Automatic Compliance Check of Window-to-Wall Ratio Software Embedded Intelligent Algorithms in Revit Modeling

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Abstract. Window-to-Wall Ratio (WWR) is a crucial building envelope element that decides the air conditioning and lighting energy consumption in the building. Controlling WWR within a reasonable range is of great significance to building energy conservation. Due to the importance of WWR’s selection in Revit modeling, an automatic compliance check software in Revit Modeling is developed to ensure the WWR of Revit model within a reasonable range. The range is given in Design Standard for Energy Efficiency of Public Buildings (GB50189-2015, China). Based on the value range, the enumeration-based WWR compliance inspection software was developed in C# language and integrated into Revit to achieve compliance check on Revit model. Software testing was conducted for a certain office building in Shanghai, China. And Ecotect was used to analyze the thermal environment of unchecked model and checked model, respectively. The result shows that this software can automatically obtain the WWR of each facade of the current model, and determine whether it meets the range of the building location. When a facade does not meet the specification, it can be quickly and automatically adjusted to the appropriate range within the scope. By comparing the Ecotect thermal environment analysis results of unchecked and checked model, it is found that the heating and cooling loads are reduced after the model is checked with intelligent algorithms.

1 Introduction

1.1 Window-to-wall ratio

At present, building energy consumption accounts for 1/3 of the total global energy consumption, and this proportion is still increasing by year[1]. Window-to-wall ratio (WWR) the ratio between the transparent area and total facade surface, is an indispensable factor in building energy consumption[2]. Related research shows that in the case that the meteorological conditions and the properties of the building are consistent, along with the increase of WWR, the heating load index of air conditioning in the building has a tendency to decrease first and then increase. When it is 0.3, the inflection point appears, reaching the minimum value; while cooling load index of the air-conditioning increases with the increase of WWR. The cooling load index increases by about 9.5% for each WWR of 0.1. It directly affects the energy consumption of the building, and the influence is different in each facade[3-5]. Concurrently, the change of WWR also has an impact on daylighting performance, and its influence is second only to the depth of the room[6]. When WWR is 43%, the quality of daylighting is better. And when it is higher than 43%, the indoor glare will occur[7]. Therefore, determining a reasonable WWR is a key step in the architectural design process. Xue Peng, Qiang Li, et al.[8] proposed a WWR optimization process based on external shading method under the premise of considering both lighting and energy consumption. The upper and lower thresholds of each facade were obtained, which provided a basis for the WWR selection. Guohui Feng et al.[9] studied the influence of each facade’s WWR on the energy consumption in a typical zero-energy building in Shenyang, China. The results showed impact level of different orientations’ WWR on energy consumption order is east (west) > south > north, and the energy efficiency of zero-energy buildings in cold regions is the highest when the WWR in east/west direction is between 10% and 15%, and in south direction is between 10% and 22.5%. LI et al. [10] proposed a method for creating a recommended WWR mapping, which is the appropriate default value for assigning WWR during modeling. G. Francesco[11] has obtained an ideal WWR range of 0.3–0.45, by comprehensive heat and light simulation and the efficiency of construction equipment, the effectiveness of artificial lighting and the compact sensitivity analysis of buildings. In 2015, Design Standard for Energy Efficiency of Public Buildings (GB50198-2015) issued by China has finely divided the WWR, which is given according to different climate zones, into different building types and different building heights[12-13]. The above research show the

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influence of WWR on building energy consumption, and the recommended value range of WWR for relative energy saving is given. However, there is no simple method or auxiliary tool for designers to ensure that WWR is within the recommended range.

In design period, how to make design more convenient from two-dimensional to three-dimensional drawing is a hot issue. At present, once WWR is found to be inconsistent with the standard in design process, it needs to be manually modified one by one. If the mistake is found lately in a big project, it will be an extremely tedious job to modify the window size, which will definitely cause working inefficiency. Autodesk Revit is taken as platform, and the range of WWR given in Design Standard for Energy Efficiency of Public Buildings(GB50198-2015) is adopted. Based on Visual Studio 2015 and C# language, a WWR evaluation and automatic modification software is redeveloped on Revit, which combined with the calculation and modification method of WWR[14-16]. It can provide an aided design tool with simple and reliable operation and good effect. So that designers can liberate from mindless and repetitive modification work. An convenient, fast and reasonable key step of WWR selection can be completed. And it can raise the work efficiency.

2 Methodology

2.1 The process of compliance check

The check process for WWR is shown in Fig.1. The process can be divided into three steps:

① Check that whether WWR is within the range given in Design Standard. In this paper, the value of WWR is not directly judged. Instead, the range of WWR is firstly converted into the range of the total window area, which is \((c,d]\). Then the total window area of each facade in the building is judged whether it is within this range and needs to be modified.

② For the WWR that does not meet the standard, the building needs to be modified. The modification method of WWR will be described in Section 2.4.

③ Inspections is carried out to ensure that the WWR of each facade is within the standard range.

Also the optimizing procedure of the window-wall ratio is the same as described above. The goal is to get the minimum air conditioning cooling load on the premise that the lighting quality meets the requirements.

