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Assessment of the Impact of Window Size, Position and Orientation on Building Energy Load Using BIM

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Abstract

In improving energy efficiency of buildings, windows play a significant role as they largely influence the energy load. Although there are many studies about the energy efficient window design, a rigorous study is missing which analyzes the mutual impact of windows' size, position and orientation on the energy load. This study aims to address this gap through a case study on a single family house. For this aim, 65 different design scenarios are created which vary by window size, position and orientation. Building information models (BIMs) are created for each scenario via Autodesk Revit®, and are used for the calculation of the total energy load conducted by Autodesk Green Building Studio®. In the first analysis stage, window-to-wall ratio (WWR) and the windows' position are studied to assess their effect on the energy load. The preliminary results at this stage indicate that the total energy load increases when the WWR grows, and the windows' position has the biggest impact on the load when the WWR is 20. Using these results, in the next stage, the position of windows in different orientation is studied to assess how the energy load changes by windows' position in each orientation. The results show that the building requires the lowest load when the windows are located in the middle height in all orientations, and the east windows' positioning affects the total energy load the most.

Keywords: Building energy load; Window design; Energy simulation; Building information modeling

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1. Introduction

Buildings are accounting for more than 40% of global primary energy use, produce substantially more carbon emissions than those in the transportation sector, and so they are the largest energy consuming sector in the world [1]. As the concern about the environmental impacts of building is increasing, private and public organizations are progressively requiring the building industry to design and construct buildings with minimal environmental impact [2]. Consequently, many studies have been done regarding the energy efficient building design. In this regard, windows are responsible for more than 10% of the building energy load and so are revealed to have considerable influence on the total energy consumption [3]. Several studies were conducted about the impact of window design on energy load regarding various factors of windows, to reduce the energy waste by windows [7,8,11]. However, as the geometry and systems of buildings are getting complicated, more complex studies are needed which analyze the mutual effect of different design factors [4]. This paper, therefore, aims to address this gap by assessing the influence of window design on building heating and cooling load, focusing on the windows' size, position and orientation at the same time. For this aim, we explain how to prepare the required building information models (BIMs), and create the required scenarios in order to perform rigorous energy load analyses. The entire simulation process is divided into two stages. In the first stage, we show how the window size and position affect the building energy load by creating models of 29 scenarios. In the following stage, the impact of window position and orientation is analyzed through 36 different scenarios. The case study in this research is conducted on a single family house, which is a two-story, 1620ft² building located in Vancouver, Canada. This building is built on the campus of University of British Columbia as a pilot home of AYO Smart Home company. This pilot project aims to develop sustainable, energy efficient and affordable housing for remote communities.

1.1. Impact of window on building energy load

As one of the key approaches to low energy design is to invest in the building's form and enclosure (e.g., windows, walls) [5], many studies treat the influence of enclosures on the energy load. Especially, several studies have been done on the effect of window design on building energy load regarding the factors such as window size, position, glazing properties and orientation. In early studies, one or two factors were analyzed concurrently. The impact of window size was analyzed solely [6], and several studies were done on window size and position [7,8,9]. Glazing properties and size were also considered together [10], and the orientation and size were analyzed at the same time [11]. In addition, few precedent articles considered the effect of orientation, size and glazing properties [12,13,14]. However, the research on the influence of window size, position and orientation on energy load is still missing. As the building designs are getting more dynamic and complicated, more detailed and thorough analysis on various window design factors should be conducted. Therefore, the assessment of the impact of the three factors on building energy load is studied in this paper.

1.2. Building information modeling for energy analysis

According to the recent studies, BIM based energy analysis is considered to be useful for energy assessment of building. Fundamentally, utilizing BIM as a data source for energy analysis makes the data input more efficient and the existing data more reusable [15]. In addition, as BIM allows a 'live', parametrically controlled digital model to be connected with a simulation program, it is fairly simple for designers to use and conduct the performance evaluations within a software interface they are already familiar with [16]. The best benefit is that the results of the energy analysis can be viewed immediately and changes to design can be immediately incorporated, thus more design iterations can be evaluated to improve efficiency and meet sustainability goals [17]. One of the studies proposed to utilize BIM for evaluating building energy performance by showing its efficiency, based on a case study that used BIM technology for optimizing energy-efficient design, which showed positive result [18].

