DEVELOPMENT OF A KNOWLEDGE-BASED ENERGY SIMULATION TOOL COMPLYING WITH CHINA'S BUILDING ENERGY EFFICIENCY STANDARDS

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ABSTRACT

Building energy simulation is a useful technique for predicting building energy performance and comparing design options. However, many building energy simulation tools are sophisticated and inconvenient for architects to use. One of the main reasons is that they require a lot of input parameters which cannot or are difficult to be defined in the early design stage. This paper develops a knowledge-based energy simulation tool in accordance with the requirements of China's building energy efficiency standards. First, the obstacles that architects face when using energy simulation tools in the early design stage are analyzed. Then, a method is proposed to develop a knowledge database which can assist architects to conveniently set up a model satisfying both China's building energy efficiency standards and energy simulation requirements. Finally, a case study is presented to demonstrate the application and usability of the approach.

KEYWORDS

energy simulation, knowledge base, energy efficiency standards, China

INTRODUCTION

The world energy use has increased dramatically and attracted widespread concern. The global energy consumption was increased by 1.3 times from 1971 to 2013, according to the International Energy Agency (IEA 2015). Energy consumption in buildings has accounted for a large part of the total energy consumption. In some regions, it has exceeded the industrial and transport sectors. Therefore, designing, constructing, and operating energy efficient buildings become a mainstream paradigm for architects, engineers, owners, facility managers and government. Chinese government adopted a series of building energy efficiency standards and green building evaluation standards,

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such as GB 50189-2015, the design standard for energy efficiency of public buildings, and GB/T 50378-2014, the assessment standard of green building (MOHURD 2015).

As the leading profession in a design team, architects should be familiar with the latest development in the field of energy efficient building design. However, the reality is far from being ideal. Despite the powerful computing capacity and its proliferation of many energy simulation programs in the last decade, architects and designers are still facing obstacles to use these tools. In this paper three mainly obstacles architects have to deal with are described. (1) Most of the energy simulation programs are not “Architect friendly”. (2) There are too many input parameters which may not be determined in early design stages. (3) A large proportion of the energy simulation tools do not follow the logic of the architectural design process. These difficulties prevent the architects from using energy simulation tools in building energy efficient design, a new method must be presented to solve these difficulties in order to make architects be more willing to use energy simulation tools.

Preparing the input date files for a simulation can be tedious, time-consumption and prone to error (Hong, Chou, et al. 2000). Knowledge base is an effective solution to this problem. A built-in knowledge base or an external database can not only reduce the input parameters but also minimize the errors caused by human. Literature and comparative surveys indicate that most architects who use energy simulation tools in design practice are much more concerned with the (1) Usability and Information Management of interface and (2) the Integration of Intelligent design Knowledge-Base. Those two issues are the main factors for identifying a building simulation program as “Architect Friendly” (Shady, Liliana, et al. 2009).

In China, the development of domestic energy efficient software, however, is still in its infancy. Only a little new projects or renovation projects have used energy simulation tools to support their energy efficient design in China. One of the most important reasons is the drawbacks of this tools described above, another reason is that most of the dominant international energy simulation software were developed on the basis of foreign regulations or standards. In China, therefore, there is a shortage of energy simulation tools or concerning database that are more suitable for the local regions.

METHODOLOGY

Method description

The shortage of necessary input data in the early design stages is an important obstacle in using energy simulation tools. Furthermore, the energy efficient design procedure, as shown in Fig. 1 represents the common practice in many architectural design firms, is repetitive and time consuming. Since detailed input data are needed, the energy simulation cannot be performed until most construction drawings are completed. However, it is often too late to make necessary changes to the design.

This paper presents a knowledge-based tool to assist architects to conduct energy simulation in the early design stage. The tool is in compliance with the Chinese standard (GB 50189-2015). It is based on Google SketchUp (Anon. A), a widely used modeling program for architects, and EnergyPlus (Anon. B), an internationally used and proven energy simulation program. The process of building design based on knowledge-based approach is presented in Fig. 2.

