Parametric Study of Heating and Cooling Energy Demand of Residential Buildings in Bhutan

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***Abstract*—A parametric study of heating and cooling energy demand of residential buildings in Bhutan has been carried out to determine baseline heating and cooling energy demand and ascertain the degree of influence of building orientation and infiltration on energy demand. Two typical residential buildings in Bhutan were modelled in TRNSYS using Type 56. The calibrated models were used to estimate heating and cooling energy demand in two different locations using measured weather data. The estimated annual heating energy is 35 GJ_h, which is equivalent to 589 MJ/m^2 of conditioned floor area for Bldg-A and 29 GJ_h equivalent to 389 MJ/m^2 for Bldg-B. The annual cooling energy for Bldg-A is 23 GJ_r equivalent to 376 MJ/m2 of conditioned floor area and 29 GJ_r equivalent to 380 MJ/m2 for Bldg-B. From the parametric analysis, it was observed that by properly orienting the building, it can achieve up to 27% and 25% savings in heating and cooling energy respectively. For every 0.5ACH infiltration reduction can result in 15% and 5% reduction in heating and cooling demand respectively. It was also observed significant energy savings can be achieved by decreasing and increasing heating and cooling thermostat respectively.**

***Index Terms*— Heating, cooling, energy demand, TRNSYS, Bhutan, residential building**

I. Introduction

Buildings currently account for 30% of the total final energy consumption worldwide and 55% of total global electricity demand with 40% subsequent CO_2 emissions [1]. A baseline study found that building thermal energy consumption in Bhutan is 242,916 tonnes of oil equivalent which is nearly 52% of the total thermal energy consumption [2]. This is expected to increase over the years due to change in lifestyle of the residents. Residential buildings in Bhutan account for 15% of the total heating and cooling demand. This means significant energy savings can be achieved if the buildings are designed and constructed with energy efficient features and materials. Buildings in Bhutan are substantially made of brick-concrete structure. The roofs are mainly made of corrugated iron sheet with most windows provided with single-glass aluminium or timber frames. In general, the building envelopes are not insulated and do not meet the minimum requirements of standards for energy efficient buildings.

Bhutan located in the Himalaya is sandwiched between China to the North, India to the East, West and South with elevations ranging from 100-7800 metres above mean sea level. The topography is highly rugged with varying terrains and settlement is limited to valleys. Bhutan has three climatic zones, subtropical, temperate and alpine [3]. The subtropical zone is hot and humid in summer, and warm in winter. Temperate zone is warm in summer and cold in winter whereas the alpine zone is cold and requires heating throughout the year. More than two third of the settlement is in a cold region where the space heating is necessary. Most of the space heating system uses either electricity or firewood whereas the cooling system is using electricity. While the electricity price is relatively cheaper compared to the neighbouring countries, most households still cannot afford good space heating and cooling system due to the high running cost. One of the reasons for the high running cost of heating and cooling is due to significant leakage between the

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building elements. The estimated heat loss through the building envelopes is between 40-70% [2]. The concept of energy efficient building is yet to kick start in Bhutan. As of now, there are no literature on the baseline heating and cooling energy demand of residential buildings in Bhutan. Therefore, this paper presents a parametric study of heating and cooling energy demand of residential buildings in Bhutan to determine baseline heating and cooling energy demand and degree of influence of building orientation and infiltration on energy demand.

II. METHODOLOGY

In this paper, TRNSYS, a transient simulation software was used to estimate heating and cooling energy demand. TRNSYS is a simulation software with modular approach and is one of the most flexible and commonly used to evaluate the thermal performance of various systems [4].

A. Building Description

Buildings in Bhutan can be categorised into three types, residential building which include single detached house and multi-apartment type structures; commercial building which include office buildings, shops, hotels, restaurants; and institutional building like government buildings, academic institutions, and hospitals [2]. Most buildings in Bhutan are constructed using the same materials irrespective of the climate and location. Other than number of rooms, there is hardly any difference in wall materials or building envelope thickness in different climates. About 57.7% and 17.4% of the households in urban and rural Bhutan respectively have their house walls made of reinforced cement concrete, bricks or cement blocks [5]. This means if a building model is calibrated based on weather parameters of one location, it can be used for predicting thermal performance in any other location by varying the weather input data. However, of late it has been observed that owners tend to add timber paneling on the inside surface of the wall specially in cold climate. In order to obtain a realistic baseline heating and cooling energy demand and to ensure that comparisons are drawn for the same type of representative buildings, two buildings, Bldg-A and Bldg-B were simulated under two different climate conditions.