2. Research objective and methodology

The objective of this research is to assess the impact of window design on building energy load. Since the building energy load is affected by a combination of various design factors, the three factors of the window, its size, position, and orientation are considered concurrently by creating various combination scenarios. The result is expected to give a guide to the designers, by showing how the window factors influence the building energy load.

In this paper, window size means window-to-wall ratio, which is the measure of the percentage area determined by dividing the building's glazed area by its wall area. The window position means the height of the window from the floor, and it is divided into High, Middle, and Low position. High position is when the top of the window is aligned with the top of the wall, the Middle position indicates the midpoint of the window is positioned in the middle of the wall, and the Low position means the bottom of the window is placed at the bottom of the wall. Lastly, window orientation means the facing directions of the windows, which are north, east, south, and west, in this case. The total load in the research means the annual heating load and cooling load. The lighting load has fixed value, as the project team indicated the lighting load in their design.

The methodology of the research is shown in Fig. 1. Based on the initial BIM model provided, the geometry of the model is simplified by eliminating the shadings and exterior structures to analyze the impact of window exclusively. Properties related to energy load are set and maintained throughout the whole research to eliminate the effect of the factors other than windows. Then energy analysis is conducted in two parts with total 65 scenarios. In the first part, window size and position is changed by 29 scenarios as Fig. 2 shows. Energy simulation is conducted for each scenario and the results are analyzed. The results indicate how the window size affects the energy load and which size of the window has the most influence on the load when its position is changed. On the basis of the results of the first part, the window position and the orientation are modified by total 36 scenarios, 9 scenarios each on north, east, south and west facing windows. Fig. 3 shows the north facing windows scenarios. The north facing window position is changing while the windows on the other sides are in the same position. This analysis is expected to reveal what combination of window position requires lowest energy load, and which side of window's position has the biggest impact on the energy load. BIM model is created and modified by using Revit®. Energy simulation is conducted by Green Building Studio®, which is connected to Revit®.