In order to improve the computational efficiency, the "enumeration - binary" coding genetic algorithm (ENUM-GA) is proposed on the basis of binary coding genetic algorithm and the one-to-one corresponding characteristics of ArrayList set index and values.

2.2 Check basis

The basis of compliance check is Design Standard for Energy Efficiency of Public Buildings(GB50189-2015,China). Articles 3.3.1-3.3.2 of this standard give the range of WWR values of Class A public buildings in various regions. It is clearly stated that the ultimate goal of the BIM-based software development in this paper is to ensure that the WWR of each building facade is within this range. According to the climatic zone and sub-climatic zone type of the building, the building shape coefficient and the heat transfer coefficient of the window, the WWR value can be obtained by looking up the table of standard. Table1 shows the WWR range of Class A public buildings in severe cold Zone A and B.

2.3 Basic data acquisition

The parameters required during the operation of the software include three parts, the building climate zone and the climate sub-zone type, the building shape coefficient and the heat transfer coefficient.

(1) Building climate zone and climate sub-zone type

According to Design Standard for Energy Efficiency of Public Buildings(GB50198-2015), the types of climate zone and climate sub-zone are divided into five sections: severe cold, cold, hot summer and cold winter.
hot summer and warm winter, mild. Each climate zone is divided into A and B sub-climatic zone.

(2) Shape coefficient
Shape coefficient is obtained by calculation. The following building envelope element parameters are required to calculate it:
①Total area of the external walls of the east, west, south and north facades: $A_e$, $A_w$, $A_s$, $A_n$, respectively.
②Total windows area of the east, west, south and north facades: $A_{we}$, $A_{ws}$, $A_{ws}$, $A_{wn}$, respectively.
③The area of roof surface: $A_r$.
④Volume of each room $V_i$ (i is the room number).

The shape coefficient of building object ($C_t$) is calculated as Eq(1):
$$C_t = \frac{A_e + A_w + A_s + A_n + A_{we} + A_{ws} + A_{wn} + 2A_r}{\sum_{i=1}^{n} V_i}$$
(1)

(3) Heat transfer coefficient
In Revit model, the property analysis of the window contains heat transfer coefficient(K). It can be obtained directly from the BIM model by Revit API.

2.4 Method of WWR compliance check

In the process of compliance check, the total area of the window on the elevation is the index which can judge whether the current model meets the standard. The calculation method is shown in Eq(2).
$$A_{w,j} = S_1 \cdot n_1 + S_2 \cdot n_2 + S_3 \cdot n_3 + \ldots + S_k \cdot n_k$$
(2)

Where $A_{w,j}$ (m$^2$) is the total area of the window of the j facade; $S_k$ (m$^2$) is the area of a certain FamilySymbol in the kth window family of the j facade; $n_k$ is the number of family instances of the qth window family.

While $n_k$ is a constant, the constraints of $A_{w,j}$ and $S_k$ are shown in Eq(3).
$$\left\{ \begin{array}{l}
A_{w,j} \in (c,d) \\
S_k \in \left[ S \mid \text{Area of each FamilySymbol in the } k\text{ th window Family}\right]
\end{array} \right.)$$
(3)

According to the constraints in Eq(3), a set of possible solutions of different enumerated elements can be obtained. An enumeration algorithm is used to find an enumerated element, [$S_1$, $S_2$, $S_3$, ..., $S_k$], which is substituted into Eq(2) so that the calculation result is satisfied the relationship of $c < A_{w,j} \leq d$. Replacing the window FamilySymbol of the kth window of the j facade with the window family symbol [$L_1$, $L_2$, $L_3$, ..., $L_k$] corresponding to [$S_1$, $S_2$, $S_3$, ..., $S_k$], respectively, WWR modification can be achieved.

3 Framework of software

The software developed in this paper is mainly composed of the extraction about building envelope element parameters and database storage management module, WWR compliance check module. The extraction about building envelope element parameters and database storage management module is responsible for extracting the ID, Host ID, Area, Volume, Heat transfer coefficient and other parameters of the envelope elements from the model and storing them in the database, which is the premise of WWR calculation. WWR compliance check module uses enumeration algorithm to calculate the WWR. And when the WWR of a certain facade is not in conformity with the standard, the model can be modified. First, the WWR of the current model is calculated by inquiring the relevant parameters of the external walls and windows in the database. Then the WWR beyond the range of the facades is adjusted where the building is located. The software development is in Visual Studio 2015. In the programming, the IExternalCommand interface must be implemented first. When user extends Revit through an external command, the interface must be implemented in an external command. Figure 2 shows the framework of this software. The core part of the software is WWR check module. The module integrates WWR compliance check method described in section 2. By calling the parameter data of the envelope in the MySQL database, WWR of each facade in Revit model is calculated and checked.

4 Software test

4.1 The situation of architecture

Software testing was conducted for an office building in Shanghai, China. The office building has 2 floors above ground. There are offices, conference rooms, entertainment rooms and clinics in the first floor. There are offices, storage rooms and bathrooms in the second floor. The structure of the building is concrete with a height of 6 m and a total area of 900 m$^2$. In unchecked model, the size of window FamilySymbol is 1500×1800 (mm). The properties of the constructions of whole building envelope are show in Table 2.

