Feasibility of Solar Thermal and Photovoltaic Integrated With Building Facade, a Case Study in Thimphu

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Abstract

Based on energy simulations, the annual energy demand of the DHI office is estimated to be 3,739 kWh. The total energy includes heating, lighting, and equipment energy requirements. The thermal energy demand of the office is 2,240 kWh and the combined lighting and equipment energy is 1,499 kWh. A radiation analysis of the front of the office is carried out to determine which facade received the most solar radiation. The annual global solar radiation received on building facade are $2.6\ \mathrm{kWh/m^2}$, $2.4\ \mathrm{kWh/m^2}$ and $2.3\ \mathrm{kWh/m^2}$ on south, west and east facing facade respectively. Accordingly, the radiation results concluded that the south-facing facade is the most promising facade, followed by the west-facing facade and the east-facing facade. The proposed STC system, designed to maintain hot water temperature of 55°C, and simulations indicate that it would generate 2,440 kilowatt-hours of heating energy per year. This thermal energy would be sufficient to meet the space heating energy needs of the DHI office. Finally, the possibility of installing photovoltaic (PV) panels on the west-facing facade area $26\ \mathrm{m^2}$ was simulated, suggesting the potential of 2,016 kWh of energy, which could replace the total lighting loads of 1,499 kWh currently received from grid supply.

Key words – *: facade, rhino, honeybee, ladybug*

1. Introduction

The socio-economic development of Bhutan depends to a large extent on the successful implementation of large hydropower stations. Consequently, Bhutan recognizes that the diversification of the energy structure is essential to cope with the uncertainty of large hydropower stations caused by climate change (Lhendup, Seldon, Om, & Sharma, 2018). Keeping in mind the pattern of rising electricity demand will automatically force us to explore other ways of clean and renewable energy to expand the energy mix. There are few potential energy sources available. Solar energy (photovoltaic and solar thermal), wind energy, bio-energy, and small hydropower installations can all play an important role in realizing a sustainable energy system.

Therefore, this dissertation aims to study the feasibility of using the building facade in Thimphu for solar power generation and solar thermal power generation. O'hegrty, Kinnane, & McCormac (2016) states "Harnessing solar energy to provide the thermal needs of building is one of the most promising solutions to the global energy issue". The installation of rooftop solar systems alone is not enough to meet the huge energy demand of buildings. Thus, exploitations of the additional surface area available on the building facade can readily maximize the solar energy output. Compared to traditional rooftop installations, the use of exterior walls offers two interesting potentials: 1) increase the usable surface, and 2) minimize unnecessary overheating problems, which occur in summer, when the solar collector is tilted vertically, STC Energy production remains almost unchanged throughout the year (Gioanardi, 2012). When the panel is oriented vertically, the sizing of the solar thermal system is easier because the radiation it receives is almost constant over the year.

This dissertation also makes an attempt to address the concept of "net-zero energy building." Evidently, the energy demand of Thimphu is the highest in the country. The study of household energy consumptions in Thimphu shows, "On the total share of electricity consumption, 34.47 % was consumed for space heating, followed by 26.69 % for hot water preparation, cooking 12.28 %, lighting 12 %, refrigeration 7.75 %, other appliances 8.65 % and least 4.04 % on the entertainment" (Chhetri & Sajjakulnukit, 2018). If carefully designed, more than half of the energy needs of the household can be met by renewable energy. Both hot water preparation and space heating energy are provided by STC, while lighting and cooking energy can be provided by solar photovoltaic. Thus, when all the energy needs of a building are generated by the building itself and no external energy is input for its use, the building is called a net-zero energy building.

1.1 Problem Statement

Facade of the building also receives solar radiation, but it is still unknown how much radiation it receives. This dissertation attempts to answer which facade (facing south or west or east) receives the most solar.

1.2 Aim and Objectives

The study aims to determine the potential of solar thermal collectors (STC) and solar photovoltaic (PV) integrated on the facade of the building to meet the energy needs of the building. Following are the objectives to fullfill the aim:

- ✓ Build an accurate building model, and perform energy simulation to inspect the annual energy consumption of the building.
- ✓ Conduct radiation analysis on the building to determine the best radiation receiving facade of the building under study.
- ✓ Conduct the solar thermal energy generation analysis by installing the solar thermal collector on the best radiation receiving facade.
- ✓ Conduct the photovoltaic power generation analysis by installing photovoltaic panels on the next best radiation receiving facade.

2. Methodology

A methodology adopted to carry out the analysis particularly on how to use Rhino and Grasshopper software for energy simulation of selected buildings is given in Figure 2.1.

