Generating Building's Operating Energy Automatically by Energy Plus and C#

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***Abstract*—The use phase of buildings always contributes to the largest share of life cycle energy consumption and life cycle environmental impacts. This paper selects different wall materials, provides a possible method to calculate operating energy consumption of alternative wall assemblies automatically, and suggests the influences that different layers have on operating energy. The results show that the operating energy consumption varies according to the insulating layer while the thickness of air gap has a negligible impact on the operating energy. And it can be seen that the material and thickness of insulation has a great influence in the building's operating energy and there should be more research focusing on the method to generate life cycle energy in order to optimize the buildings performance in the architectural design.**

***Key words*: Operating energy, wall assembly, auto-generation.**

I. BACKGROUND

The world is facing serious environmental problems, such as global warming and waste accumulation, resulting in a huge change in the climate. Construction industry, accounting for nearly 40% of the world's energy consumption, 30% of raw material use, 25% of solid waste, 25% of water use, 12% of land use, and 33% of the related global greenhouse gas (GHG) emissions [1,2], has an enormous impact on the environment. The construction industry covers several stages, including mining, manufacturing, construction, operating, maintenance and demolition, and each stage consume a large amount of energy while releasing considerable emission.

It is indicated that the operating phase of buildings always contributed to the largest share of life cycle energy consumption and life cycle environmental impacts because of its extensive duration. For example, Kofoworola & Gheewala [3]showed that the operating energy of an office building in Thailand is 81% of its total energy consumption, while the study of Mithraratne & Vale [4] reported that the operating energy accounted for 57%-74% in residential buildings. Another research in Italy suggested that the use phase of low energy house consumed less than 50% of its life cycle energy consumption [5].

Meanwhile, the hearting and cooling system is the largest source of energy consumption during the use phase. It is shown identified that the proportion of space heating and cooling reaches 48% of its operating energy, followed by lighting (37%), ventilation fans (7%) [6]. The envelope system is an important part of building, and its physical performance determined by its construction and material has a direct impact on the operating energy.

This study, focusing on the operating energy, is based on Future House, which was designed and built in 2013, by research team of Southeast University, China. The paper selects different wall materials, generates the operating energy in Energy Plus automatically by using C# language, compares the results and puts forward the envelope design optimization suggestions.

II. INTRODUCTION

Future House is a lightweight residential building with kitchen and bathroom modules , equipped with solar photovoltaic and thermal systems, which can satisfy its daily operating needs. It consists of two structural units of 6000 mm × 2100 mm × 3000 mm and 6000 mm × 2900 mm × 3000 mm, with a 20-mm-wide space in between is shown in Fig. 1,

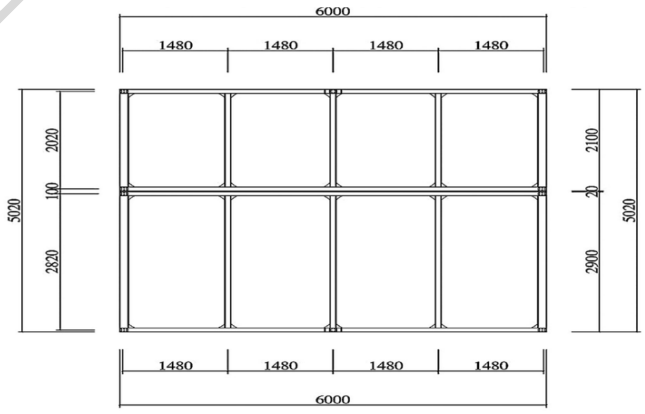


Fig. 1. Plan of Future House

providing about 30 m2 indoor space and 15 m2 outdoor platform. The construction of Future House took only 16 days from preparation of materials to installation of related equipment. The Future House is a typical case of industrialized construction method—initially built in the factory, forming two main modules and two roof modules, transported to the construction site by trucks for final assembly, which took about 7h in this case. Future House has been disassembled, transported and assembled for several times since it was first

