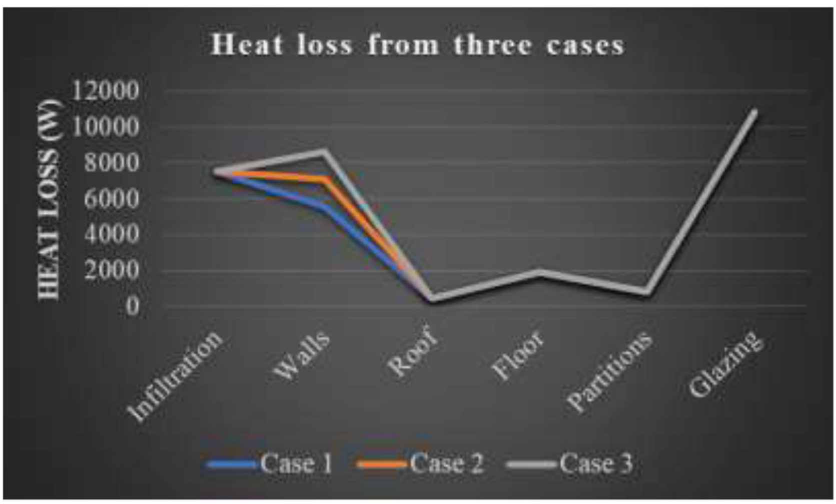


Figure 6: Cross-sectional view of walls. (a) Case 1; (b) Case 2; (c) Case 3.



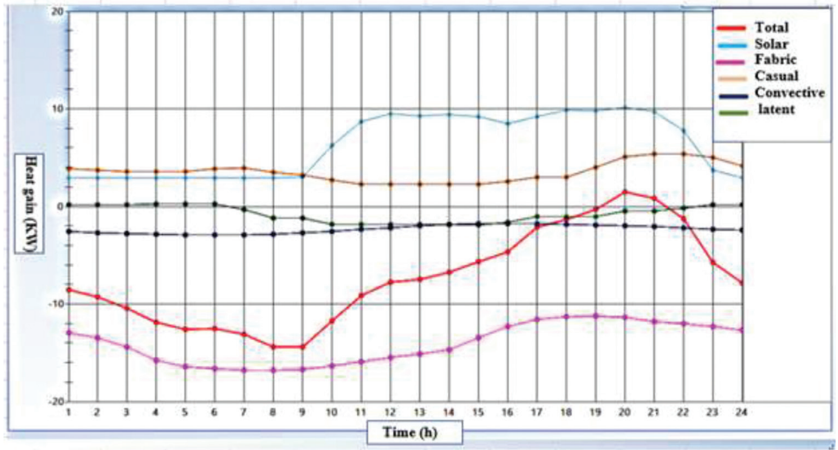
(a)



(b)

Figure 7: Heat loss graphs. (a) Heat loss from scenario 2 (without insulation); (b) Heat loss from three cases (with insulation).

so, therefore, scenario 2 was chosen for the simulation of these diverse types of walls. The simulation was carried out in an energy simulator, and the result is showed in Fig. 7b for the three cases. The two comparative graphs were plotted between the existing scenario 2 and three cases as shown in Fig. 7. In all the cases, the energy performance of the wall had improved in terms of heat retention. For cases 1, 2, and 3, the heat loss from the walls is 5566W, 7095W, and 8638W, respectively. Thus, integration of walls with insulation had improved the building's heat performance, according to these findings.



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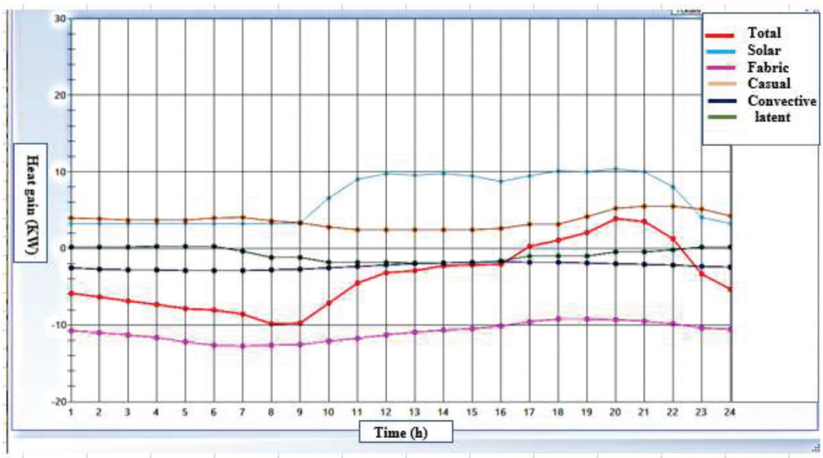