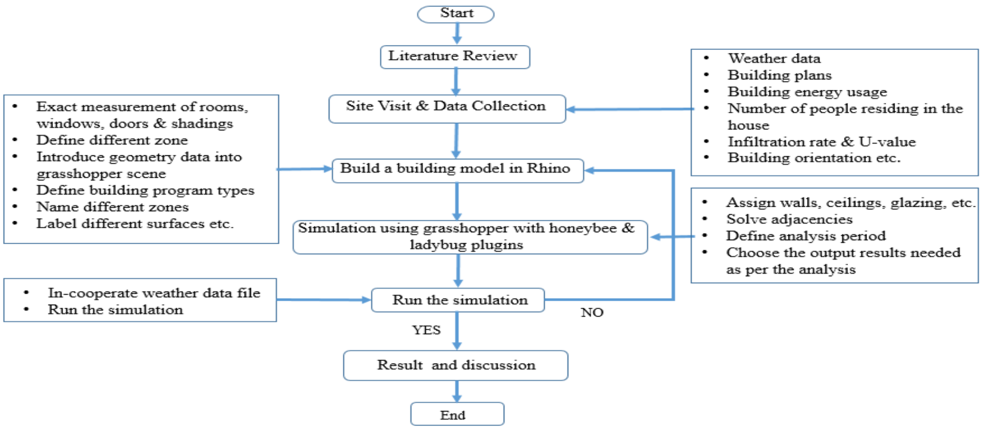

Figure 2.1 *The Methodology Adopted*

2.1 Data Collection

Weather data is the most important parameter for building energy simulation. The weather data of Thimphu is collected from the Photovoltaic Geographic Information System (PVGIS). The weather data of this study (i.e. TechPark, Thimphu), is the typical meteorological year (TMY) data of 10 years starting from 2006 to 2015 is downloaded from the PVGIS (Join Research centre (JRC), 2021).

The additional data collected from the building during site survey are; measurement of apartment layout, number of people living in the room, infiltration rate of the apartment unit, thermal conductivity of the walls, building orientation, energy consumption, and hot water demand.

2.2 Site Survey

Figure 2.2 *Site Chosen to Perform Study on STC and PV Integration*
A blower door test, a wall U-value measurement test, and an instant energy consumption assessment were all performed during the survey. All these tests were conducted on the first floor of the Druk Holding and Investment (DHI) office building located at Thimphu TechPark.

2.3 Blower Door Test

Figure 2.3 *Measurement Set-up of Door Blower Test*

The air change per hour (ACH) value from the measurement test is 2.02 ACH. The blower door test in important because infiltration value is used in the energy simulation of the building.

2.4 Measurement of Thermal Conductivity (U-Value) of Building Envelope

Berardi (2018) otlines the heat transfer in building components occurs through three modes: conduction, convection and radiation. Therefore, a correct measurement of the building envelope's U-value is critical, as this value refers to the insulation level of the walls. In order to compare the results the measured U-value is compared with the simulated U-value. The U-value $2.87\ (\mathrm{W/m^2.K})$ from experiment is out of the range of the international standard, so it is not accepted in the Bhutan standard either. Therefore, Bhutanese buildings, must accomplish more in terms of internal wall insulation.

2.5 Modeling and Energy Simulation of Selected Building

In this dissertation, Rhino software is used for modelling, and Grasshopper uses honeybee plug-in software tools to simulate the energy of the building. Honeybee version 0.66 has 219 components, which is enough to run a building energy simulation. In order to run the simulation, each simulating tool needs an engine. As the core engine for running the simulation, honeybee combines energy plus and open studio. These engines incorporate all mathematical and thermodynamic algorithm ideas in the form of equations; the user interface makes it easier to enter data and see results, and it caters to a variety of user requirements (Maile, Fischer, & Bazjanac, 2007).

The building's total annual energy demand was estimated using an energy simulation in this dissertation. Then, utilizing STC and solar PV devices, it is investigated further to see if it is possible to meet the building's annual energy need by generating electricity from the building facades.

Table 2.1 Compile Surface and Subsurface information

Sl. No	Types	Constructions	Length (m)	Breadth (m)	Height (m)	Area (m^2)	Volume (m^3)
1	exterior wall (south facing)	exterior wall	12.60		2.74	34.52	341.78
2	exterior wall (east facing)	exterior wall	9.90		2.74	27.12	
3	exterior wall (west facing)	exterior wall	9.90		2.74	27.12	
4	exterior wall (north facing)	exterior wall	12.60		2.74	34.52	
5	window (large)	single Pane	3.5		2.6	9.1	
6	window(small-1)	single pane	1.35		2.6	3.51	
7	window(small-2)	single pane	1.35		2.6	3.51	
8	window(small-3)	single pane	1.35		2.6	3.51	
9	window(small-4)	single pane	1.35		2.6	3.51	
10	window(small-3)	single pane	1.35		2.6	3.51	
11	window(small-4)	single pane	1.35		2.6	3.51	
12	floor	concrete slab	12.6	9.9		124.74	
13	ceiling	concrete slab	12.6	9.9		124.74	

Information from Table 2.1 is used to construct the building model which is shown in Figure 2.5.

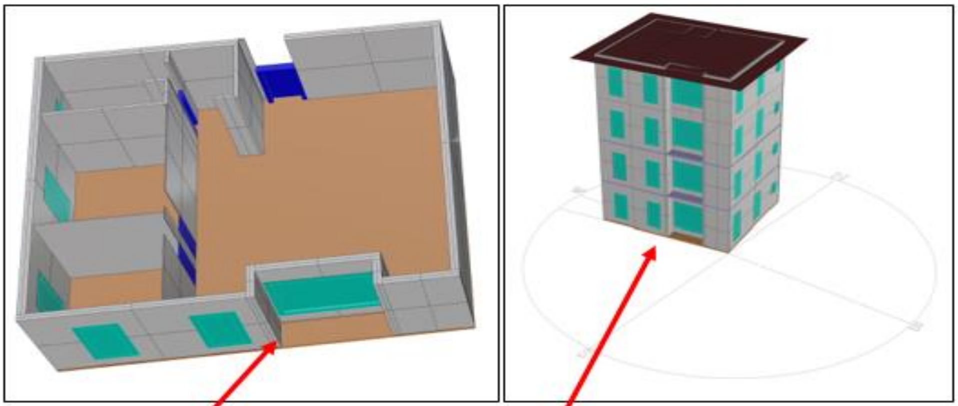

Figure 2.4 *Model Building Using Rhino Software*
The interior design model of the DHI office building (first floor) developed using Rhino is shown in Figure 2.4 a. The orientation of the building is presented in Figure 2.4 b. The south-facing facade of the building is at an angle of 260° away from the true north.

