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Energy simulation to estimate building energy consumption using EnergyPlus

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ABSTRACT

To achieve sustainable and green design, performance simulations are often used to verify these criteria and modify the design. The conventional approach of manual trial-and-error is too time-consuming to be practical. The evaluation of building energy consumption usually requires building energy profiles on month and category basis. EnergyPlus-Windows-32-8.1.0.009, simulations were integrated to obtain this information but generating simulations requires a significant amount of experience, time, and effort to enter detailed building parameters. This paper presents a simple methodology to estimate source and site energy, where maximum energy requirement are 1485.14 MJ/m^2 and 447.6 MJ/m^2; respectively for D (mass type wall with attic) category within different categories (A-F) building. Moreover utility use per total floor area also calculated. Maximum U -factor with or without film are 0.512, 0.554 W/m^2.K; respectively for wall of building. For one year max tariff charge is 63.5$ on electrical source energy consumption for D category building. In addition to summer and winter clothes maximum and minimum uncomfortable time are 436.25 (for D-category and 390.75 (for E-category) hours as annual. The methodology has been applied to hypothetical buildings placed in Jessore, Bangladesh.

Keywords: Building Energy simulation, HVAC System, Human comfort, Energy Plus

1. Introduction

Concerning the rude use of energy and with climate change caused by gas emissions have impacts for civil construction. Population growth and economic progress have led to an increase in the demand for energy. The worldwide increase in demand for energy has put rising pressure on identifying and implementing ways to save energy. Energy efficiency is an important factor related to the energy issue; according to Omer [1] a building has three parameters directly related to energy consumption: thermal comfort (thermal conditioning), visual comfort (lighting) and air quality (ventilation). An annoying factor in the varied environment is the fact that the degree of industrialization in the building and construction industry is rather low. Each building is essentially a prototype. This is coupled with traditionally high costs and a complex planning process, this is usually hierarchical according to the different trades acting as a barrier for innovation. In order to make innovation possible, improved components and operational concepts are necessary to achieve an optimal design of buildings. Energy saving concepts includes passive and active measures. In the passive approach, investigation of innovative building envelope characteristics, increasing the use of natural ventilation, and the application of building thermal mass as energy storage are providing promising opportunities for energy efficiency. The active measures involve optimization of HVAC system operation taking into account the combination and performance of technologies.

Daylight is an important strategy in obtaining a more efficient architecture which is integrated with the climate in which it is inserted, and therefore it is necessary to study the ambient light. In order to carry out a more advanced study there is a need for data related to the daylight of the location in which the building will be constructed. However, the analysis of the ambient daylight must also take into account the heat exchange which occurs through the windows. Studies such as those by Ochoa and Capeluto [2], Li and Wong [3], and Ghisi and Tinker [4] use the joint simulation of the daylight and heat gain of a building in order to verify the performance of the design decisions taken, to study the daylight in dense areas and to analyze the ideal window size in climatised buildings. Energy consumption analysis of buildings is a difficult task because it requires considering detailed interactions among the building, HVAC system, and surroundings (weather) as well as obtaining mathematical/physical models that are effective in characterizing each of those items. The dynamic behavior of the weather conditions and building operation, and the presence of multiple variables, requires the use of computer aid in the design and operation of high energy performance buildings. Drawbacks in using computer simulations include the considerable amount of detailed input data and time from even experienced users [5-6]. Furthermore, simulation tools may not be cost-effective at the first stage of analysis, which makes others tools, such as screening tools, a better option. Several methodologies to estimate energy consumption have been developed. Some of them are based on statistics and other on simulations [5,7–13]. On-line building energy predictions based on neural networks and genetic algorithms [14–16] can also be used in some applications. In general, it is accepted that weather data

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can play an important role on forecasting energy consumption in buildings [7]. Papa et al. [17] proposed a normalized energy use index (NEUI) based on a temperature function. In their work, they discussed the influence of weather variables such as solar radiation and air velocity, and conclude that temperature is the most important factor on energy consumption. Their reasoning is that, since the equipment daily energy consumption is always the same, and because there is not significant variation of daily routine, changes in HVAC energy consumption is predominantly a function of temperature. To obtain the temperature function to compute the NEUI, they used EnergyPlus as a simulation tool. Since even more detailed building simulations will not reproduce exactly the energy consumption profile, there is an accepted degree of uncertainty in the estimated energy demands as consequence of the accuracy of the tool and inputs that the user needs to be aware of in order to make the final conclusions [6,18,19].