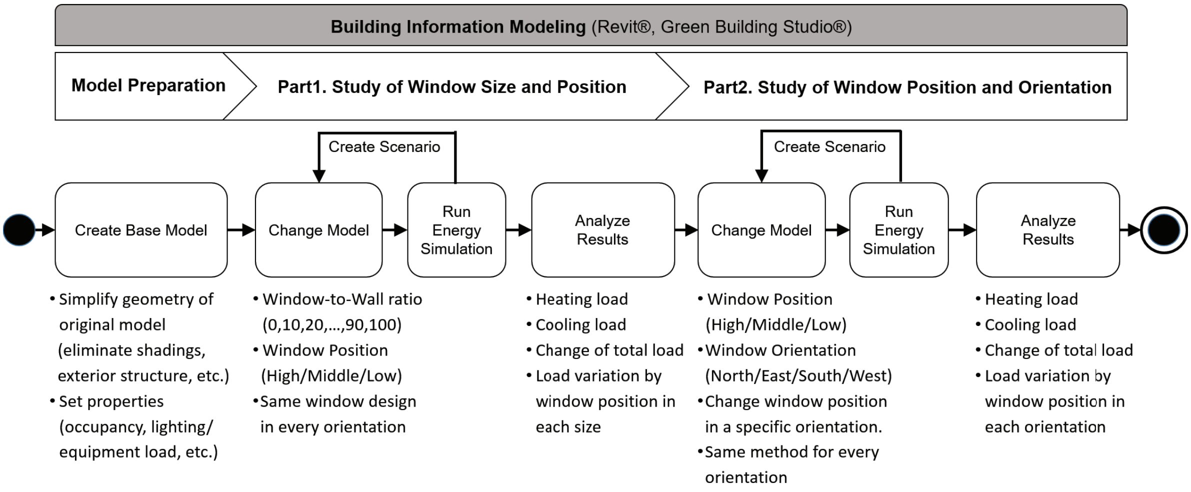


Fig. 1. Research methodology

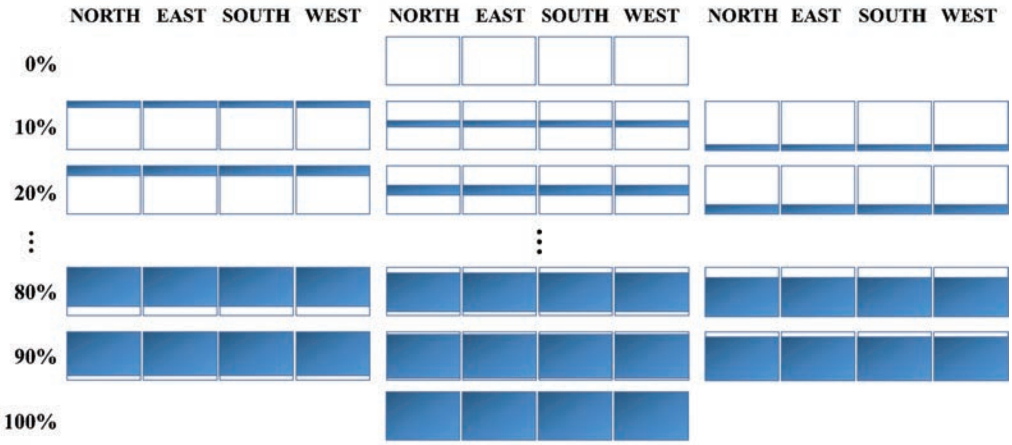


Fig. 2. Window size and position changing scenarios

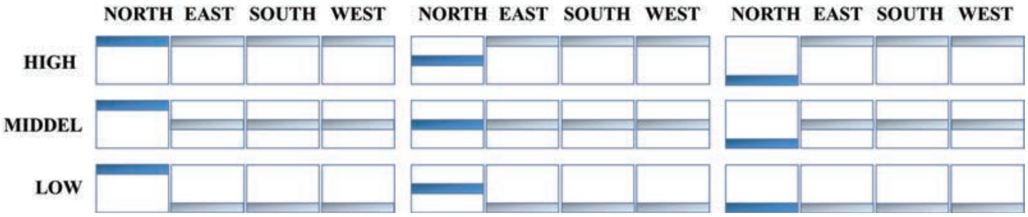
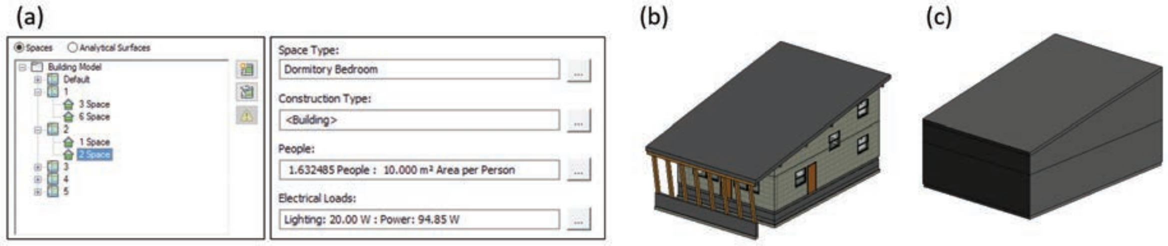


Fig. 3. Window position and orientation changing scenarios (North facing windows)

3. Research activities

3.1. Base model

To conduct the energy analysis, a simplified BIM model is created, based on a BIM model of a single family house. It is a two-storied house, which has two rooms and one bathroom on each floor, and one living room that is connected throughout two floors. Every room has windows, except an unconditioned storage room on the first floor, which has no window. As Fig. 4 (a) shows, the properties of rooms, such as occupancy schedules, lighting load, and equipment load are fixed in every scenario. The exterior structures, shadings, and doors are eliminated to observe the impact of windows exclusively. Fig. 4 (b) is the original BIM model of the building, and (c) is the simplified BIM model used for the energy analysis in the research.