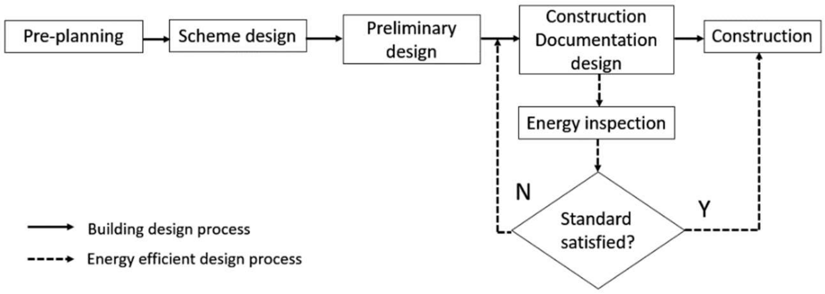

Fig. 1. *Current energy efficiency design process in China*

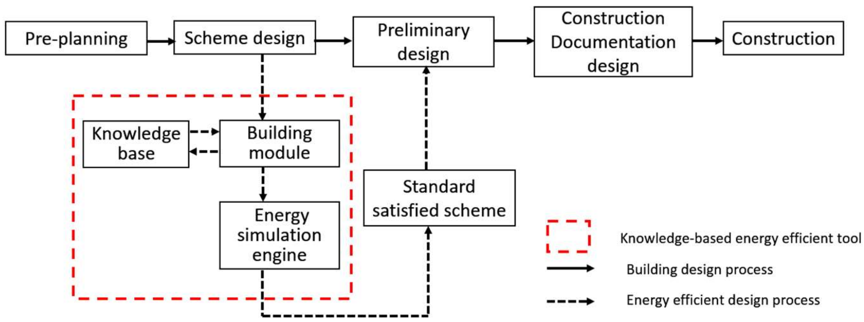

Fig. 2. *Knowledge-based energy efficiency design process*

Program selection

The program selected to achieve the knowledge-based approach is OpenStudio (Anon. C). It has a plugin for SketchUp, which makes it ideal for architects to use, since the majority of architects in China rely on SketchUp to develop architectural models. Combined with EnergyPlus, OpenStudio is able to provide both a user-friendly modeling environment and a reliable energy simulation engine. However, it is still challenging to use OpenStudio in designing energy efficient buildings in China because it contain very little information about China's energy efficiency standards or local design practices. Therefore, this work is intended to develop a knowledge-based approach based on OpenStudio to assist building energy efficient design in China.

Variable comparison between China's standard and OpenStudio input file

It is necessary to compare the requirements of the China's energy efficient standard and the input design variables needed by EnergyPlus, because the energy simulation engine of OpenStudio is EnergyPlus. Three categories can be identified as follows. Table 1 summarizes all the design variables in accordance with the above three categories.

Category I: the design variables that are explicitly specified in the Chinese building energy efficient design standard and required in the EnergyPlus input file.
Category II: the design variables that are explicitly specified in the Chinese building energy efficient design standard but not required in the EnergyPlus input file.
Category III: the design variables that are required in the EnergyPlus input file but not explicitly specified in the Chinese building energy efficient design standard.

The current China's energy efficient design standard for public buildings is GB 50189-2015. It can be seen that the data in OpenStudio knowledge base are far beyond those specified in GB 50189-2015, and they are more close to the actual building. But some detailed parameters of the building envelope which will not be determined until deeper design stages are not necessary for the energy consumption simulation. Therefore, we can use a simplified method to unify the data in the designed knowledge base and the energy efficiency standards, in order to reduce the input variables.

Table 1. *Design variables of three categories*

Variable type	Category I	Category II	Category III
Form		Shape coefficient, Ratio of window to wall (WWR)	
Structure			Constructions, Material layers
Opaque envelope		U-factor, Thermal resistance of insulation	Thickness, Conductivity, Specfic heat, Density, Roughness, Thermal absorptance, Solar absorptance, Visible absorptance
Transparent envelope	U-factor, SHGC, Visible transmittance		
Internal loads	Occupant, Lighting, Electric equipment, Internal loads schedules		
HVAC system	Operation schedule, Thermostat setpoint, Air change flow		

Input data simplification method

Takes GB 50189-2015 as an example, this part will discuss the date processing method of adding the data in the standard into the designed knowledge base. In this section, the office building in hot summer and cold winter climate zone will be considered as the representative object of this study.