In the residential sector 47% of the total energy consumption in the Bangladesh, that justifies a variety of initiatives for building energy consumption reduction. As examples, the Building Technologies Program of the DOE Energy Efficiency and Renewable Energy Office is working to achieve the goal of net-zero energy buildings, and the Bangladeshi Green Building Council promotes the design, construction, and operation of high performance green buildings through the Leadership in Energy and Environmental Design program. Jessore is a district in the southwestern tip of Bangladesh. Energy consumption in the Jessore building sector is momentous. For reducing that, the entire external building envelope must be designed in accordance with the Bangladeshi building code.

Source energy is the most equitable unit of evaluation. Source energy represents the total amount of raw fuel that is required to operate the building. It incorporates all transmission, delivery, and production losses. On other hand site energy, which is the amount of heat and electricity consumed by a building as reflected in your utility bills. U value is a measure of heat loss in a building element such as a wall, floor or roof. It can also be referred to as an 'overall heat transfer co-efficient' and measures how well parts of a building transfer heat. This means that the higher the U value the worse the thermal performance of the building envelope.

Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures and humidity. There are three distinct seasons in Bangladesh: a hot, humid summer from March to June; a cool, rainy monsoon season from June to October; and a cool, dry winter from October to March. In general, maximum summer temperatures range between 30°C and 40°C. April is the warmest month in most parts of the country. January is the coldest month, when the average temperature for most of the country is about 10°C. Lightweight cotton clothing is advised throughout the year, with an umbrella or raincoat for the monsoon season. Be prepared for high temperatures and humidity, no matter where you go. A sweater and warmer clothing is advised for cooler evenings. Warmer clothing is advised for the northern mountainous areas of Bangladesh, which can have quite cold winters.

2. Simulation Technique

The global increase in demand for energy has generated pressure on saving energy. Consequently, Energy efficient buildings are an important factor related to the energy issue. Various building energy simulation softwares are used now-a-days to simulate building energy consumption and to design energy efficient building such as EnergyPro, EnergyPlus, EAB, REScheck etc. Among them EnergyPlus is developed by US department of Energy and it is getting popular to simulate and design of energy efficient building.

The methodology proposed in this paper is based on energy calculation obtained using data from EnergyPlus. It is a widespread and accepted tool in the building energy analysis community around the world [21]. This program combines the best capabilities and features from BLAST and DOE-2 along with new capabilities. EnergyPlus models heating, cooling, lighting, ventilating, and other energy flows as well as water in buildings. The Building Energy Software Tools Directory [22], which is a directory providing information on 375 building software tools for evaluating energy efficiency, renewable energy, and sustainability in buildings, introduces EnergyPlus as a tool for application on energy simulation, load calculation, building performance, simulation, energy performance, heat balance, and mass balance. EnergyPlus is free of use and can be downloaded from the official website [20]. Support from the U.S. government, worldwide use, capabilities, and resources, are the main reasons EnergyPlus has been chosen as the simulation tool to generate the data used in this study to estimate energy consumption. EnergyPlus has been used in other studies as source of energy consumption. Stadler et al. [21] used EnergyPlus as source of site end-energy loads for the analysis of distributed generation (DG) technology. Similarly, Fumo et al. [23] used it for the analysis of combined cooling, heating, and power (CCHP) systems. As an example of how EnergyPlus has been used to estimate building energy performance as reference for other cases, Griffith and Crawley [24] used EnergyPlus to propose a methodology for evaluating energy performance for the U.S. commercial buildings sector to estimate the technical potential on zero-energy buildings. They used data from the 1999 Commercial Buildings Energy Consumption Survey (CBECS) to create a baseline building energy model as it were being built in 2005.

It is obvious that an energy simulation needs to be performed to solve the design optimization problem.

