Assessment of the impact of windows and building orientation on the energy intensity of container houses using BIM

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Abstract. With the rapid development of the container industry, the use of container houses has become extensive. This paper uses the method of orthogonal experiment to study the change of the energy consumption of the container by changing the size, height, direction of the container window and the direction of the container building. The building used a container house in Xiangfang District, Harbin City, Heilongjiang Province, China as a case. 71 scenes were created, 3D modeling was performed using Revit and imported into Green Building Studio for Energy Use Intensity (EUI) calculation. This research is divided into three processes. The first process is to study the impact of window-to-wall ratio. Through the first process, a rule is obtained, and the height of the window has the greatest impact on energy consumption when the window-to-wall ratio is 0.2. Therefore, in the second process, the window-to-wall ratio of the windows is fixed to 0.2. When the height of the windows of different orientations changes, the energy consumption of the container house changes. In the third process, based on the results of the first two research processes, the orientation of the container house is changed, namely the north-south orientation and the east-west orientation, and the energy use intensity calculation is performed again. The results show that the window-to-wall ratio has the greatest impact on the energy use intensity of the container house. The larger the window-to-wall ratio, the greater the energy consumption. The height and orientation of the windows have an impact on the energy use intensity but not much.

Keywords: Energy Use Intensity, Orthogonal experiment, Building information modeling, Container house.

1. Introduction
Containers are the most important carrier and cornerstone of current international transportation. However, the rapid development of the container industry has also brought about problems. For instance, the empty containers occupy too much land, and the waste containers are difficult to recycle in time. There are as many as millions of empty containers and decommissioned containers every year, and the cost of maintaining empty containers is very high, so people try to transform these containers into houses [1]. Container buildings have the advantages of energy saving, environmental protection, low cost, convenient disassembly and movement, high strength and durability, etc. [2]. So, they are widely used...
in port terminals and construction sites. In recent years, the application of container construction has become extensive, and its use worldwide is also showing an increasing trend [3] [4]. Research on container building has become a hot spot in the architectural design field. T. Michele et al. conducted a study on the implementation of a new type of heat pump that combines the contributions of solar energy and thermal power in the implementation of energy-saving container houses in residential houses [5]. T. Ali Murat et al. conducted a study on the impact of the tightness of container houses on their energy efficiency [6]. A. Nihat conducted research on the optimal life span of container houses [7]. A.B. Kristiansen and others studied the impact of vacuum insulation panels on the energy efficiency of container buildings and proposed a plan [8]. W. Bowley and P. Mukhopadhyaya used off-grid passive container houses to conduct sustainability research on container houses [9]. There are few studies on the subsequent use of container construction.

Nowadays, with the global warming, people pay more attention on the energy saving and environmental protection of the building, and building energy consumption accounts for 40% of all energy consumption, making it one of the largest energy consumers [10]. The energy consumption of container construction in the subsequent use process is worthy to be focused. Container houses are transformed from abandoned containers; thus, the later transformation is limited to the modification of the envelope structure (walls, roofs, doors and windows, etc.), which significantly impact on the energy consumption of the building [11]. However, as far as we know, no scholar has conducted research on the energy consumption during the use of container buildings, especially the research on the enclosure structure of containers. Among envelope structure, windows are the most important part of the peripheral structure, and there have been previous studies shown that the design of windows has a great impact on the energy consumption of buildings [12]. At the same time, the orientation of the building also has a great impact on the energy consumption of the building which determines the amount of solar energy received and affects heating and lighting [13]. Heating and lighting are two important factors affecting the energy consumption of buildings [14].

This paper builds a building information model based on BIM, uses Green Building Studio to analyze the energy consumption of the model, and evaluates the impact of windows on the energy consumption of container house by changing the size, height and direction of windows, as well as the direction of buildings. This research can be used not only to guide the initial design of container buildings, but also provide a reference value for how to place the container when it is moving to minimize the daily energy consumption.

2. Objective and methodology

The study used container house on a construction site in Xiangfang District (45.72°, 126.68°), Harbin City, Heilongjiang Province, China as the research object, and measured the energy usage of each model by energy use intensity (EUI). Before the building is constructed, BIM can perform modeling and virtual analysis [13]. At the same time, it can also exchange information with the green building studio through the gbMXL extended format [15]. Using these advantages, BIM and Green Building Studios are selected for building model establishment and energy consumption analysis.

