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Performance Simulation of Residential Building Envelope with Real Environment in Thimphu, The Capital City of Bhutan

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Abstract: ***Buildings are one of the world's largest consumers of energy and also there are many strategies to reduce the energy consumptions in the present era. The strategies can be applied right from the design phase for the new buildings and retrofits can also be done to the old buildings. In-order to apply the best strategies of energy consumption reduction and to understand building energy consumption pattern, needs to carry out Energy performance of the buildings. Energy performance of building can be evaluated by measuring energy consumptions or performing simple or detailed simulation. In this study, one of the buildings from Ministers' Enclave of Bhutan is selected as model building. The simulation was carried out to evaluate the building performance by creating different scenarios based on building envelope. The different scenarios were created for simulation purpose only. The energy saving were deduced by comparing the output result obtained from simulation in EnergyPlus. The EnergyPlus and DesignBuilder were eTools used for simulation. The EnergyPlus as the main simulation engine and DesignBuilder as Graphics User Interface for EnergyPlus. All the output from the simulation was analyzed and details were presented in the subsequent sections.***

Keywords: performance, Building, simulation, consumption

1. Introduction

Energy is one of the building blocks of modern society and that the availability and cost of energy resources are key factors in a country's economic growth. Energy is not an end in itself but a means to achieve the goals of healthy economy and healthy environment.

Residential/building sector is the fastest growing entity in energy consumption. The residential/building energy consumption amounts for 40% of the total global energy consumed annually (Omer, 2008). The energy consumption in the building was mainly for heating and cooling in winter and summer seasons respectively and also for Domestic Hot Water production.

Therefore, in this present Era, a great deal of effort is placed all over the world in achieving sustainable development in the construction industry with the aim of reducing energy consumption in both the construction and management of buildings, thus limiting its consequences on the local and global environment. Many energy analysis techniques are available to get the energy consumption of building in numerical values. These values always provide scope for energy managers to take further action on reducing it. The main challenge is accurately assessing and analyzing building energy consumption and savings potentials, since buildings are complex systems defined by the way in which they are designed, constructed and operated. Yet doing so creates a foundation for making sound policy decisions. Building energy analysis can quantify the cost and savings potential sector, helping to prioritize investment decisions.

In particular, small country, like Bhutan, is also experiencing rapid economic growth in recent years and at same time living standards also keeps increasing. The higher standards of living have resulted in a significant increase in energy consumption from the residential sector, and this trend is expected to continue into the future. Many new buildings being constructed in a year and they do not perform well as they could with today's technology in energy efficiency.

2. Methodology and Model Building

2.1 Methodology

Computer-based simulation is dominant in evaluating the building energy consumption. The researchers and the professionals also accept as a tool for evaluating building energy consumption. There are many different computer-based simulation tools that are available for performing whole building simulation like DeST, DOE, Energyplus, DesignBuilder, and TRANSSY and so on. The best simulation tools are very dynamic in nature considering all the parameters and all energy exchanges during all year.
For the modelling purpose, the simulation tool used is DesignBuilder and EnergyPlus. It is a simulation tool operating under transient conditions, based on the resolution methodology of BLAST and DOE – 2 developed respectively by the Department of Defence (DOD) and the Department of Energy (DOE) with ASHRAE contributions.

2.2 An Introduction of the model building

The building used as model is one of the buildings from ministers' enclave, used by the ministers and those holding equivalent ranks, as shown in the Figure 1. The building is built on 557.42 square meter land located in Thimphu, capital city of Bhutan at latitude 27^{0}28'16'' north and longitude 89^{0}38'14" east. The building is of two – story and its orientation is 24 metres in the east – west direction and 15 metres in the north – south direction. The building has no air conditioning system and it just functions on natural ventilation or window airing system and has floor to floor height of 3.5 m. By the virtue of its location at a height of almost 2380 m above the sea level, the main concern is of heating, since climate mostly remains cold throughout the year. The building has a fairly standard construction with medium weight 150 mm concrete floors and ceiling slabs. The insulation of 50 mm glass wool is used in all external walls and on first floor ceiling. The external and partition walls got erected with bricks and cement plastered on each sides. Plank flooring is laid over the concrete slab flooring. The external opening constitutes windows and doors made of wooden frame with varying sizes as per the functional needs. On all the windows and external door (French door), double glazed glass of 20 mm (5 +10 + 5) is used. The lighting system serving the building is mainly of regular 40 watts fluorescent lamps. Electricity connected from the grid is the main source of energy used in heating the building and production of domestic hot water.