EnergyPlus was used to simulate the space conditioning load of the building. EnergyPlus is an energy analysis and thermal load simulation program [25]. It has been widely used, like its predecessor programs, BLAST and DOE-2, by architects, engineers, and researchers. In the top view of building shown in Fig. 1, the exterior wall system is composed of four exterior walls, namely 4WE, 1SE, 3NE and 2EE.

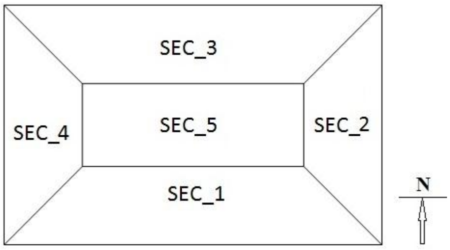

Fig. 1: Top view of building.

where the first number represents the section number, the second letter represents the orientation, and the third letter “E” represents “Exterior”. Therefore, “3NE” denotes the north-facing exterior wall of section 3. The main components of the enclosure system in **Table 1** and all sections physical parameters are summarized in Table 2.

Table 1 Physical parameters of the building-I

Categories	Enclosure	
	Wall Type	Roof Type
A	Steel Framed	Insulation entirely above deck
B	Steel Framed	Attic and other
C	Mass	Insulation entirely above deck
D	Mass	Attic and other
E	Wood Framed	Insulation entirely above deck
F	Wood Framed	Attic and other

Table 2 Physical parameters of the building -II

Enclosure Section	**Area [m^2]**	**Volume [m^3]**
N_1_FLR_1_SEC_1	91.06	346.02
ZN_1_FLR_1_SEC_2	35.09	133.33
ZN_1_FLR_1_SEC_3	91.06	346.02
ZN_1_FLR_1_SEC_4	35.09	133.33
ZN_1_FLR_1_SEC_5	47.71	181.32
Total	300	1140
Conditioned Total	300	1140

For internal heat gains, all section was set to have 5 people per 100 m^2 and they were assumed to be in the building from 08:00 to 17:00 on regular work days and Friday is weekend day. Lighting level was set to be 10.76 W/m2 for all five sections. The air flow rate is 0.22 m^3/s (max.) on exterior part of the building. Since the study was concerned with the categories (A-F) of buildings conditioning load and energy consumption.

To analyze the categories of building, an obvious approach is designing different type materials in wall and roof, simulating each case to obtain the energy consumption and comparing the results. Many building performance simulation programs including EnergyPlus cannot be directly integrated. Therefore, one needs to develop customized codes to link the performance simulation program to the optimization algorithm. The most convenient way to run EnergyPlus is using the EPLaunch program that comes with the EnergyPlus downloadable package. EP-Launch has an interface through which the user can open IDF-Editor to edit the input file, specify the location of the EPW weather data file, and run a single simulation. Although being easy to use, the approach of running EnergyPlus in EP-Launch cannot be integrated into modeFRONTIER. Another way to run EnergyPlus is using RunEPlus batch file. The command is simply one line in DOS mode, i.e., “RunEPlus <input file name> <weather data file name>.

After properly editing the RunEPlus.bat file and writing the DOS command lines, a work flow to perform insulation optimization was established. The work flow consisted of four steps. Step 1 contained all the input variables, i.e., the insulation of six walls. DOE (Design of Experiment) initializing the input variables and the optimization algorithm were defined in step 2. Step 3 was the linkage that enables the integration of EnergyPlus. A DOS batch file was written and several support files such as Energyþ.ini, Energyþ.idd, DElight2.dll, and ExpandObjects.exe were transferred to the working directory. Optimization objectives were defined in step 4. Other nodes were mainly to perform calculations and other tasks needed. This four-step work flow can be used as a general format for many optimization problems encountered in architectural design. The range and step of the input variables were defined in step 1. In this study, the input variables were transferred to the “InputFile” node. In this node, one can open the input file, 1.idf, of EnergyPlus and specify the location of each variable. The work flow ends with two optimization objectives, namely minimizing source & site energy consumption and minimizing summer or winter clothes uncomfortable time with lowest energy cost.