Space Type: Dormitory Bedroom

Construction Type: <Building>

People: 1.632485 People : 10.000 m² Area per Person

Electrical Loads: Lighting: 20.00 W : Power: 94.85 W

Fig. 4. (a) Properties setting; (b) Original BIM model; (c) Simplified BIM model

3.2. Energy analysis process and results

3.2.1. Impact of window size and position on energy load

To assess the impact of window size and position on building energy load, window size and position are changed in 29 scenarios. Window-to-wall ratio (WWR) is changed from 0 to 100 percentages by 10 percentage scale and the position of the window is changed from high, middle to low. Fig. 5 shows the snapshots of BIM model, which are 10 percentages and 20 percentages scenarios. As it shows, the window position is changing from high, middle, and low height. There is one window on the first floor since the storage room on the first floor has no window in the original design, and there are two separate windows on the second floor because there is an unconditioned space between two rooms. Energy simulation is conducted after each scenario model is made and the results are collected.

Fig. 5. Snapshots of window size and position changing scenarios (North facing windows)

Fig. 6 shows that the annual energy load increases as the window size gets bigger, regardless of the window position. The lowest total energy load is 2923kWh when WWR is 0, and the biggest load is 4250kWh when WWR is 100. The gap between the two loads is 1330kWh, which is 45 percentages of the lowest, indicating that window size largely impacts the energy load of the building. Therefore, designers should carefully consider the impact of the window size, not simply increasing the size to achieve view and daylight. Fig. 7 shows the energy load variation by window position change in each window size. The difference indicates the degree of impact of window position on energy load. The maximum difference is 23kWh, when the window-to-wall ratio is 20 percentages. Therefore, although the influence is insignificant, the position of the window has the biggest influence on energy load when WWR is 20 percentages. As the other window sizes show less or no load variation, it can be assumed that window position merely affects the energy load when WWR is other than 20 percentages.

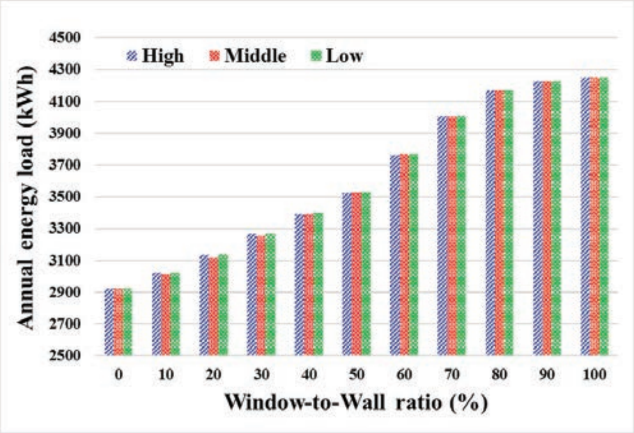


Fig. 6. Annual energy load by window size and position change

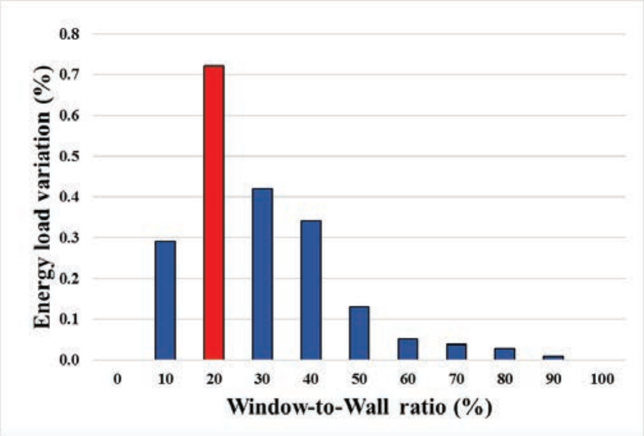
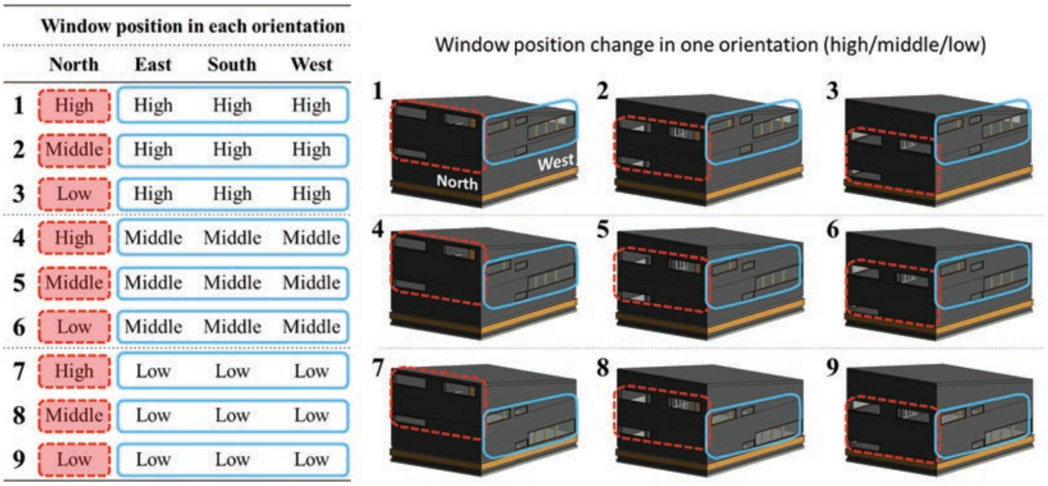