Fig. 2. Framework for the software

| Table 2. Properties of the constructions of whole building envelope. |
|-----------------|------|------|-----|
| **Material** | **Wall** | **Roof** | **Window** |
| Thickness       | 200  | 400  | -   |
| Color correction | 1.25 | 1.25 | -   |
| HTC             | 5.23 | 2.62 | 3.13 |
| Comprehensive   | -    | -    | 0.44 |

4.2 Result

In order to verify the change of building energy consumption between the unchecked and checked WWR, the energy consumption assessment function is developed in Revit to calculate the loads of the model directly. The results of the review in the Revit...
environment show a reduction in energy consumption. In order to further verify the correctness of the conclusion and the reliability of the developed software, Ecotect, which is independent of Revit, is selected as the tool for comparison. Building models that are identical to those in Revit are established in ECOTECT, and the energy consumption assessment is performed on the unchecked and checked model whose conditions are consistent except the WWR. The meteorological data of Xi'an Shaanxi Province (between 107.40 degrees to 109.49 degrees east longitude and 33.42 degrees to 34.45 degrees north latitude) is provided by ECOTECT. The results are shown in Tables 4 and 5.

Figure 3 shows that the WWR of the checked model's four facades are 0.1748, 0.1780, 0.1579 and 0.1872, respectively, which meet the requirements. Figure 4 shows the window FamilySymbol of the checked model is 1200×1500 (mm). Table 3 and Table 4 show the results of thermal environment analysis under the premise that the parameters of the model are consistent with each other except WWR. By comparing the heating and cooling loads of each month and the total load, it can be found that the building's cooling and heating loads is reduced after model checking. Tests show that the software can automatically modify the WWR by replacing the window FamilySymbol according to the expected process and method. The result is reliable and has certain energy-saving effect.

Table 3. Monthly Loads of unchecked model

<table>
<thead>
<tr>
<th>Month</th>
<th>Heating (kWh/m²)</th>
<th>Cooling (kWh/m²)</th>
</tr>
</thead>
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<tr>
<td>Jan</td>
<td>12.47</td>
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</tr>
<tr>
<td>Feb</td>
<td>7.83</td>
<td>0.00</td>
</tr>
<tr>
<td>Mar</td>
<td>6.17</td>
<td>0.27</td>
</tr>
<tr>
<td>Apr</td>
<td>1.10</td>
<td>0.79</td>
</tr>
<tr>
<td>May</td>
<td>0.00</td>
<td>5.14</td>
</tr>
<tr>
<td>Jun</td>
<td>0.00</td>
<td>9.81</td>
</tr>
<tr>
<td>Jul</td>
<td>0.00</td>
<td>14.24</td>
</tr>
<tr>
<td>Aug</td>
<td>0.00</td>
<td>12.99</td>
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<tr>
<td>Sep</td>
<td>0.00</td>
<td>10.58</td>
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<tr>
<td>Oct</td>
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<tr>
<td>Nov</td>
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</tr>
<tr>
<td>Dec</td>
<td>7.30</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td>36.20</td>
<td>57.25</td>
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</table>

Table 4. Monthly Loads of checked model

<table>
<thead>
<tr>
<th>Month</th>
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<th>Cooling (kWh/m²)</th>
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</thead>
<tbody>
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<td>7.65</td>
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<td>4.94</td>
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<td>Jul</td>
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<td>Nov</td>
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<tr>
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</tr>
<tr>
<td>Total</td>
<td>35.10</td>
<td>54.06</td>
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</tbody>
</table>

6 Conclusions

In order to achieve the purpose of energy saving, certain methods should be adopted in the design process to ensure that the WWR of the building model is within the standard range. This paper relies on the API provided by Autodesk Revit to successfully modularize the two processes, which are extraction of model parameter and the compliance check of WWR, automatically. And the feasibility of the software is tested. Results show that the software can obtain the WWR before and after model checking, and can evaluate whether the ratio meets the standard. For the facade that does not conform to the standard, the WWR is automatically modified by the enumeration algorithm to meet the requirements.
Designers do not need to consider whether the ratio meets the standard or not when modeling, and only need to run the software at a certain stage to ensure the compliance of the ratio in established model. The software brings great convenience to the architects, which can improve the rationality and effectiveness of the design. Furthermore, with Ecotect as the tool, under the premise that meteorological conditions, building envelope properties and other conditions are consistent, the energy consumption analysis of the building model before and after the WWR check is carried out. The results show that the change of WWR can reduce the heating/cooling loads of the building and provide new ideas for energy-saving research in the architectural design stage.

Of course, there is still room for improvement in this paper. At present, the result of WWR adjustment is only to make it meet the requirements of the standard, but the corresponding energy consumption of the building is not the minimum at this time. Further research can be done to control the WWR in the corresponding value of the minimum energy consumption state under the premise that the thermal parameters of the building except the WWR remain unchanged.

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References