3. Result and discussion

Fig. 2 shows total source energy with the categories (A-F) of building. By simulation, it has been obtained that total energy required is 410-450 GJ as source energy and the conversion factor for site to source energy is

3.31with respect to electricity used. From the Fig. 2, highest value of source energy per total building area required for D category building is 1485.14 MJ. On the other hand the lowest values is 1368.92 MJ for A-category building and the sequence is D>E>F>C>B>A.

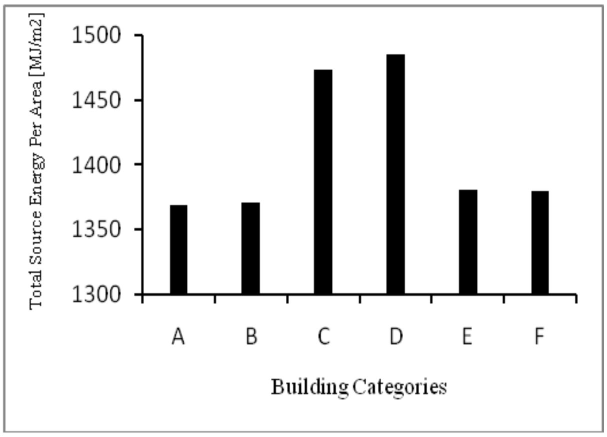

Fig. 2: Source energy per total area with the categories (A-F) of building

Utility use per total floor area as electricity intensity has been measured by the quantity of energy required per unit output or activity and total energy coming from utility as electricity with different categories (A-F) is about 120-140 GJ, as well as using less energy of a building reduces the intensity with building category that shows in Fig. 3. The electrical intensity needed for A-category building per total area as lighting and other are 110.91 and 128.72 MJ/m^2; respectively but the minimum electricity intensity required for steel framed wall, A-building is 412.52 MJ/m^2 and the progression is D>E>F>C>B>A. And 447.6 MJ/m^2 is maximum value of total electrical intensity used in building D.

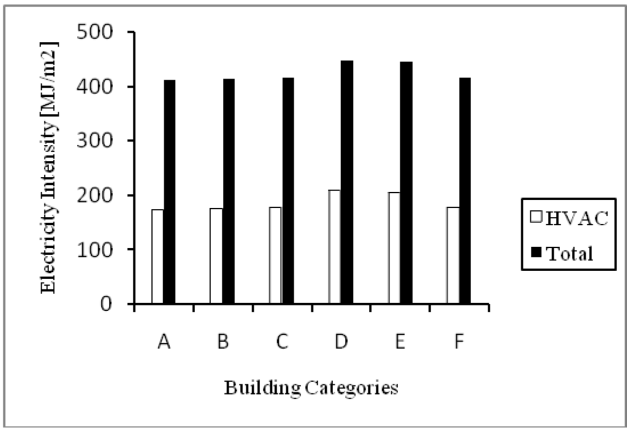

Fig. 3: Utility use per total area of building as electricity intensity with different category of building.

Fig. 4 shows thermal performance of building A with respect to U value. From the figure we can say that, with or without film the thermal performance of wall is almost 1.6 times greater than ceiling of buildings. For building A with no film, the U factor of wall and ceiling are 0.385 & 0.288 W/m^2.K; respectively that are almost 6 and 4 % higher than of building A with film. For other type of buildings, the U-factor shows similar value.

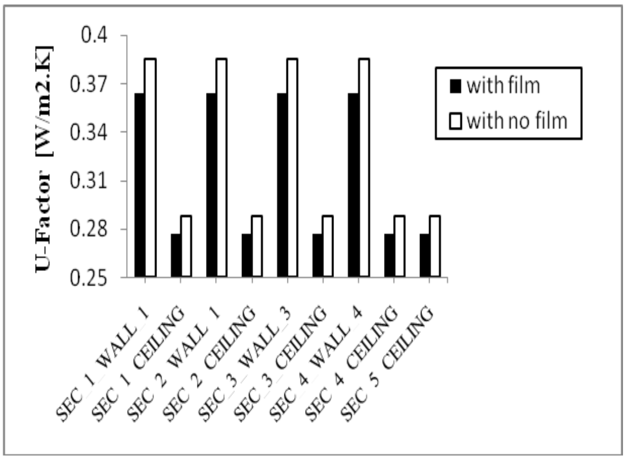

Fig. 4: U-factor in different section of building A.