Zoning of the modelled building is as per the floor plan corresponding to the number of rooms as shown in the Figure 3. Each zone is separated by internal partition brick walls. In each zone the level of activity differs. At present, localized heating system is used in the building. Considering the present scenario of heating system, only few zones were considered as heating required. The geometrical model of the building is as shown in Figure 2.

2.3 Local Climatic context

The model building is located in Thimphu, the capital city of Bhutan which is located at 2380 m from sea level. The temperature varies from -4.0^{0}C to 27.04^{0}C with harsh cold winter and warm summer. The Figure 4 presents 14 years (1996–2009) average of mean monthly maximum and minimum temperatures of Thimphu, the capital city. The annual heating and cooling degree days is also calculated and Figure 5 represents heating degree and cooling degree days respectively with baseline temperature as 20^{0}C.

Based on the heating degree days, Thimphu falls in Zone 7 of very cold climate with reference to International Climate Zone Definitions of ANSI/ASHRAE/IESNA STANDARD 90.1-2004. Similarly, with reference to Italian Climatic Zone definition, Thimphu falls in the Climate Zone D with the heating period from 1st November to 15th April and 12 hours of heating per day. With referring to both the climatic zone definition, buildings in Thimphu require more energy in heating than cooling. The daily load curve of Thimphu also shows that winter load is much higher than summer load as shown in Figure 6. The increase in winter load is all due to heating of homes and production of hot water.

3. Simulation Result and Discussion

3.1 Simulation Methodology

For the analysis of energy performance of building located in Thimphu, Bhutan, the simulation was carried out using meteorological data acquired from Department of Energy, MoEA. The basic criteria for identifying cases were based on the building envelope or façade. The tabulation clearly shows the different scenario for the different cases in Table 1.

3.2 Energy consumption – Performance evaluation

The simulation was carried out for the different scenarios as tabulated in Table 1 for obtaining the energy consumption for each scenario in EnergyPlus. The results generated from the EnergyPlus for different scenarios are presented below in graphical representation. The graphical representation clearly shows the energy consumption reduces with the improvement of building envelope and also with the reduction of infiltration rate. With the proper design and selection of appropriate building envelope the achievable energy saving can be 15.92% with reference to the Base case. The graphical representation of Figure 7 provides the summary of energy performances of different scenarios. For all the scenarios while simulating, the set point temperature considered is 18 ^{0}C.

3.3 PMV and PPD

The PMV is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale (+3 Hot; +2 Warm; +1 slightly warm; 0 Neutral; -1 slightly cool; -2 Cool; -3 Cold), based on the heat balance of human body. The acceptable thermal environment for general comfort is -0.5<PMV<+0.5 (ASHRAE STANDARD 55-2004).

As shown in the Figure 8, the PMV is calculated by taking average values of variables, such as Mean Radiant temperature, inside air temperature and Relative humidity of 1st January.

Based on the above figures, the thermal condition of building always falls below ASHRAE recommended value of -0.5<PMV<+0.5 (ASHRAE STANDARD 55-2004).

The results may be true, since existing building do not have centralized heating system and presently only localized heating system is used. Therefore, the heating schedule provided in the simulation was also considered as per the existing usage pattern, i.e heating in the morning and evening hours only.

3.4 Indoor temperature of Best case

Error! Reference source not found. and Figure 10 present the indoor temperature profile selected rooms of Ground and First floor indoor living space on 1st January. As shown in the **Error! Reference source not found.**, living area (GF anteroom) has the highest indoor temperature of 20.8^{0}C at

16:00 hours. The highest temperature shown by Figure 10 is 22^{0}C of living area (FF master bed room) at 16:00 hours.
Based on this analysis, the values of hourly indoor temperature of 1st January were less than the design conditions recommended in ASHRAE STANDARD 55-2004.