The first building, Bldg-A is a 3-storyed residential building with four flats on each floor. Each flat has a floor area of 81 m^2 but only 60 m^2 was assumed to be thermal conditioned. The building is located in Phuentsholing (PLing) at 26°50'59.0"N Latitude and 89°23'47.9"E Longitude at an altitude of 360 m above sea level. It is occupied by three persons for most of the time in a year. The house was divided into four thermal zones, living, kitchen and two bedrooms in the TRNSYS model. The second building, Bldg-B is a 4-storeyed residential building with two flats on each floor. Each flat has a floor area of 94 m^2 but only 75 m^2 was assumed to be thermal conditioned. Bldg-B is located in Thimphu at a Latitude of 27°36’23” North and 89°56’43” East Longitude at an altitude of 2,300 m. It is occupied by 7 persons most of the time in a year. The building was divided into five thermal zones, living, kitchen and three bedrooms. This building has timber floor and also timber paneling on the inside surface of the walls.

B. Building Model

TRNSYS Type 56 was used to model two buildings, which are typical residential buildings in Bhutan, using measured building physical parameters. It is necessary to calibrate a building model to predict a realistic building thermal performance. Therefore, TRNSYS building model was calibrated using one-year measured weather data and space temperature. The calibrated model was then used to estimate heating and cooling energy demand.

Kitchen, store and bathrooms were not conditioned in both the buildings. Air temperature of two thermal zones in one of the flats in each building was monitored for over a period of one year along with the weather parameters. The measured thermal zone temperature and weather parameters were used to calibrate the building models. Fig. 1 and 2 show floor plan of two buildings. The major difference between the two buildings is walls of Bldg-B has relatively lower U-value (Table I) due to an extra layer of timber paneling on the inside of the walls and timber floor as shown in Fig. 3 and 4. The calibrated models of Bldg-A and Bldg-B were used to predict heating and cooling energy demand in two locations, one in Thimphu that has heating dominated load and other in PLing which has a cooling dominated load.

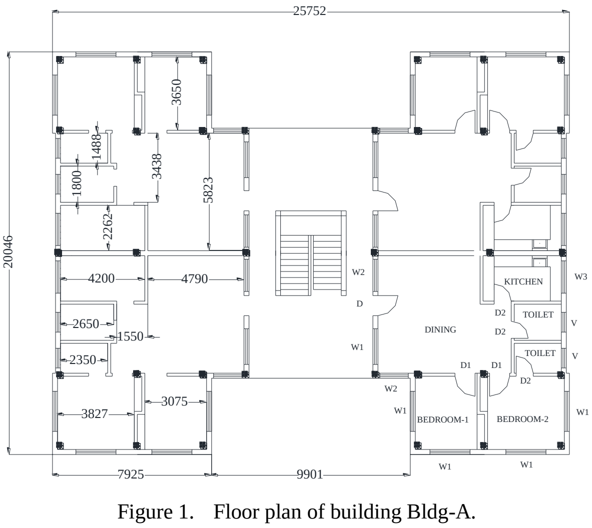

Figure 1. Floor plan of building Bldg-A.

TABLE I. WALL THERMAL TRANSMITTANCE (W/M^2K)

	External wall	Internal wall	Internal wall-1	Floor	Bathroom floor
Bldg-A	1.9	2.843	-	3.303	3.303
Bldg-B	1.392	2.843	1.33	2.182	3.768

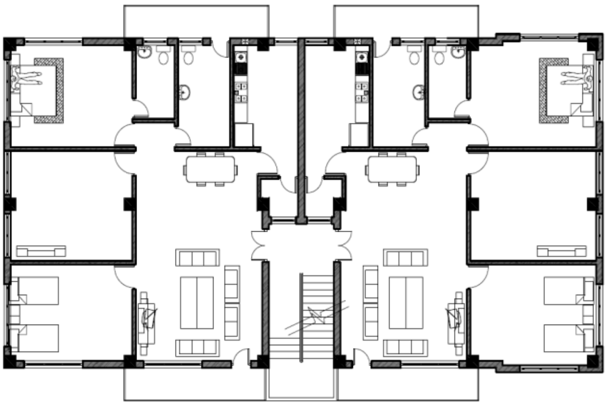

Figure 2. Floor plan of building Bldg-B.