In addition, the size of the window is expressed by the window-to-wall ratio (WWR). The window-to-wall ratio ranges from 0 to 1 with an interval of 0.1, a total of 11 groups. The height of the window is not the main influencing factor. For the convenience of calculation, only low, medium and high conditions are set. When the height of the window is low, the lower edge of the window is close to the ground; when the height of the window is medium, the center line of the window is the center lines of the walls coincide; when the window height is high, the upper edge of the window is close to the eaves. The orientation of the windows is divided into four orientations: east, west, south, and north. Through studying the orientation, the impact of windows with different orientations on energy consumption can be revealed.

The research used the idea of orthogonal experiment. First, the effect of window-to-wall ratio and height of windows on energy usage intensity was studied. 11 types of window-to-wall ratios were combined with 3 types of window heights, and there were 33 scenes in total. Since when the window-
to-wall ratio was 0, there were no windows on the wall; when the window-to-wall ratio was 1, all windows were on the wall. In both cases, the combination of the window-to-wall ratio and the window height was the same. There were 29 effective scenes in the combination of wall ratio and height.

![Figure 1](image1.png)

**Figure 1.** Container house when (a) WWR is 1 and (b) WWR is 0

By establishing these 29 building information models through BIM, and then importing the models into Green Building Studio for energy use intensity calculation, the law and degree of influence of the window-to-wall ratio and energy use intensity can be obtained.

**Table 1.** Scene of changes in window-to-wall ratio and height

| Position | WWR | 0    | 0.1  | 0.2  | ... | 0.8 | 0.9 | 1    |
|----------|-----|------|------|------|-----|-----|-----|------|
|          |     |      |      |      |     |     |     |      |
| High     |     |      |      |      |     |     |     |      |
| Middle   |     |      |      |      |     |     |     |      |
| Low      |     |      |      |      |     |     |     |      |

Based on the result of window-to-wall ratio and height, the height and orientation of the windows were studied. Combined 3 different heights with 4 orientations, the height of the windows on one direction was changed, and the height of the windows on the other directions remained unchanged. There were 36 models in total. These 36 building information models were established through BIM, and then the models were imported into Green Building Studio for energy intensity calculations to obtain the impact of window height and window orientation on the energy consumption of container buildings.
### Table 2. Scene of changes in window height and orientation (south window)

| Others | South | High | Middle | Low |
|--------|-------|------|--------|-----|
| High   |       |      |        |     |
| Middle |       |      |        |     |
| Low    |       |      |        |     |

According to the previous model and calculated laws, the direction of the container house was changed. The first model is: the length of the south and north walls of the container house is 6m, and the width of east and west walls of the container house is 3m, as shown in Fig.2. The second model is: the north and south walls of the container house is 3m, and the east and west direction is 6m, as shown in Fig. 2. Established these two building information models through BIM, and imported these two models into Green Building Studio for energy intensity calculation, and got the best placement method and location of the container house.

![Figure 2.](image)

**Figure 2.** (a): East-west container house; (b): North-south container house
3. Research activity

Used BIM to build a building information model. The size of the container house is 6000mm*3000mm*2800mm, the wall panels are 50mm thick color steel sandwich panels, the two sides are 0.9mm steel plates, the middle is fireproof rock wool, and the floor is plywood. There are windows in all directions. In order to simplify the calculation, the doors and eaves will be simplified to obtain a simplified model, as shown in Fig.4. The room type is residential and operates 24 hours a day [13].

![Figure 3. Original BIM model](image)

![Figure 4. Simplified BIM model](image)

3.1. The impact of WWR and window height on building energy consumption

Combined window-to-wall ratios of 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1 with window heights: high, medium, and low to obtain 33 scenes. The results were shown in Fig.5. It can be seen that the effect of window-to-wall ratio on building energy consumption was significantly greater than that of window height. When the window-to-wall ratio was 0, the energy consumption of the container house was the smallest, and the energy use intensity was 3202.6 MJ/㎡/year; when the window-to-wall ratio was 1, the energy consumption of the container house was the highest, and the energy use intensity was 4858.2 MJ/㎡/year. Regardless of the height of the window, the energy consumption of the container house increases with the increase of the window-to-wall ratio. This is mainly because the enlargement of windows reduces the energy consumption of lighting to a certain extent, but their thermal insulation capacity is significantly lower than that of walls, and more energy is needed to maintain the temperature in the house. Although reducing the size of windows can effectively reduce energy consumption, it tends to reduce the livability of the house, so these two factors can be considered in the design.