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constructed, realizing the possibility to make a quick turnover. [7]

The study presented in this paper focuses on the relationship between wall assemblies and operating energy, selecting alternative materials of the insulating layer and different thickness of air gaps, retaining the structure, plan and materials (roof, floor, windows and doors) constant. The composite roof construction with interdigitated U-shaped stainless steel plate outer layer ensures waterproofing while double timber board encased rock wool insulation inner layer provides improved thermal performance (see Fig. 2). The floor construction uses gypsum board as the outer layer and the same inner layer assembly of roof as the inner layer (see Fig. 2). The original wall assembly of Future House is shown in Fig. 3. The outermost layer use aluminum sheets with polyurethane foam filling inside, and the inner layer is made up of two timber boards with rock wool insulation inside to improve its thermal properties. The 80 mm × 30 mm timber keels between the timber boards are embedded in the rock wool insulation, making the inner layer more stable. There is also an air gap of 80 mm as the same thickness as the structural profiles, between the inner layer and the outer layer, in order to improve its thermal insulation properties.

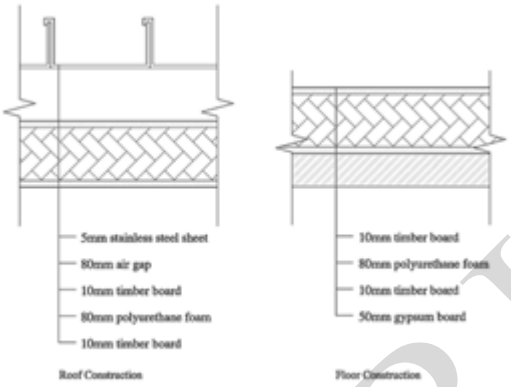


Fig. 2. Roof and floor construction of Future House

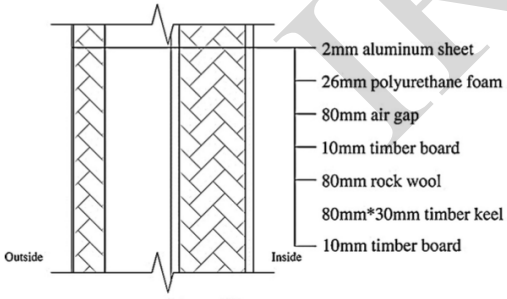


Fig. 3. Exterior wall construction of Future House

There are two kinds of materials used in the insulating layer, polyurethane foam and rock wool, with the thickness of 100mm, 80mm, 60mm, 40mm respectively, while the air gaps are designed with thickness of 5mm, 10mm, 20mm, 30mm, 40mm, 50mm and 60mm. As a result, there could be 56 kinds of wall assemblies according to different material selection.

The study uses C# code to generate idf files automatically and establish the energy consumption during the operating stage by Energy Plus (Version 8.1). The original setting in the Energy Plus is based on hypothetical mode for HVAC operating and the weather statistics of Nanjing, (the same location as Future House), provided by Energy Plus.

The operating mode assumed that two people occupied the house and that there are different schedules based on weekdays and holidays. The weekdays were divided to three periods: 0:00–09:00, 09:00–17:00 and 17:00–24:00, according to Chinese conventional work time. During the period from 00:00 to 09:00 and 17:00 to 24:00, the HVAC system starts heating when the temperature is below 20 ◦ C and cooling over 25◦C, and the electric engine was set to full load to ensure efficient operation of HVAC system. However, during work time from 09:00 to 17:00, the heating setpoint is 10 ◦ C and cooling setpoint is 35 ◦ C and the electric engine was set to half load to operate at low intensity of HVAC system. The electric engine was set to full load and operated 24h to maintain the indoor temperature between 20 ◦ C and 25 ◦ C over the weekends and during Chinese holidays. The special public holidays during the run period are based on Chinese holidays in 2014.