3.5 Figures and Tables

Figure 1: Model Building

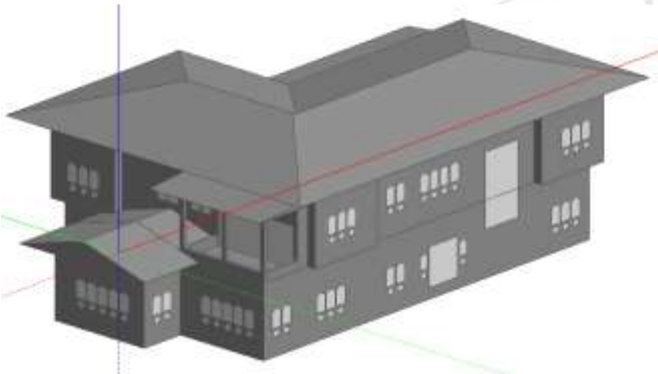

Figure 2: Perspective view of residential building models in DB

Figure 3: Indoor layout of model building

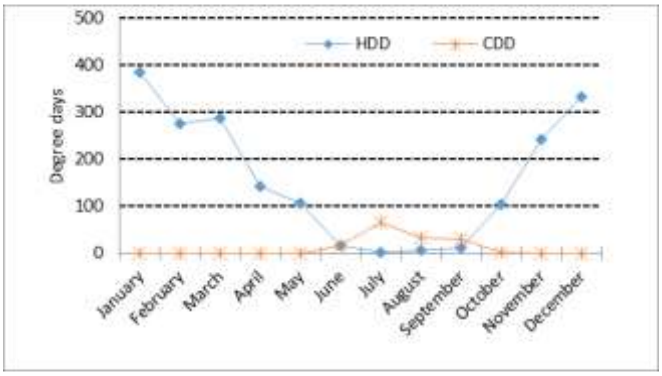

Figure 4: Heating and cooling Degree Days

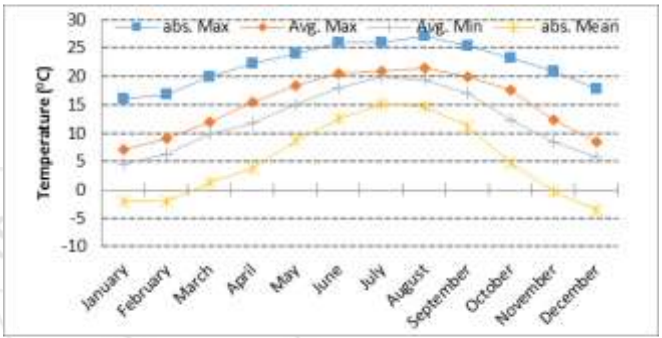

Figure 5: 14 years averaged temperature, Source: MoEA

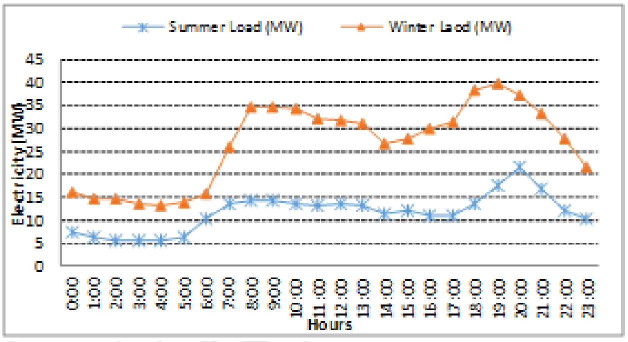

Figure 6: Thimphu daily load curve, Source: BPC data book 2014

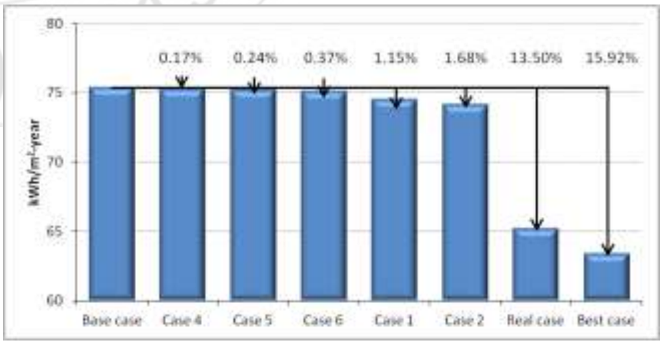

Figure 7: Energy performance summary

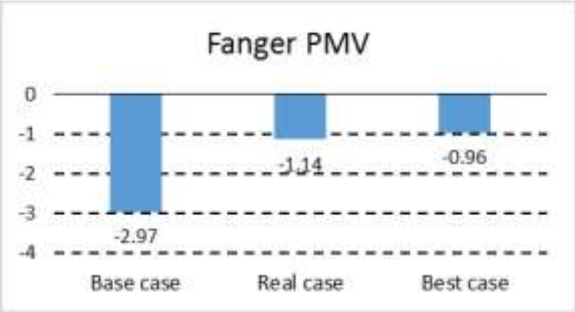

Figure 8: PMV value for 1st January

Table 1: Different scenarios for simulation

Scenario	Insulation thickness (mm)			Window glazing			ACH	Set point temperature
	50	100	150	Double/ Clear	Triple/ clear	Triple/Low emissive		
Base case							1.5	18 ^{0}C
Case 1	*						1.5	18 ^{0}C
Case 2		*					1.5	18 ^{0}C
Case 3			*				1.5	18 ^{0}C
Case 4				*			1.5	18 ^{0}C
Case 5					*		1.5	18 ^{0}C
Case 6						*	1.5	18 ^{0}C
Real Case	*			*			0.5	18 ^{0}C
Best case			*			*	0.5	18 ^{0}C
Real Case	*			*			0.5	20 ^{0}C
Best Case			*			*	0.5	20 ^{0}C

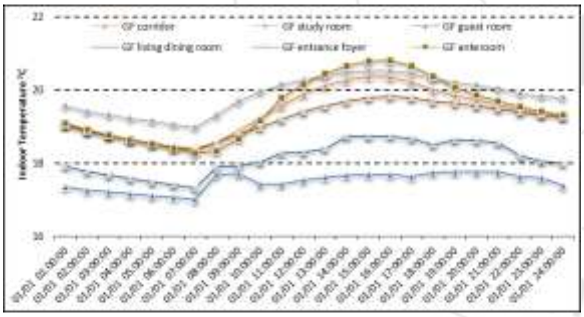

Figure 9: Indoor temperature of Ground floor on 1st January

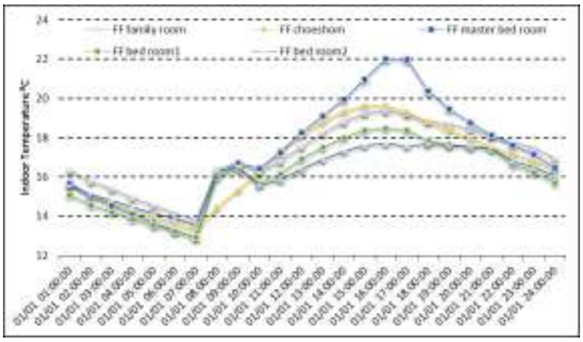

Figure 10: Indoor temperature of First floor on 1st January

4. Conclusion

Globally residential sectors are characterized by highest energy consumption. It is the area where every country should develop methodologies and technologies to reduce its energy demand. While presenting the opportunities for energy conservation there always remains the challenges for matching the ultimate satisfaction of every individual's needs.

Bhutan, a small country with high renewable energy integrations has also started embarking on the residential energy efficiency, since energy consumption is increasing substantially every year. But there has been very slow uptake of evaluation and optimization methodologies in Bhutan and the region around. In this paper, case study methodology has been adopted for studying possible and feasible interventions for refurbishment. Thus, the following measures have been considered: insulation of building envelope (with different thickness); installation of higher performance glazing system, replacement of heating system of a residential building in Bhutan. The simulation result also shows that the improvement of building envelope can reduce the energy consumption by 15.92%. The indoor comfort condition depicted by PMV and PPD is around -1.0 and 35% respectively. The comfort conditions are out of acceptable range while comparing to other developed countries. The possible reason could be the fact that many homes in Bhutan do not have centralized heating system, heating for 24 hours. The tenant uses only localized heating system and that too with heating hours of 4 - 6 hours in a day during winter seasons. However, simulation result shows a great improvement of thermal comfort while comparing between Base case and the Best case as shown in Figure 7.

Finally, to achieve global sustainable future, the policy maker and governmental organization should focus more on public behavioral changes in addition to other investment on energy efficiency.

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