2.6 Interface the Rhino Model into Grasshopper Scene

Once the building geometry has been modelled in the Rhino canvas, it is ready to be imported into the grasshopper scene. After importing the building geometry into the grasshopper scene, the honeybee and ladybug plugins are used to execute the energy simulation is used.

It must be ensured that imported geometries are 100 % correct before moving on to the next steps. It is necessary to cross-check the dimensions of model to the site's original dimensions. This fact is how the model is validated.

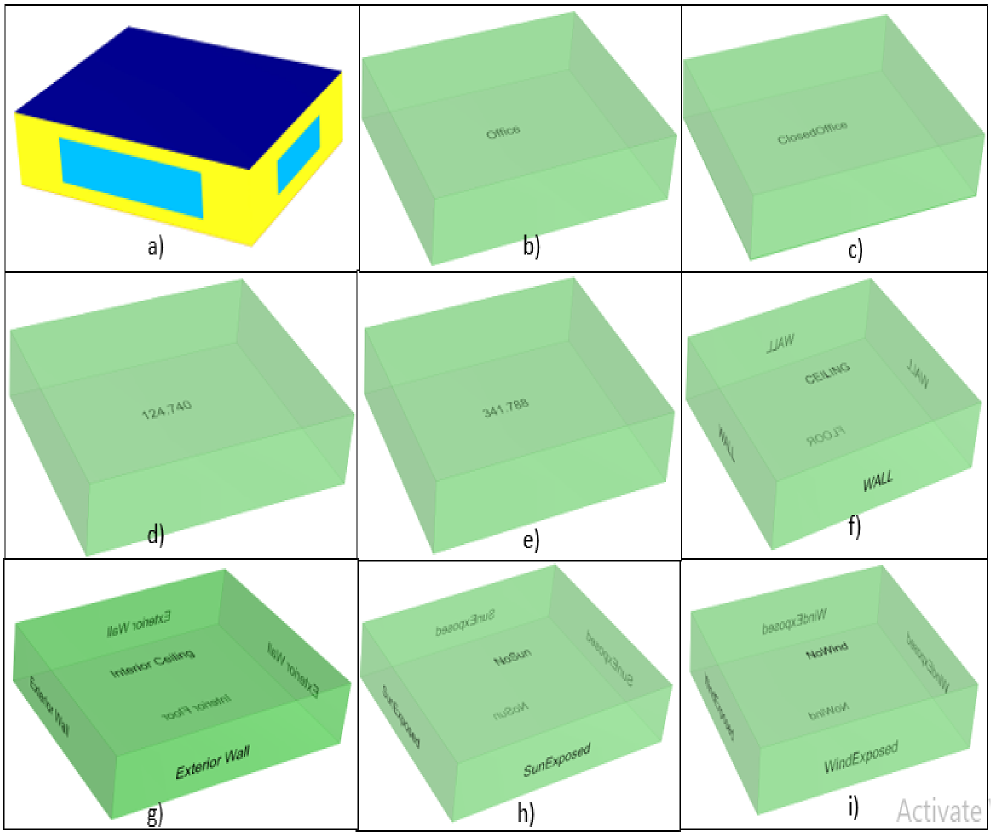

Figure 2.5 *Representation of Honeybee Label Surface and Honeybee Label Zone*

Figure 2.5 (a) depicts a simplified model of the DHI office building's first floor zone in a grasshopper scene. As mentioned earlier, the ceiling and floor are represented in rectangular form, and the windows are grouped together for convenience. Figure 2.5 (b) Depicts an office-type building plan. Figure 2.5 (c) represents a closed office type building zone program. Figure 2.5 (d) and (e) show the zone area in m^2 and the zone volume in m^3 for the corresponding zones. "It should be observed that the area and volume of the DHI office building model's first floor zone in grasshopper are equal to the area and volume as shown in Table 2.1." This is a simple procedure that must be completed in order to cross-check and confirm the accuracy of our input files. The quality and reliability of data contained in weather files, as well as the correct modelling of buildings and their properties, characterization of operational schedules all influence the simulated result in energy simulation (Erba, Causone, & Armani, 2017). As a result, referring to Table 2.1, Figure 2.4 validates the correct modelling of the studied building.

Figure 2.5 (f) illustrates the zone surface, while Figure 2.5 (g) describes the energy plus construction surface. The area exposed to external conditions such as sunlight and wind is shown in Figure 2.5 (h). All this information indicates that the model is correct, therefore, proceeding step can be followed.