Envelops

The data of envelopes is one of the most important portions in the knowledge base.
GB 50189 specifies the limited values of thermal performance of envelops according to different climate zones, shape coefficient and window to wall ratio. Obviously, only two mainly related parameters of the building envelopes are specified in the standard, namely U-value (or R-value) and Solar Heat Gain Coefficient (SHGC). The OpenStudio knowledge base contains a wider range of data than the standard, each part of the building has its specific structure, and the structure is composed of several layers of material, and each material has several properties, which makes the data in knowledge base is too much complicated and increases the run time of the simulation.

In this research, the opaque constructions like roof, exterior wall are simplified as single layer structure in the designed knowledge base, it means that this construction is composed of only one fictitious material layer. The type of this material is “standard opaque material”, and its thermal properties are roughness, thickness, conductivity, density, specific heat, thermal absorptance, solar absorptance and visible absorptance. Considering the simplified single layer structure, and the greatest impact that thickness and conductivity of materials have on the U-value, these two parameters are set to meet the standard. The other six parameters are set to default values because they are not necessary to be defined early and have little influence on energy consumption.

For window construction, the simplified single layer structure is also used, and the material type is “simple glazing” which has the thermal properties as U-factor, SHGC and visible transmittance. The U-factor and SHGC are set according to the limited values, and the visible transmittance takes the default value that can meet the minimum requirement. Since the specified performance of exterior window is distinct according to different window to wall ratio ranges, different templates are added to the designed knowledge base. For buildings in cold and severe cold areas, different templates are added according to different shape coefficient ranges.

Space types

GB 50189-2015 contains 5 building types (hotel, hospital, school, market and school) and 7 space types. The appendix B of GB 50189 gives the reference set of different spaces. Specifically, it contains thermostat setpoint and operating schedule, lighting power density and its schedule, occupancy and its schedule, air change flow and its schedule, equipment power density and its schedule.

The space type related data in OpenStudio knowledge base is stored in the nested structure according to different building types and different templates: Templates of standards – climate zones – building types – space types – internal loads and the name of schedules – hourly schedules for temperature setpoints and thermal loads. GB 50189 contains less data comparing with OpenStudio, but the attributes of a space in GB 50189 basically cover the variables that influence the energy consumption. So the data in the standard is transplanted to the designed knowledge base directly, and the data that the standard does not contain is set to null or default value. By this mean, the attributes of space types that GB 50189 specified are stored in the knowledge base. The ideal loads air system is selected as the only system template in the knowledge base.

The knowledge base complying with China's energy efficiency standards is established after the data of construction sets, internal loads and schedules are processed with the method described above. This simplified method can guarantee the minimum input parameters that a normal simulation needs.

Integrating with OpenStudio

The work of integrating GB50189 with Openstudio consists of six parts, namely the establishment of climate zones and building types, the establishment of the construction and material database, creating space types and assigning their attributes, the establishment of schedule database, the implementation of calling the data in the knowledge base by programming and debugging. These steps involve a large amount of data processing work which takes a lot of time and effort. Finally after a number of debugging procedures, the integration of GB50189 with OpenStudio has been achieved successfully. Designers can conveniently generate an energy simulation model that in line with China's energy efficiency standards with the assistance of the designed knowledge base.

In addition, in order to meet the needs of more cases, the knowledge base has been expanded. Three new templates are established according to the Chinese Assessment standard for green building standard GB / T 50378-2014. The thermal performance of envelops in these three templates are better than the standard GB 50189, the improvement rates were 5%, 10% and 20%. The knowledge base contains 6 climate zones and 5 public building types, and 4 construction set templates finally.