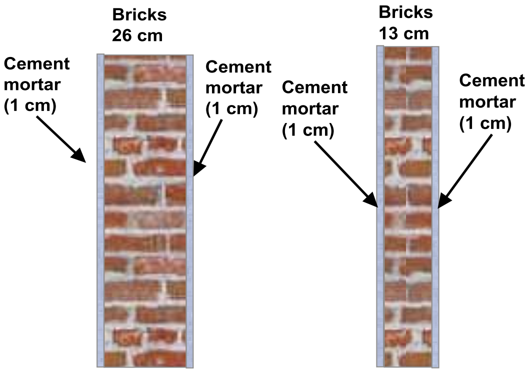

Figure 3. External and internal walls of Bldg-A.

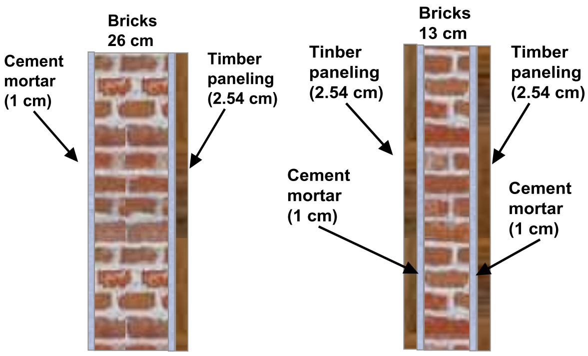

Figure 4. External and internal walls of Bldg-B.

C. Occupancy and Other Schedules

The heating and cooling energy demand of buildings not only depend on weather conditions and physical characteristics of its envelope but also on the usage, internal gains, air leakage, building orientation, thermostat settings and occupant behaviour. In order to obtain a realistic estimate of heating and cooling energy demand, the buildings were modelled using the measured physical parameters taking into account the internal gains, leakage, true orientation, occupancy schedule, lighting and television use. Fig. 5 and 6 presents the occupancy, lighting and television (TV) use schedule of Bldg-A and Bldg-B respectively. These schedules are representative based on the inputs of the building occupants. In reality, this will vary day-to-day and are unpredictable.

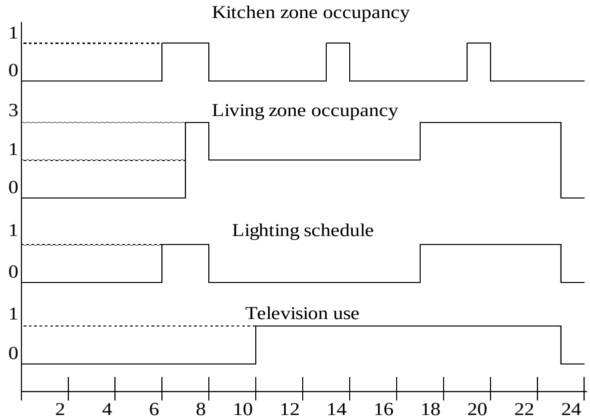

Figure 5. Occupancy, lighting and TV use schedule of Bldg-A.

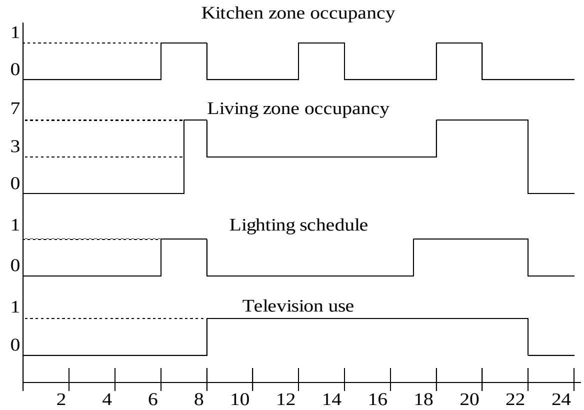

Figure 6. Occupancy, lighting and TV use schedule of Bldg-B.

D. Weather

In this paper, measured time-series weather data was used to simulate the calibrated building models. Fig. t and 8 shows average monthly ambient air temperature and average monthly global horizontal irradiation for PLing and Thimphu. The mean ambient air temperature is 23.8°C and 11.4°C for PLing and Thimphu respectively with nearly equal mean global horizontal irradiation of 166 W/m2. From the weather data, it is evident that Thimphu will have heating dominated load whereas PLing will have a cooling dominated load.