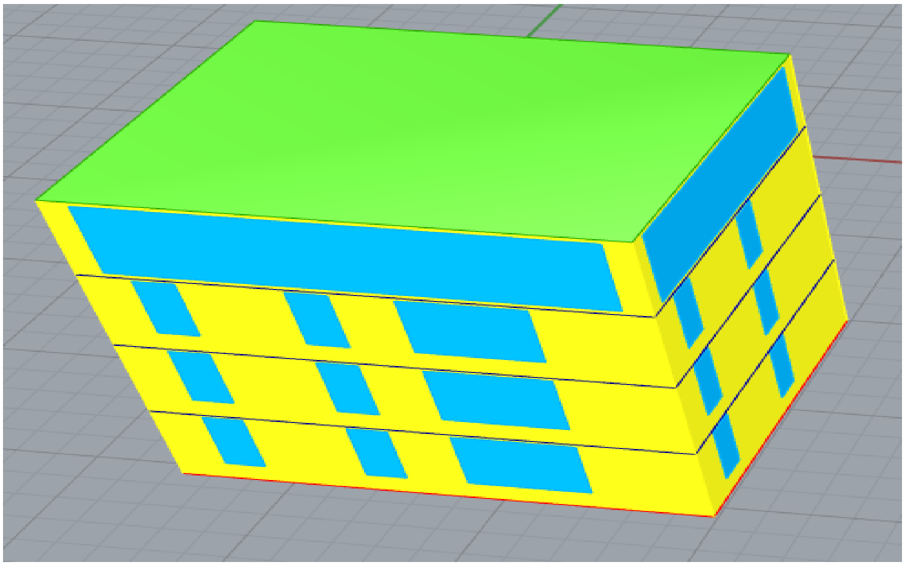

Figure 2.6 *Complete Honeybee zone model of Building Ready for Energy Simulation*

Figure 2.6 shows the entire grasshopper model of the DHI office building structure, which is ready for energy simulation. The thermal properties of the building materials such as thickness, conductivity, density and specific heat capacity are used to design each surface of the model.

The occupancy, lighting, and equipment loads and infiltration values for specific honeybee zones are assigned in the model. Finally, the most important data for energy simulation (i.e. weather data) is in-cooperated in the simulation and its run for energy simulation.

2.7 Radiation Analysis of Selected Building

Studying the possibility of building external wall for photovoltaic and STC energy generation is the focus of this dissertation. South facing facade is always not an option to install active or passive solar devices at buildings, due to geographical location and the climatic conditions (Chow, Chan, Fong, & Z.Lin, 2005). As a result, this study uses radiation analysis techniques to determine the best facade for PV and STC installation. The facade with the most potential is the one with the highest level of solar radiation.

The model build for energy simulation as shown in Figure 2.4 b is the first input data for radiation analysis. Next, context geometry and weather data is in-cooperated into the simulation and finally the radiation analysis is performed.

2.8 Solar Thermal Energy Generation Analysis

Space heating and hot water production are examples of thermal energy demands in the home. In order to meet the ever-increasing energy demand, people began to study renewable energy. One of them is the generation of solar thermal energy. Solar collectors can be used to generate solar thermal energy. If proper sizing of solar thermal system is achieved, the solar heating system may be the next viable and efficient renewable energy technology (Hegarty, Kinnane, & McCormack, 2014).

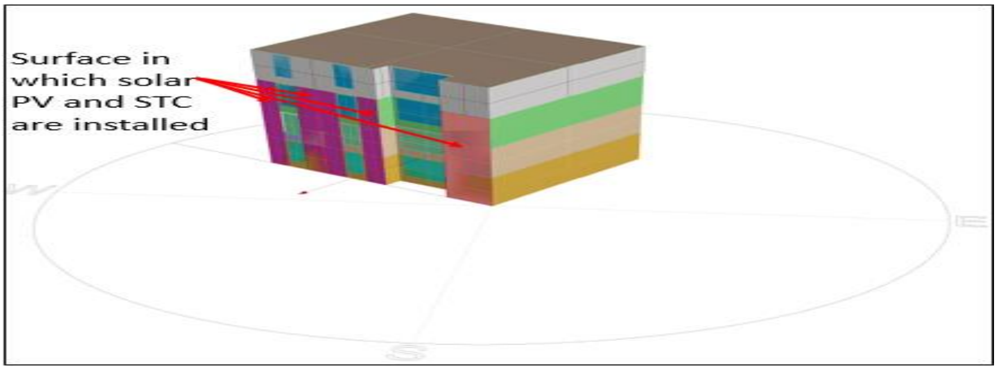

Figure 2.7 *Available Facade Area on Which PV and STC are Integrated*

Purple color indicated by red arrow in Figure 2.7 represent the empty space on which STC or PV are installed. The available south-facing facade surface area of DHI office is $21 \mathrm{~m}^2$. The ratio of aperture to facade surface area is found to be $16/21$. Therefore, facade area is the first input data in this analysis.

Other input data like Collector types, efficiency of collector, quantity of hot water, temperature of service hot water, pipes size, motor sizes, context geometry and weather data are few basic inputs that are required to conduct solar thermal energy generation analysis.

2.9 Solar Photovoltaic Energy Generation Analysis

The development of building-integrated photovoltaic (BIPV) technology has transformed the exterior walls into renewable energy generators (Attoye, Aoul, & Hassan, 2017). There are various obstacles to the concept of integrating photovoltaic into the external walls of buildings, but several technologies are emerging. Rain curtain cladding (ventilated facade) and curtain wall are two major building facade systems suitable for solar photovoltaic (Sharma & Kothari, 2017).

The west-facing facade of Figure 2.6 is an input for this analysis. The west-facing facade provides an area of $26 \mathrm{~m}^2$. Few other input data such as type of PV panels and module efficiency, context geometry and weather data are basic input data required to perform the analysis.

3. Result

The outcomes of the analysis are divided into four sections: energy demand simulation of the DHI office building, radiation analysis, solar thermal energy generation analysis, and photovoltaic energy generation analysis. The total annual energy demand of the DHI Office building is obtained from the energy simulation. In order to identify potential facade, radiation analysis is performed using the ladybug tool. Once, the most radiation potential facade is identified, the integration of STC and PV systems are considered in the simulation.