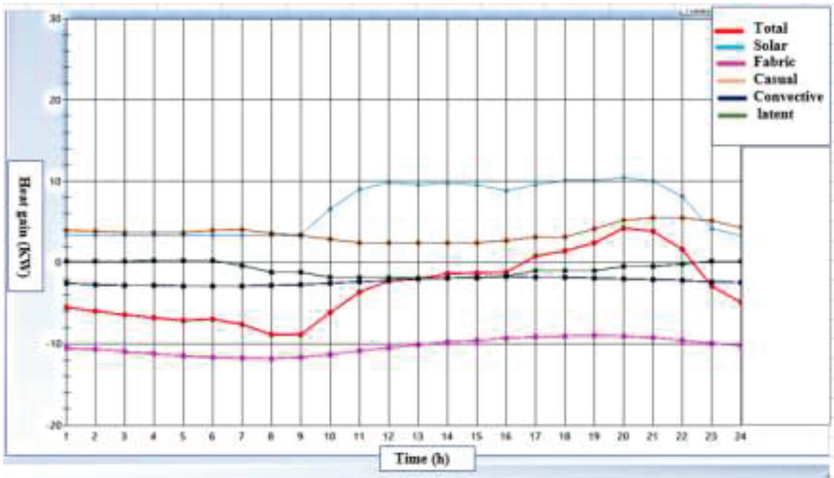
(b)

Figure 8: Heat gain graphs. (a) Scenario 2 (without insulation); (b) Case 1 (with insulation).

Figure 8 demonstrated the heat gain for scenario 2 (model constructed with brick wall and concrete slab flooring) and case 1 (model constructed with insulated wall and concrete slab flooring). So, from the graphs, the insulated wall can add more heat to room than uninsulated wall. Similarly, in cases 2 and 3, the result was also positive as shown in Fig. 9.

6 CONCLUSION

Heat loss can be minimized up to 46–65% by adopting the insulated walls as compared to the traditionally plastered brick wall without insulation. The total annual energy consumption of the apartment was 15,301.43 kW, which is equal to $546. The result also reflected that the heat is largely lost through walls, glazing, and infiltration, while Bhutanese residential structures do not currently have an HVAC system, but if one is installed in the future, the annual



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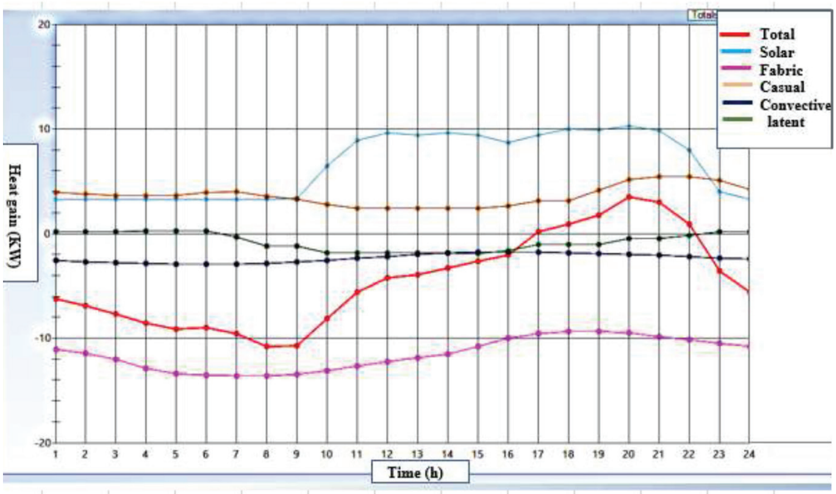

(b)

Figure 9: Heat gain graphs. (a) Case 2; (b) Case 3.

energy usage of the building may climb. The materials such as timber and stones are best choice to use in Bhutan, if no insulation walls are being used. This study was limited to one type of typical Bhutanese residential buildings, but the future researchers can conduct energy simulations on different dimensions and with different types of buildings in the future.

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