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BIM APPLICATION FOR ANALYZING IMPACTS OF CONSTRUCTION PARAMETERS ON ENERGY USE AND ENERGY COSTS IN BUILDINGS

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Abstract

Energy-saving solutions in buildings in Vietnam are a great concern for sustainable development nowadays. However, energy-efficient and cost-saving designs based on the integration of Building Information Modeling (BIM) and building energy analysis are still limited. This study aims to provide energy-efficient and cost-saving designs for buildings by performing the cloud-based building energy simulation. Particularly, the analysis of the impact of changing building parameters on energy consumption and energy cost was performed in this study. Considered building parameters includes building orientation, wall construction, window-to-wall ratio (WWR), lighting efficiency, daylighting and occupancy controls, and, heating ventilation, and air conditioning system. The findings of the study can facilitate building designers, building owners or investors can obtain the best solution for designing the buildings. The first contribution of the study, to provide an in-depth analysis of the impact of the building parameters of energy cost and energy consumption. The second contribution is to contribute to the domain knowledge promotion of the digital transformation in the construction industry.

Keywords: building information modeling; energy cost; energy simulation; building energy performance; energy-efficient buildings.

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1. Introduction

Using energy wastefully in construction projects during the property explosion period for 20 years is still a topic frequently mentioned in sustainable development conferences. This issue gets lots of attention from all levels of state management because it must guarantee international commitments, especially the commitment to COP climate change meetings. It is a fact that saving energy also brings much more practical benefits not only to the cost but the environment [1–3].

The growth of sustainable buildings creates opportunities for improving energy efficiency and reducing carbon dioxide emissions in cities [1]. The international market for green building projects has grown significantly over the past 10 years. The demand for green building activities is increasing in the future. In Vietnam, it only accounts for 13% but it is expected to double by 2021. Vietnam has

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the highest rate of green building development in 2021 in the world. It accounts for 61% compared with the world average - 30% and Singapore - 25% [4].

In recent years, the Building Information Model (BIM) has been gradually applied to Vietnam's construction industry. The Prime Minister has approved the BIM scheme in building construction and construction management in Decision No. 2500/QĐ-TTg dated December 22, 2016. To meet the trend of the 4.0 industrial revolution, BIM has gradually become a leading tool in the project design and analysis of the project lifecycle. The method of parametric design and data management of the properties in the building will help to simulate, visualize and analyze the plans more accurately [5]. BIM has been applied to monitor construction project schedules and manage the actual bills of quantities in the construction project [6].

Franco et al. [7] have assessed and analyzed the comparatively development of green buildings across various nations globally. Politics, economics, technology, society, and the environment were studies. As a case study in Manila, unintended risks were identified and various policy strategies were proposed to mitigate unintended risks. Azis [8] proposed solutions to improve energy performance in green buildings. He found that the vegetated green envelope component is promising to achieve the highest energy efficiency. Annual cooling loads and lighting loads can save potentially18%–25%, and 5%, respectively in residential buildings.

Shin and Haberl [9] have review comprehensively thermal zoning for building energy simulations. Dat and Quang [10] determined energy use intensity (EUI) and the proportion of energy use in hotel buildings in major cities of Vietnam. Hajare and Elwakil [11] have reviewed the application of BIM for integrating life cycle assessment (LCA) and life cycle cost (LCC). Three manners for BIM-integrated LCA and LCC were found including (1) applying BIM software to export bills of quantities, (2) transferring data from BIM to other platforms, and (3) combining information in the BIM model.

Singh and Sadhu [12] applied the BIM model for assessing multicomponent energy in a building. Parameters such as orientation, materials, and internal and external loads were changed to evaluate building energy performance. Huang et al. [13] applied the quantitative analysis to analyze the benefits and barriers of BIM application to promote green building design. Lu et al. [14] integrated LCC analysis and energy simulation to evaluate the tradeoff between initial investment and long-term benefits. The building envelope is the potential to improve energy efficiency. Green buildings can reach to reduce cooling demand and lighting by 18%–25%, and 5% respectively [15].

One of the most important sustainable building design goals is energy efficiency and cost over the life of the building. This study aims to provide energy-efficient and cost-saving designs for buildings by performing the cloud-based building energy simulation. Particularly, the analysis of the impact of changing building parameters on energy consumption and energy cost was performed in this study. Considered building parameters includes building orientation, wall construction, window-to-wall ratio (WWR), lighting efficiency, daylighting and occupancy controls, and heating ventilation, and air conditioning (HVAC) system. The findings of the study can facilitate building designers, building owners or investors can obtain the best solution for designing the buildings.