3.1 Energy Demand Simulation Results

Table 3.1 *Simulated Result from Honeybee Energy Simulation*

Simulated Result Without Insulation				Simulated Result With Insulation			Reduction in Heat Load due to Insulation [%]
Units	Heating Load in [kWh]	Lighting Load in [kWh]	Equipment Load in [kWh]	Heating Load in [kWh]	Lighting Load in [kWh]	Equipment Load in [kWh]	
Grd. Floor	2137	586	913	1356	586	913	36.5
1st Floor	2240	586	913	1425	586	913	36.3
2nd Floor	2121	586	913	1298	586	913	38.8
3rd Floor	1562	586	913	1056	586	913	32.3

For the annual energy demand simulation result of the DHI office building, heating temperature is set at 20 °C and cooling set at 40 °C, are shown in Table 3.1. The cooling temperature is kept high to account for the fact that cooling energy is not necessary for cold place like Thimphu. Table 3.1 depict two types of heating results simulated with and without internal wall insulation. The result in the red bordered line is derived from measured data during the site visit. The other results were obtained assuming same input data as all office has similar dimension and energy utility as the first floor.

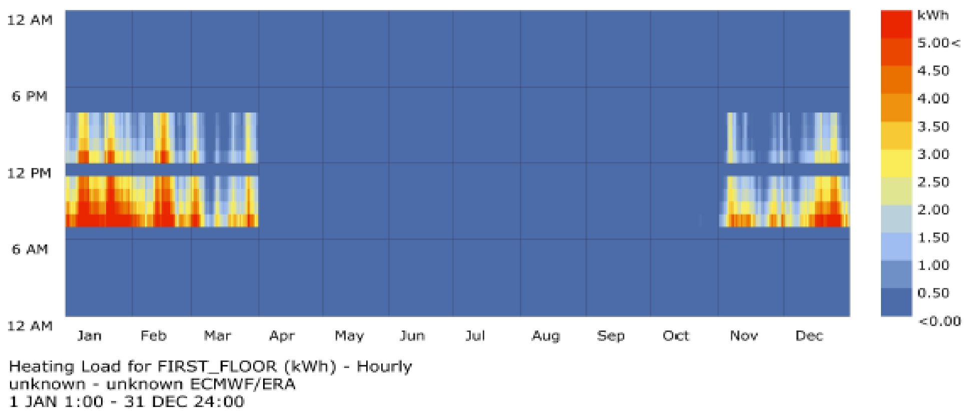

Figure 3.1 *Hourly Heating Load of First Floor in kWh*

Figure 3.1 represents the heating demand per hour simulated for whole year. During the winter months (January, February, March, November, and December), the DHI office's heating energy demand runs about nine hours from 8 a.m. to 5 p.m. After lunch, the heating load drops significantly because the room has acquired adequate solar gain. In winter, the heat load varies between 1.5 kWh and 5 kWh per hour, as shown by the bar scale on the right hand side of Figure 3.1. Since the ambient temperature exceeds the comfort temperature range, the heating load is not necessary in the warmer months (April, May, June, July, August, September, and October) as indicated in Figure 3.1 with deep blue color.

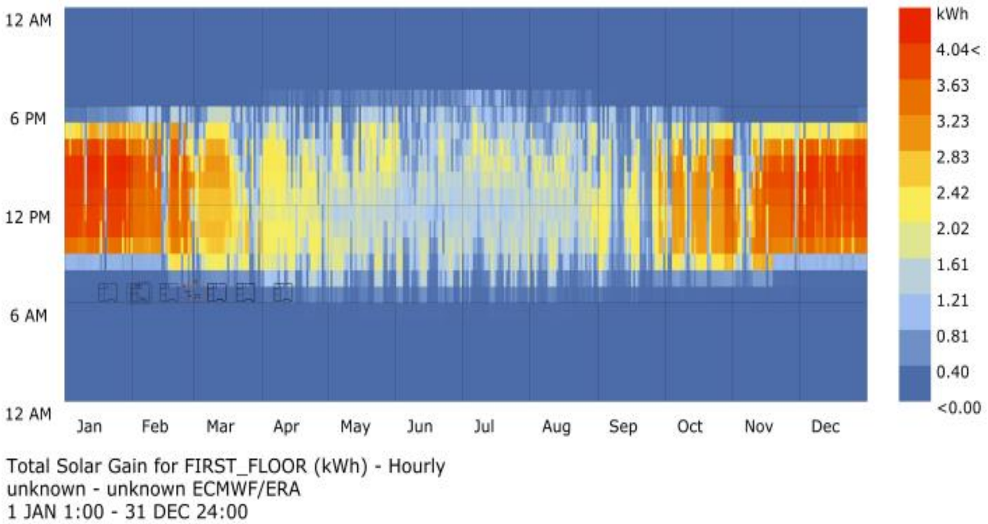

***Figure 3. 2** Hourly Total Solar Gain in First Floor during Whole Year*

The hourly solar gain on the first floor is higher in the winter and lower in the summer, as presented in Figure 3.2. Solar gain is higher in the winter months, as represented by the red color in the Figure 3.2, and lower in the summer months, as indicated by the pale blue color. The simulation result is correct because the site (27° N latitude) has a low solar angle in winter, so most of the radiation is received on the facade, and vice versa.