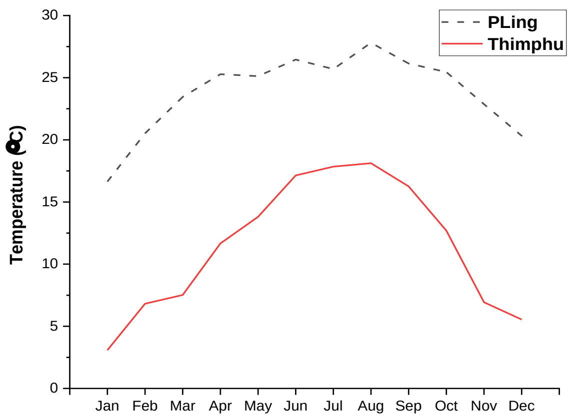

Figure 7. Monthly average ambient air temperature.

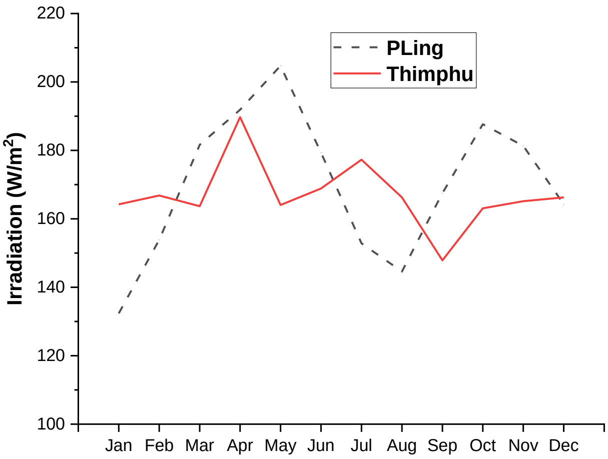

Figure 8. Monthly average horizontal irradiation.

III. Results and Discussion

A. *Heating and Cooling Energy Demand*

The heating and cooling energy demand of two buildings were generated by running the TRNSYS model using measured weather data in PLing and Thimphu. Heating and cooling schedules were not taken into account in this paper. The heating thermostat was set at 18°C and cooling at 24°C with infiltration of 1ACH (air changes per hour) in the rooms and 3ACH in the attic. There is no ventilation system in either of the buildings. The main façade (wall having the most windows) was oriented towards true south.

The annual estimated heating energy for Bldg-A is 35 GJ_h, which is equivalent to 589 MJ/m2 of conditioned floor area (Table II). Whereas for Bldg-B, it is 29 GJ_h, equivalent to 389 MJ/m2 of conditioned floor area. Fig. 9-12 presents monthly heating and cooling energy respectively. Bldg-B has lower heating energy requirement compared to Bldg-A. As Bldg-B has timber paneling on the inside surface of walls, it has lower thermal transmittance. As a result, lower heat loss through the walls, thus low heating energy requirement.

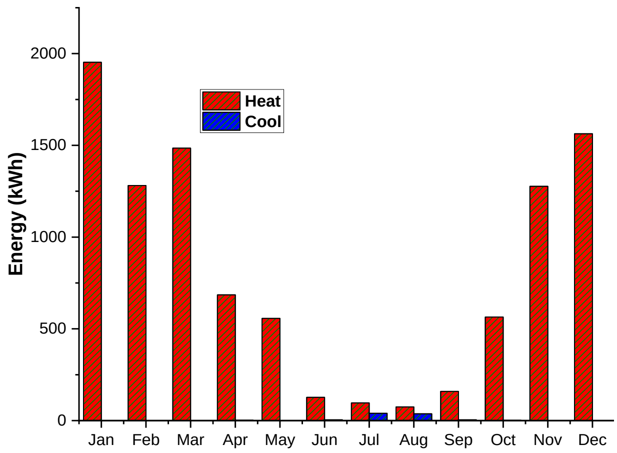

Figure 9. Monthly heating and cooling energy of Bldg-A in Thimphu.