Fig. 7. Energy load variation by window position change in each size

3.2.2. *Impact of window position and orientation on energy load*

In the second part, the impact of window position and orientation is assessed by new scenarios. The WWR is fixed to 20, as the previous part showed that the window position has the biggest influence when WWR is 20. The other window size scenarios are assumed to have small or no influence on the energy load. To estimate the impact of window position each building face, the scenarios are created as Fig. 8. The position of north facing window is changed from high to low, while the other side of the windows is in the same position. Same scenarios are created in the other three orientations. These scenarios are analyzed to find out which combination of window position requires the lowest energy load, and which side of window's position has the biggest impact on the energy load.



	Window position in each orientation			
	North	East	South	West
1	High	High	High	High
2	Middle	High	High	High
3	Low	High	High	High
4	High	Middle	Middle	Middle
5	Middle	Middle	Middle	Middle
6	Low	Middle	Middle	Middle
7	High	Low	Low	Low
8	Middle	Low	Low	Low
9	Low	Low	Low	Low

Fig. 8. Snapshots of window position and orientation changing scenarios (North facing windows)

The results are classified by orientation, as Fig. 9. Scenario name indicates how the windows are positioned. For example, 'High-North-Middle' means windows are in high position except north facing window positioned at the middle. The lowest load is 3116.49kWh in the 'Middle', when all the windows are located in middle height and the highest load is 3146.965kWh in the 'Middle-East-Low', when the east window is positioned at low and others are located at the middle. Fig. 10 shows the energy load variation by window position in each orientation. The biggest load variation is 1% in the east facing window scenarios, meaning that the east side window position has the biggest impact on the energy load. The other side windows show less or no load variation.