III. METHODOLOGY

The first step of the study is to establish an original file, which defined the constant environmental and operating information, such as the location, weather statistics and operating mode. Meanwhile, the physical performance parameters of all related materials should be input in the "Material" unit in order to modify the wall construction in C#.

In C#, the program will read the original idf file and establish different groups based on the related layers: "insulating layer" and "airgap", in which the ID and name of each material should be list, as shown below:

```
List<string[]> Insulatinglayer = new List<string[]>() {
new string[] {"A01","A01 Polyurethane board 100mm"},
new string[] {"A02","A02 Polyurethane board 80mm"},
```

Then, the code will modify the "Building" and "Construction" part in the original idf file. The building should be named after the material ID, for example, "A01-B01", means the insulating layer is polyurethane foam of 100mm and the air gap is 5mm. And the exterior wall construction should also be replaced by the following code:

```
foreach (string[] x in Outsidelayer)
{
foreach (string[] y in Insulatinglayer)
{
foreach (string[] z in Airgap)
{
foreach (string[] i in Innerinsulating)
{
string filename1 = x[0].ToString() + "-" + y[0].ToString() +
"-" + z[0].ToString() + "-" + i[0].ToString();
filename = x[0].ToString() + "-" + y[0].ToString() + "-" +
z[0].ToString() + "-" + i[0].ToString() + ".idf";
string name = path + "\\"+filename;
string con1 = readText.Replace(org1, x[1].ToString() +
constructionwallres1);
```

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```
string con2 = con1.Replace(org2, y[1].ToString() + constructionwallres2);
string con3 = con2.Replace(org3, z[1].ToString() + constructionwallres3);
string con4 = con3.Replace(org5, i[1].ToString() + constructionwallres5);
string conname = con4.Replace(orgname, filename1.ToString() + buildingres);

File.WriteAllText(name, conname);
}
}
}
}
```

The final step is to input the group of idf files into Energy Plus and simulate the operating energy consumption of all wall assemblies.

IV. RESULTS

The results indicate that the lowest annual operating energy is 20.01 GJ, using 100mm polyurethane foam as the insulating layer, while the highest is 20.81 GJ with 40mm rock wool insulation, nearly 4% higher than lowest one.

Table I: Correlation Analysis

Variates	Pearson's Correlation Coefficient	Significance	N
Operating Energy vs Insulating layer	0.672**	0.000	56
Operating Energy vs Air Gap	0.000	1.000	56

** Correlation is significant at the 0.01 level

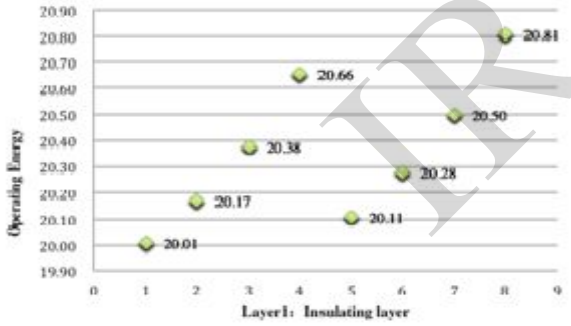


Fig. 4. The operating energy of different wall assemblies

It can be seen from the correlation analysis that, the correlation is only significant between operating energy and insulating layer, as shown in Table 1, while the thickness of air gap has a negligible impact on the operating energy.

Fig.4 shows that, the annual operating energy consumption varies according to the insulating layer, and the thicker the insulation is, the lower the operating energy is. Meanwhile, the building's operating energy is lower with polyurethane foam than that with rock wool of the same thickness.

V. CONCLUSION

The paper shows a possible method to calculate the annual operating energy automatically and the results indicate that the material and thickness of insulation has a great influence in the building's operating energy. However, the total energy consumption during use phase also depends on the life span of the building. As a result, there should be more research focusing on the method to generate life cycle energy in order to optimize the buildings performance in the architectural design.

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