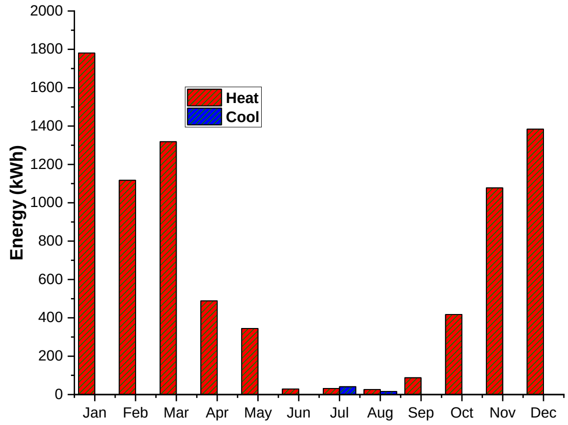

Figure 10. Monthly heating and cooling energy of Bldg-B in Thimphu.

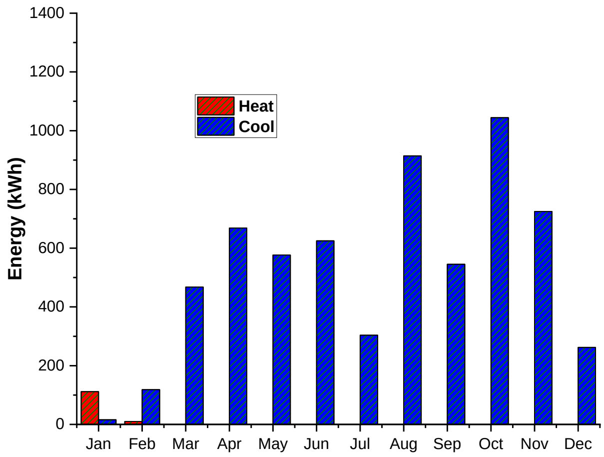

Figure 11. Monthly heating and cooling energy of Bldg-A in PLing.

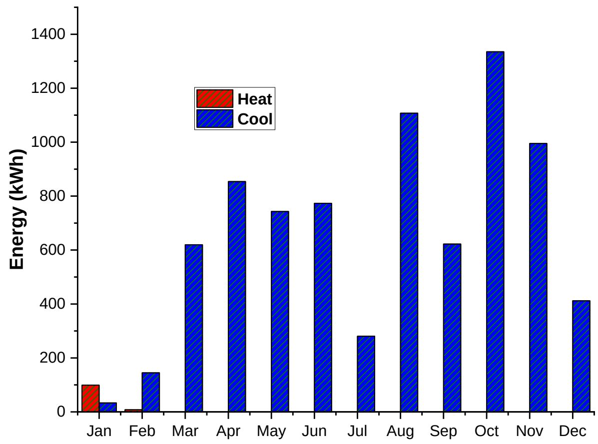

Figure 12. Monthly heating and cooling energy of Bldg-B in PLing.

The total annual cooling energy for Bldg-A was estimated to be 23 GJ_r, which is equivalent to 376 MJ/m^2 of conditioned floor area (Table II). Whereas for Bldg-B, it was estimated to be 29 GJ_r, which is equivalent to 380 MJ/m^2 of conditioned floor area. Bldg-A has lower cooling energy requirement compared to Bldg-B which could be attributed to higher thermal transmittance. As a result, higher flow through the walls, thus low cooling energy requirement. It is also evident from Fig. 9 & 10

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and Table I that cooling demand in Thimphu is not significant as compared to the heating demand. Therefore, cooling in Thimphu will not be considered for further analysis. Conversely, heating demand is not significant in PLing compared to cooling demand. Therefore, heating will not be taken into account in PLing.

TABLE II. SUMMARY OF HEATING AND COOLING ENERGY

Mode	Location	Energy Demand	Bldg-A	Bldg-B
Heating	PLing	Annual (GJ)	0.44	0.39
		Per unit (MJ/m^2)	7.32	5.14
	Thimphu	Annual (GJ)	35	29
		Per unit (MJ/m^2)	589	389
Cooling	PLing	Annual (GJ)	23	29
		Per unit (MJ/m^2)	376	380
	Thimphu	Annual (GJ)	0.32	0.21
		Per unit (MJ/m^2)	5.28	2.74

IV. PARAMETRIC STUDY

A. *Building Orientation*

The orientation of the building has a significant influence on its thermal energy demand. For example, Albatayneh et al [6] found that by placing the windows of the buildings in the Northern hemisphere in the southern walls was able to reduce heating demand by approximately 35% per annum. Nasrallah [7] reported that the heating energy demand of the office building varied by about 24% with orientation while cooling energy varied by about 28%. Ramos and Bandera [8] concluded that optimum orientation to achieve lower heating and cooling energy demand is by having large windows facing the South. Mokrzecka [9] reported a 50% difference between the minimum and maximum heating energy demand by varying building orientation.