The annual energy charge on electricity for all categories buildings is about 2600 to 2900 ($) in jessore, Bangladesh. From Fig. 5 the annual tariff charge (63.5 $) on electricity is maximum for the building D at the month of August because of high source energy used. The lowest tariff is 58.95 $ of building A & B at that month. During month December to January annual tariff charge is minimum value comparing other months.

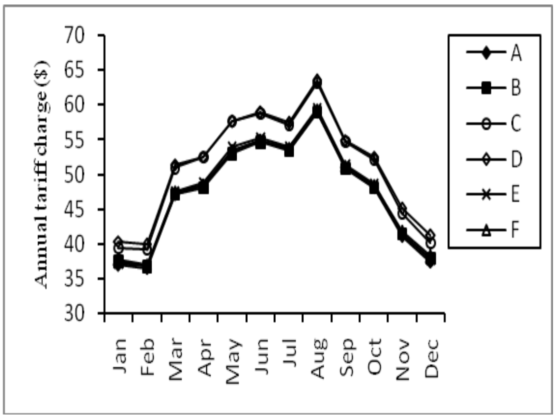

Fig. 5: The annual tariff charge on electricity in different categories (A-F) building

Fig. 6 shows that January to March clothes uncomfortable time increase almost linearly. From March to June maximum uncomfortable time is observed for all categories buildings for the reason of hot humid summer. Following June to December clothes uncomfortable time decrease randomly. From the Fig. 6, evaluate a value that is near to the ground at the month of December for all categories buildings. Since categories A-F buildings, the clothes uncomfortable time is highest as a value of 396.5 hours at June in Building A and the lowest value is 413 hours at that month in building C. building arrangement with considering summer or winter clothes uncomfortable time is D>B>F>C>A>E. As of above discussion, C & A category building required moderate energy but feasible with respect to comfortable time than other category buildings.

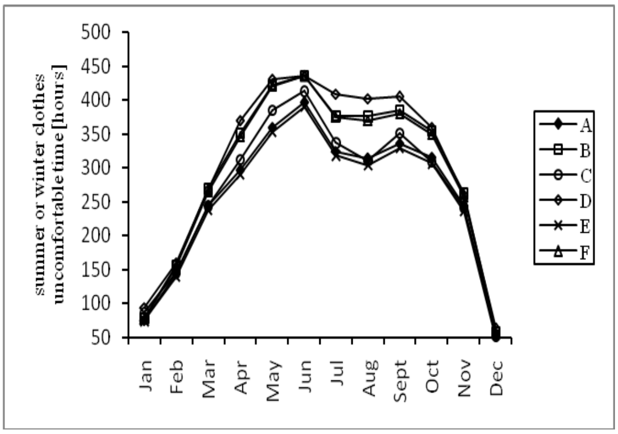

Fig. 6: summer or winter clothes uncomfortable time throughout the year in different categories (A-F) building

4. Conclusion

This paper has shown that it can be used to integrate EnergyPlus-Windows-32-8.1.0.009, to conduct optimization. Some basic computer knowledge is required to establish the work flow. To achieve sustainability, many design objectives considered are related to physical performances of the building and thus, they need to be simulated using computer programs. Using an office building in Jessore, Bangladesh as an example, we have demonstrated how to integrate EnergyPlus into the optimization software tool to search for the best result to minimize the source and site energy as well as winter or summer clothes uncomfortable time at lowest energy cost with different categories (A-F) building. The sequence for source & site energy is D>E>F>C>B>A. On behalf of utility per total floor area, the progression of electrical intensity is D> C>E>F> B>A. Building with or without film, the thermal performance of wall is greater (almost 1.6 times) than ceiling of buildings. Also, maximum tariff charge is 63.5 $ on electricity for D category building annually. Preferable building order with respect to summer or winter clothes uncomfortable time is D> B > F>C>A >E. From above result we can say that, category of C & A building required moderate energy but feasible with considering comfortable time than other category buildings. EnergyPlus is successfully integrated into the optimization software tool through writing a DOS batch file. In the future, there is a need to study how to integrate other building performance simulation programs. By doing so, the technique can be used to solve more residential building design optimization problems.

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