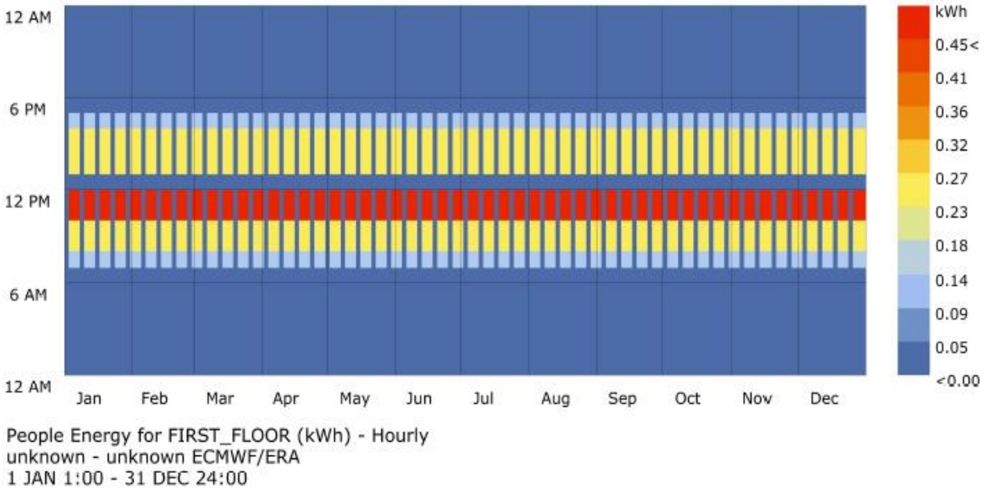

Figure 3. 3 *Hourly Energy Gain from Occupants in the Room for Whole Year*

In the integrated energy simulation, the occupants contributes to heat gain in the room. Therefore, it is very important to understand the heat gain contributed by the occupants in the room, as presented in Figure 3.3. Because only a few officers arrive at that time, heat gain from individuals was lower in the early hours of the office, as demonstrated by the pale blue color in the Figure 3.3. Before lunch, all the officials in the office were present, as shown in the red color in the same figure, indicating that the heat gain from the occupants was the highest. There is no heat gain in the room from occupants during lunch break, as all people are out for lunch. After lunch, few officers go for site visit. Also, in the evening only few officers stay back, therefore less people's heat gain in the room during these times.

In winter, the annual heat energy consumption is 2240 kWh, while the energy demand for lighting and equipment is 1499 kWh. Internal wall insulation, on the other hand, can lower the thermal energy requirement to 1425 kWh. No heat is needed in summer because the ambient temperature is within the comfortable range. The Figure 3.4 clearly represent the room temperature in summer months are higher compare to winter months. As a result, the energy demand of the DHI office during the summer months is for lighting and equipment.

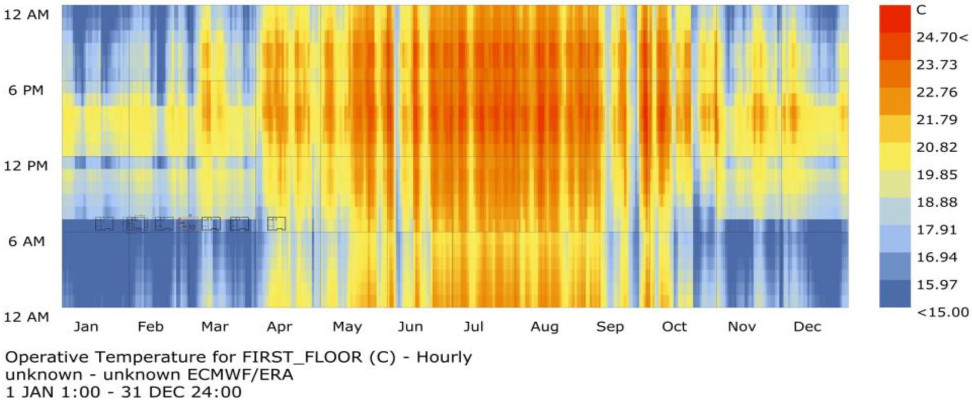

Figure 3. 4 *Operative Temperature of the Room*

3.2 Radiation Potential Analysis Results

Table 3. 2 *Radiation Result of Different Orientated Facade*

Orientation of Facade	Analysis Period	Simulated Total Radiation Results in $[\frac{kWh}{m^2}]$	Radiation per Meter Square in $[\frac{kWh}{m^2}]$ (calculated)	Best Orientation in [°]
South	1 day	797	5.27	360
	Jan.& Feb	37768	4.23	360
	June, July & Aug.	25055	1.8	70
	1 Year	144706	2.6	10
East	1 day	725	4.79	250
	Jan.& Feb	35565	3.9	250
	June, July & Aug.	18601	1.3	320
	1 Year	132187	2.3	240
West	1 day	735	4.8	70
	Jan.& Feb	36259	4.06	70
	June, July & Aug.	20958	1.5	20
	1 Year	137057	2.4	60

From the Table 3.2 annual global solar radiation on south-facing facade is $2.6\ \mathrm{kWh/m^2}$. The annual global solar radiation on west-facing facade is $2.4\ \mathrm{kWh/m^2}$ and east-facing facade is $2.3\ \mathrm{kWh/m^2}$. The radiation result shows south-facing facade receives the most radiation over the year and is identified as most potential facade.

In comparison to the east and west facades, the radiation analysis on the building facade clearly demonstrates that the south facing facade receives the maximum radiation. To confirm this claim, the graphical result in Figure 3.5 clearly shows that the south-facing facade is the most promising.