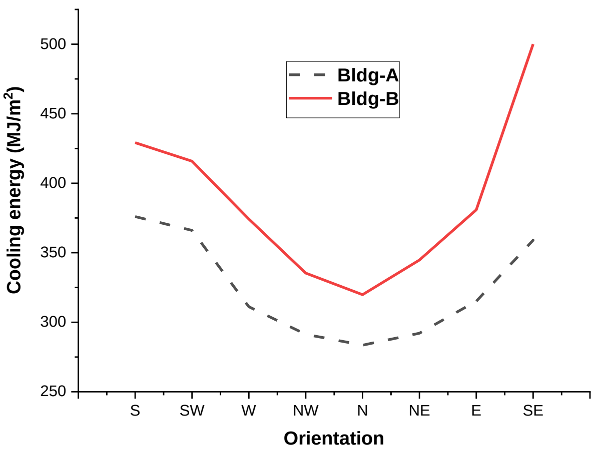

Figure 13. Heating energy for different building orientation.

In this paper, it is observed that heating energy demand varies up to 27% with varying building orientation with the lowest facing South. Similarly, cooling energy demand varies up to 25% with building orientation with the lowest facing North (Fig. 13 and 14).

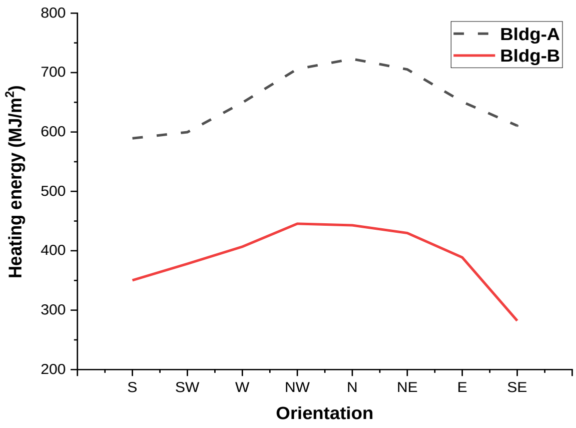

Figure 14. Cooling energy for different building orientation.

B. *Infiltration Rate*

Air infiltration, an unintentional flow of outside air into the building has been proven as one of the largest contributors to thermal energy demand of buildings. A study conducted by Jokisalo et al [10] observed for every one-unit increase of building leakage rate resulted in a 6% increase in heat energy consumption of a single detached Finnish house. Nabinger and Persily [11] concluded that by retrofitting reduced building envelope leakage by 15% which resulted in a 10% reduction of heating and cooling energy demand. Similarly, Emmerich et al [12] predicted annual heating energy savings ranging from 2 % to 36 % by reducing infiltration with the highest in heating-dominated climate regions. The tighter building uses less heating energy than leaky building. Most buildings in Bhutan were reported to have high air leakage as the gaps between the buildings elements are hardly sealed. A study conducted by Jentsch et al [13] reported infiltration ranging from 0.8 to 5.3 ACH with a mean value of 2.11 ACH. In order to estimate the impact of air infiltration on heating and cooling energy demand, the infiltration rate was varied from 0.5 to 3 ACH.

The impact of air infiltration is more significant in case of heating dominated climate as shown in Fig. 15 which is true for both the buildings. The per unit heating energy demand can be reduced up to 30% by reducing the infiltration from 1ACH to 0.5 ACH. The heating energy demand of Bldg-B is two times more at 3ACH than 1ACH. In case of Bldg-A, an increase of infiltration from 1ACH to 3ACH results in only 45% increase in heating energy. On an average, 0.5ACH variation resulted in a 15% change in heating energy. For cooling dominated climate, for every 0.5 ACH variation, there is 5% change in cooling energy of both the buildings. It is evident from the results that infiltration has a significant impact of heating and cooling energy demand.

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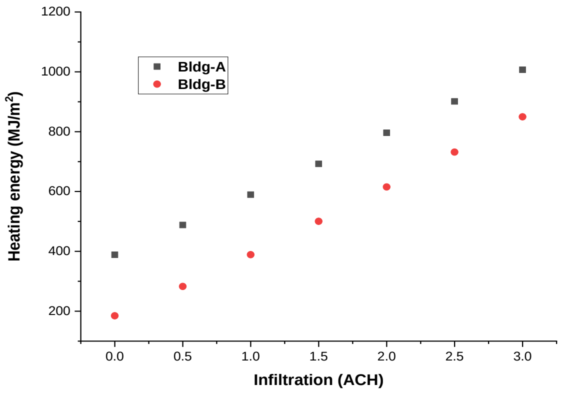

Figure 15. Heating energy for different infiltration rate.