![Figure 5. EUI changes with window-to-wall ratio](image)
Analyzing the variation of the energy use intensity of the three heights under each window-to-wall ratio, it can be found that they were all within 0.173 MJ/㎡/year, so the energy consumption problem can be hardly considered and the livability and structural stability can be considered, when designing the window position.

3.2. The impact of window height and window orientation on building energy consumption

In the study in Section 3.1, it was found that when the window-to-wall ratio was 0.2, the height of the window had the greatest impact on the building energy consumption of the container house. Therefore, when analyzing the impact of window height and window orientation on building energy consumption, the window-to-wall ratio was 0.2. Combining the height of the windows: high, medium, and low, with the four orientations of east, west, south and north, there were 36 scenes. In the figure, the abscissa Low-Middle indicates that the height of the window which in the direction that the height of the window is changed is low, the windows in the other direction are of medium height. The results showed that no matter which direction the height of the window was changed, the energy consumption of the container house was the smallest when the window height is high. This is because the solar incident angle is the largest when the window is at a high position, and the energy consumption is slightly higher. However, it is worth noting that comparing to the size and orientation, the effect of the height of the windows on energy consumption is small. This is because the height of the container building is too small compared to the height of the sun, and the change of window height has too little influence on the solar incidence angle. Therefore, window position is not considered in the energy consumption of the container building, and the user's comfort and convenience are mainly considered.

![Change North Window](image)

**Figure 6.** EUI changes with window height and orientation (north wall)
Figure 7. EUI changes with the height and orientation of the windows (east wall)

Figure 8. EUI changes with window height and orientation (south wall)

Figure 9. EUI changes with window height and orientation (west wall)
Simultaneously analysed the variation of energy use intensity of windows with the orientations that windows’ height was changed at different heights, and found that the windows on the south side had the least impact on building energy consumption, and the windows on the other sides had the same impact on building energy consumption. This is because the location of the building is in the mid-latitude area of the northern hemisphere. If the container building is located in the southern hemisphere, the windows on the northern side should have the least impact.

![Figure 10. The variation of EUI with the height of the window on each facing wall](image)

### 3.3. The impact of container orientation on building energy consumption

According to the above research, the window-to-wall ratio of the container house was fixed at 0.2 and the height of the windows was high, and two models were established. The first model had a length of 6m in the east-west direction, and a width of 3m in the north-south direction, as shown in the Fig.11. Model two had a length of 3m in the east-west direction and a width of 6m in the north-south direction, as shown in the Fig.11. The two models were imported into Green Building Studio for calculation, and the energy use intensity of model one was 3546.9 MJ/㎡/year, and the energy use intensity of model two was 3600.9 MJ/㎡/year. It can be seen that the energy consumption of the building is lowest when the container house is long from east to west and short from north to south. This is because the area of the wall in the long direction is larger, and under the same window-to-wall ratio, there is a larger window area. When placed in the north-south direction, better light can be gotten, which will increase the energy consumption of the building in summer and reduce energy consumption in the winter, but it can reduce lighting energy consumption throughout the whole year, so it has a better energy saving effect. In the northern hemisphere, when placing container houses, placing the side with larger windows on the south side can achieve the better energy-saving effects.
4. Conclusion

In the research of this article, the energy consumption of the container was studied by changing the window size, window height, window orientation and direction of the container house. Through these 71 scenarios, the energy consumption of the container house gradually increases with the increase of the window-to-wall ratio of the windows. This shows that the greater the window-to-wall ratio of the window, the greater the energy consumption of the window. However, when the window-to-wall ratio of the window is 0.2, the height of the window has the greatest impact on the building energy consumption of the container house. For container houses, when the height of the windows is high, the energy consumption of the container house is the smallest. At the same time, the windows on the south side of the container house have the least influence on the energy consumption of the container house, and the other side windows have the same influence on the energy consumption of the container house. When the container house is moved or placed, if the container house is long from east to west and short from north to south, the building energy consumption of the container house is minimal.

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