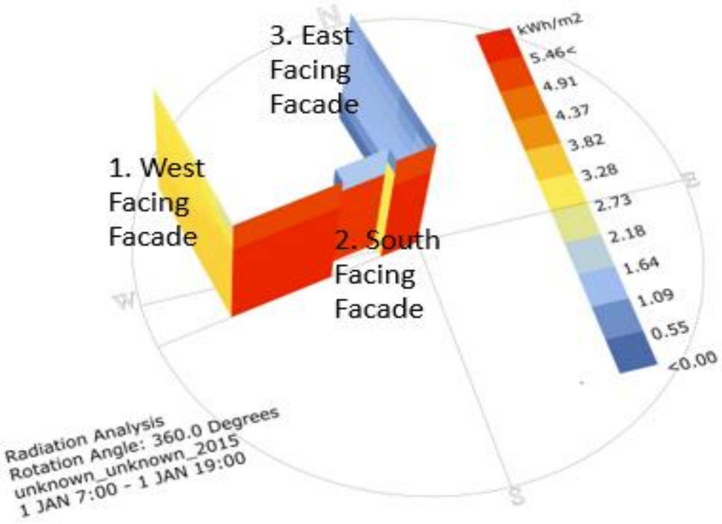

Figure 3. 5 *Radiation Analysis on West, South and East Facing Façade*

3.3 Solar Thermal Potential Analysis

Table 3. 3 *Solar Thermal System Size and Energy Generation*

Collector Area [m²]	System Size [kWth]	Tank Size [l]	Avg. Heat form Tank per Day [kWh/day]	Heat from Tank per Year [kWh]	Auxiliary Heat per Year [kwh]	Annual Solar Fraction [%]
First Floor Only						
16.78	12	900	6.68	2440	921	71.74
Whole Building						
67.12	50	5000	27.57	10065	3352	74.83

Table 3.3 displays the summary of solar thermal system sizing and thermal energy generation. From the Table 3.3, the annual thermal energy from the hot water tank is 2440 kWh. The thermal energy stored in hot water is delivered into rooms by circulating hot water through radiator pipes. The ratio of aperture to facade surface area in this study is 16.78/21.68

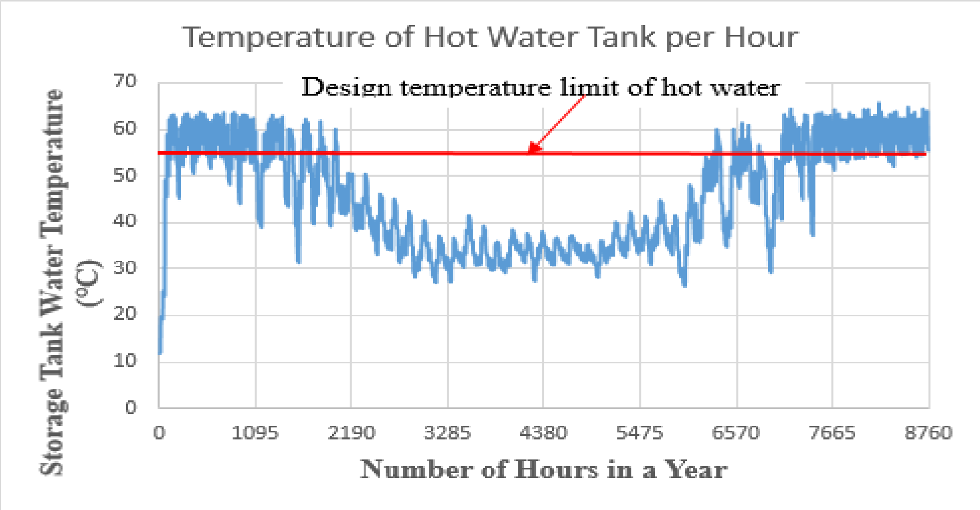

Figure 3. 6 *Temperature of Hot Water Tank per Hour*

The temperature of the water in the tank in Figure 3.6 starts at 11 °C, which is the average cold water temperature in Thimphu throughout the year. The temperature of hot water used for room heating is set at 55 °C. Design temperature limit for hot water is indicated by the red line in the Figure 3.6. Hot water temperature, on the other hand, exceeds 55 °C in the winter and falls below the design temperature in the summer. In the winter, the temperature of hot water exceeds 55 °C due to the fact that solar energy received on the facade is higher than in the summer. Excess energy generated on weekends (Saturday and Sunday) and in the winter can be utilized to heat swimming pools, hot tubs, toilet pans, greenhouses etc.

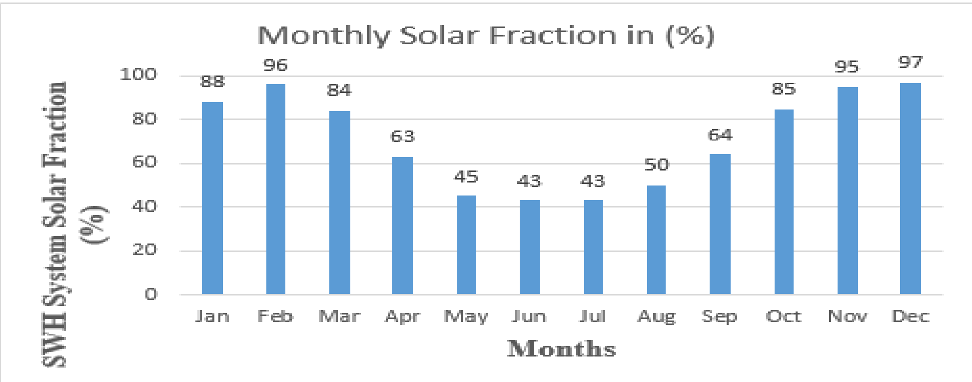

Figure 3.7 *The Monthly Solar Fraction in %*

The solar fraction of several months is illustrated in Figure 3.7. The solar fraction refers to the amount of heating load provided by the SWH system throughout the course of the year. As presented in the same figure, the monthly solar energy ratio in winter is greater than that in summer. The solar power ratio depicted in the Figure 3.7 is only related to the DHI office, not to the entire building.