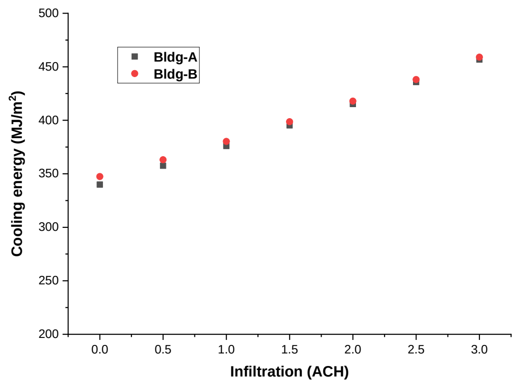

Figure 16. Cooling energy for different infiltration rate.

C. *Thermostat Settings*

Heating base temperature is 18°C and 24°C for cooling based on the common thermostat settings used in Bhutan. In order to estimate the impact of temperature setting on heating and cooling demands, thermostat setting was varied from 14°C to 20°C for heating and from 22°C to 28°C for cooling. Fig. 17 and 18 shows per unit heating and cooling energy demand for varying thermostat settings. The influence of thermostat settings on heating and cooling energy demand can be approximated by a second-order polynomial equation as shown in (1) and (2).

$$Q_{heat} = 8.255t^2 - 167.99t + 939.19 \quad (1)$$

$$Q_{cool} = 9.428t^2 - 517.78t + 7926.7 \quad (2)$$

where t is the thermostat setting (°C)

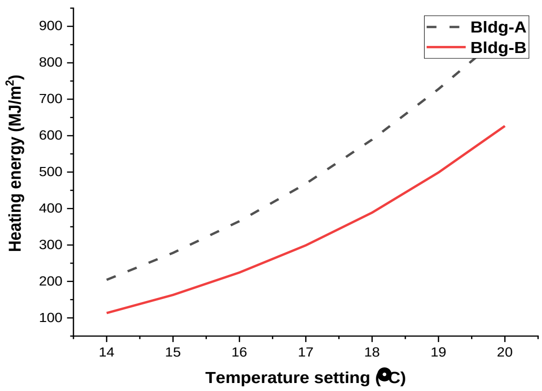

Figure 17. Heating energy for different thermostat settings.

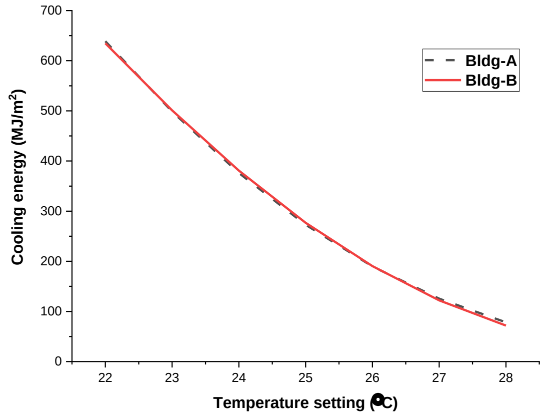

Figure 18. Cooling energy for different thermostat settings.

V. CONCLUSIONS AND FUTURE WORK

The purpose of this paper was to determine baseline heating and cooling demand of residential buildings in Bhutan. Two different buildings were modelled using TRNSYS Type 56 and calibrated with measured building space temperature and weather inputs. A parametric analysis was carried out to ascertain the degree of influence of building orientation and infiltration on heating and cooling energy demand of buildings. By correctly orienting the building, it is predicted that energy savings up to 25% can be achieved. Whereas reducing infiltration from 1ACH to 0.5ACH results in only 15% energy savings. The per unit impact on the building heating and cooling energy is more by varying orientation than infiltration. However, as most buildings in Bhutan were reported to have high infiltration (average 2.11 ACH), significant energy savings can be achieved by reducing the air infiltration. Reducing infiltration from 2.11 to 0.5 ACH can result in 45% energy savings. Finally, to further improve the accuracy of the baseline heating and cooling demand, need to include more buildings in similar weather conditions.

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