CASE STUDY

To test the reliability and usefulness of the developed knowledge-based tool, a case study is performed by comparing it with T-BEC T20V2 (Anon. D), which is a mainstream program for designing energy efficient buildings in China. In this study, an office building following the model of the DOE medium office building (Anon. E) is selected as the benchmark building to provide a geometric form for the performance comparison between the developed knowledge-based tool and T-BEC T20V2. The building location is Nanjing, China, in a climate zone referred to as “hot summer and cold winter” in accordance with China’s standard. The medium office building is a 3-story rectangular-shaped building with one core thermal zone and four perimeter thermal zones on each floor as shown in Fig. 3. The total floor area is 4,982 m^2, and the floor height is 4 m, the window-to-wall ratio of each facade is 33%. The construction set, internal gains, schedules and HVAC system are defined to represent the typical condition of office spaces in Nanjing, China.

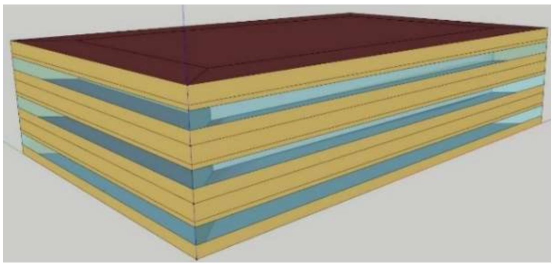

Fig.3. *Projection of the benchmark medium office building*

RESULTS

This study performed a whole year energy simulation of the medium office building using T-BEC T20 and the knowledge-based tool (KB-T). The simulation results of the two tools are compared and analyzed in this section. The data being compared is the annual electricity consumption of per unit area. The specific results are shown in Fig.4. We can see that the energy consumption of cooling calculated by KB-T is 20.5% higher than T-BEC T20V2, while the heating energy of the former is 37.4% lower than the latter. However, the total energy consumption of cooling and heating is only 7% lower than the latter. Overall, the validation results of KB-T are relatively reliable despite of some deviations from the data.

The author believes that there are several reasons for the deviation of the data. The kernel of KB-T is EnergyPlus, while the kernel of T-BEC T20V2 is DOE-2, which leads to different methods of heat transfer calculating. And the meteorological data used by the two tools have certain differences. What's more, there are some unpredictable factors that may cause discrepancies in the validation results.

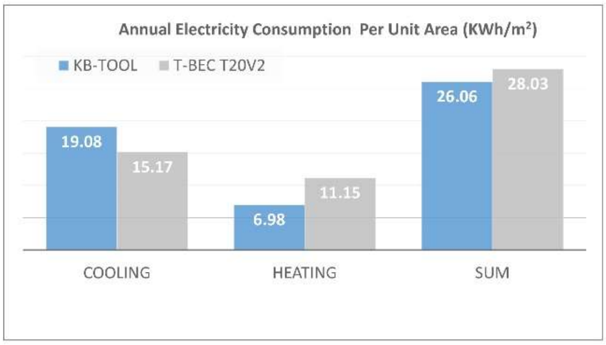

Fig.4. *Simulation results of different tools*

CONCLUSION AND DISCUSSION

This study develops a knowledge-based tool to perform energy efficient design in China regions, which can make full use of the advantages of both knowledge base and energy simulation engine on the premise of meeting China's energy efficiency standards. OpenStudio and SketchUp are selected to achieve the knowledge-based approach. The author compares the requirements for design variables in China's energy efficient standard and the input variables in OpenStudio. Then, the author uses a simplified method to unify the data in the designed knowledge base and the energy efficient standard. The knowledge base is established after the data of envelops, internal loads and schedules are built up, and has also been expanded. Then, the integration of the knowledge base with OpenStudio has been achieved successfully by programming. Finally, a case study is performed to test the reliability and practicability of the knowledge-based tool, and the results of validation and analysis are carried out.

Although this study achieves a successful approach for designing buildings in compliance with the energy efficient standards of China, there are some deficiencies. The tool is currently only available in public buildings in China, more building types and more energy efficiency standards should be added. Besides, the workflow of this tool will be more integrated and user-friendly in future research.

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