The DHI office building's annual energy demand simulation generated 2240 kWh of thermal energy, which is used for space heating. Similarly, the solar thermal collector located on exterior wall of the DHI building generates 2,440 kWh of heat energy per year. These two results show that a solar thermal collector provide 200 kWh more thermal energy than the office's actual thermal energy requirement.

3.4 Solar PV Energy Generation Analysis

The radiation studies provided in Table 3.2 indicated that the west-facing facade is the next potential facade. The DHI office building's west facade has a total size of $31.2\ \mathrm{m}^2$. The windows in west facade cover $4.4\ \mathrm{m}^2$, so the remaining facade area is $26.8\ \mathrm{m}^2$. The installation of PV panels were considered on this available space, and energy generation is calculated using the "Ladybug photovoltaic Surface" component.

The AC and DC power generated by the photovoltaic panels on the west facade are presented in Table 3.4. Compared with DC power generation, AC energy is less, because the conversion losses are involved in AC power generation.

Table 3. 4 *Photovoltaic System Size and Energy Generation*

West Facade Area [m^2]	System Size [kW]	PV Tilt Angle [°]	AC Energy per Year [kWh]	DC Energy per Year [kWh]
26.8	4	90	2016	2383

The annual DC energy generated is more compare to the annual AC energy generated. Because the extra conversion losses occurs in inverters and transformers in AC generation.

3.5 Result Analysis

The integrated energy demand of DHI office is represented by the thermal energy demand generated from the energy simulation. Many factors controlled the room's thermal energy, including solar gain, people's gain, lighting and equipment gain, and so on. The yearly heating demand of the DHI office (located on the first floor) was 2,240 kWh, as shown in Table 3.1. A total of 1,499 kWh was used for lights and equipment. However, by combining interior wall insulating materials could reduce these thermal energy requirements even more. When using 50 mm wood wool board insulation, the heat energy requirement is reduced to 1,425 kWh. Thus the DHI office's annual total energy use (without insulation) is 3739 kWh. The DHI office's annual total energy consumption (with insulation) is 2925 kWh. As a result, by insulating internal walls using 50 mm wood wool insulating material, the annual thermal energy demand is lowered by around 36%.

Referring, the Table 3.2, south-orientated facade receives the highest radiation, followed by the west and east-facing facades, conferring to the radiation analysis of the facades with varied orientations. Figure 3.5 provides evidence for the above statement. Because the south facade is red, signifying significant radiation, whereas the west facade is yellow and the east facade is pale blue, suggesting that the south and west facades have poor radiation. In Table 3.2, the red bordered line denotes a better performance than the other two. Therefore, the south-facing facade is considered the most viable option for installing PV and STC equipment.

The DHI office's simulated annual thermal energy need is 2,240 kWh, whereas STC's simulated annual thermal energy (hot water) output at 55 °C was 2,440 kWh, according to the analysis. STC generated 200 kWh more annual thermal energy than DHI's anticipated annual thermal energy needs. Therefore, theoretically, the heating energy demand of DHI Office can be met with the installed capacity of

12.48 kW, because this is the system size used in the simulation analysis.

DHI offices use approximately 71.74 % of solar energy each year. In the winter, however, the proportion of solar energy is 97 %, indicating that solar energy provides the majority of the space heating energy. On the contrary, the proportion of solar energy in summer is as low as 43 %. This fact is due to the heat produced by solar radiation on the facade in the summer is insufficient to reach set temperature.

The office's total energy use, including lighting and equipment, was 1,499 kWh. Photovoltaic panels were installed on the west front, which was the second most potential facade, to meet this energy need. The facade generated 2,016 kWh of AC energy, which was 517 kWh more than the demand. It shows that photovoltaic power generation on the office's exterior may easily meet the office's lighting and equipment energy requirements. Therefore, the photovoltaic system on the west facade had a capacity of 4 kW to meet the energy needs of the DHI office (capacity obtained from simulation).

4 Conclusion

The DHI Office's total annual energy use (without insulation) was 3,739 kWh. The DHI office's total annual energy consumption (with insulation) was 2,925 kWh. Due to the use of internal insulation, the annual energy demand of the DHI office has been reduced by approximately 21%.

A radiation analysis was performed for the DHI office to determine the most potential facade. The total radiation received in different analyses period, is tabulated in Table 4.2. The radiation analysis of the facades with different orientations concludes that the south-facing facade receives the most radiation, followed by the west and east facades.

The STC generated 2,440 kWh of thermal energy per year, which was 200 kWh higher than the DHI office's yearly heat consumption. This shows that solar hot water for space heating is a viable option in Thimphu.

The annual lighting and equipment load of the DHI office was 1,499 kWh. However, annual AC energy generated from the west-facing facades was 2,016 kWh. Hence, energy generated was sufficient to meet the office's lighting and equipment energy needs, and there will be no energy shortage on sunny days.

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