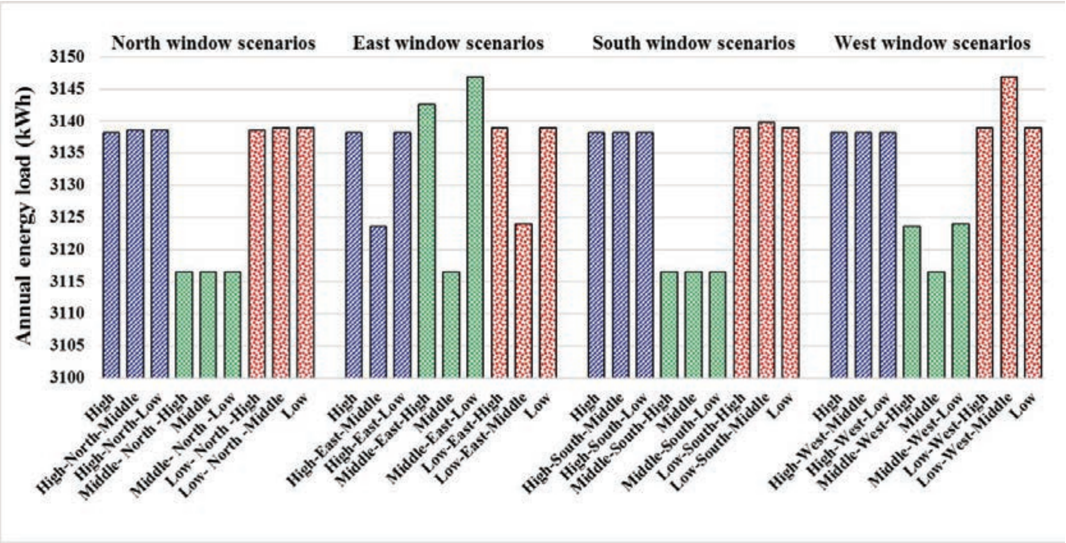


Fig. 9. Annual energy load by window position and orientation change

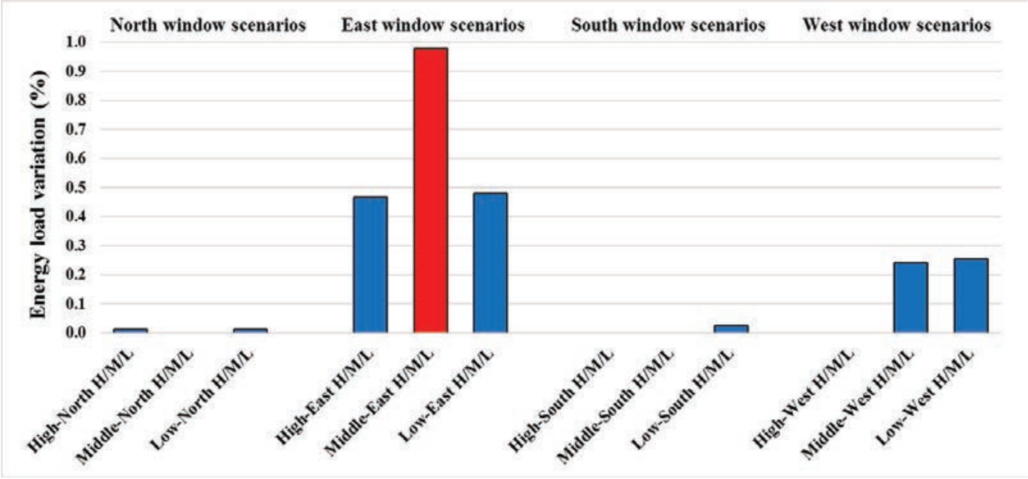


Fig. 10. Energy load variation by window position change in each orientation

4. Conclusion

To analyze the impact of window design on building energy load, the window size, position, and orientation are changed in 65 scenarios, and the heating and cooling load of each scenario is analyzed. First, the size and position of the windows are changed in 29 scenarios. The energy simulation result shows that the annual energy load significantly increases as the window size increases regardless of the window position. This indicates that the window size is the critical factor that should be considered during window design phase. In addition, the load variation by the window position in each size indicates that the position of the window has the biggest influence on energy load when WWR is 20. In this case, the variation has insignificant impact as it is less than 30kWh, but the variation is expected to increase in bigger building case. In the next stage, the window position of each orientation of the building is changed in 36 scenarios. The energy load is the lowest when all the windows are located in middle height, and the load variation by window position shows that the east window has the biggest influence on total energy load. The variation is 1% of the total energy, which is 30kWh in this building, but it will increase when it is applied to bigger scaled building. Therefore, the east window position should be designed by considering the impact on energy load.

5. Limitation and further research

As this study is based on a small-scale building, the total energy load is relatively small, so the energy load variation is insignificant when it is interpreted to cost. If the same methodology is applied to a bigger scale building, the energy load variation would be higher and this might lead to considerable cost saving. Therefore, further research should be done to assess of the impact of the window design on the energy load of bigger building. Also this research is limited to a case study of a building located in Vancouver, BC. If the location and sun angle changes, the critical orientation of window might change. More studies in various location should be conducted. In addition, visual comfort is neglected in this research to consider the heating and cooling load exclusively. In real project, visual comfort should be considered when the window is designed. Lighting load is also not considered since the required lighting load was relatively small in the original design, but if the building scale changes and users require more lighting, the lighting load should be considered.

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