In this study, the Autodesk Revit was used as a BIM tool, one of the most professional building design tools. Revit software assists in creating sustainable building architectural models with the integration of efficient cloud analysis and energy simulation tools from Autodesk, including Insight and Autodesk Green Building Studio (GBS). The study provides a solution in practical application when researching to provide energy-efficient and cost-saving designs for buildings by performing the cloud-based building energy simulation. The research topic has not been yet widely disseminated in Vietnam. As the first contribution of the study, the study provides an in-depth analysis of the impact of the building parameters of energy cost and energy consumption as well as energy savings opportunities. The findings of the study facilitate designers in making an effective design for buildings. The second contribution of this study is to contribute to the domain knowledge and practice community promotion of the digital transformation in the construction industry forward the evolution 4.0.

The remainder of this paper is organized as follows. Section 2 presents the research methodology in which the proposed process of building energy analysis was detailed. Section 3 describes a case study and analytical results. Section 4 provides the concluding remarks and future work.

2. Research methodology

Fig. 1 presents the whole process of building energy simulation using the Autodesk Revit, Autodesk GBS, and Autodesk Insight. The settings of building parameters were performed with the Autodesk Revit, which includes building geometry, construction materials, building operation schedule, building type, HVAC system, and weather data. Building geometry and construction materials were presented in Section 3.1. Fig. 2 shows an example of energy settings in the Revit.

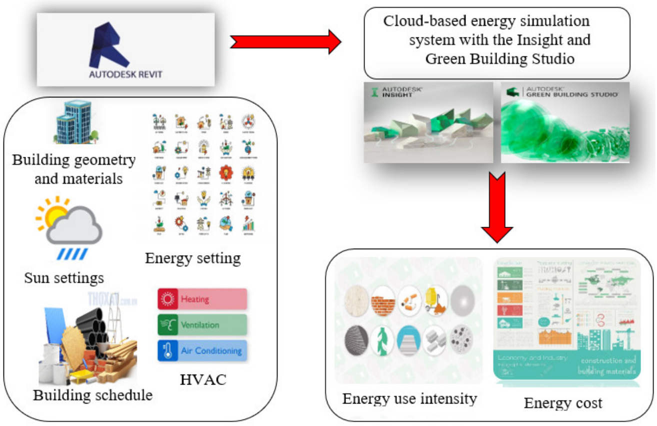
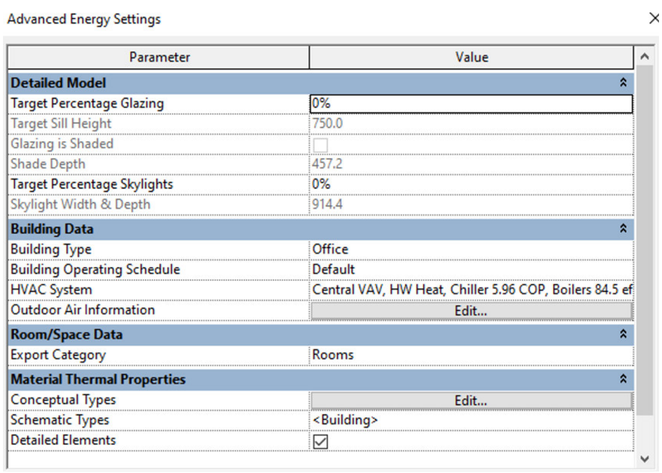


Figure 1. Energy analysis with Autodesk Revit, Green Building Studio and Insight


Advanced Energy Settings

Parameter	Value
Detailed Model	
Target Percentage Glazing	0%
Target Sill Height	750.0
Glazing is Shaded	☐
Shade Depth	457.2
Target Percentage Skylights	0%
Skylight Width & Depth	914.4
Building Data	
Building Type	Office
Building Operating Schedule	Default
HVAC System	Central VAV, HW Heat, Chiller 5.96 COP, Boilers 84.5 ef
Outdoor Air Information	Edit...
Room/Space Data	
Export Category	Rooms
Material Thermal Properties	
Conceptual Types	Edit...
Schematic Types	<Building>
Detailed Elements	☑

Figure 2. Example of energy settings

Building energy simulation was performed in the Autodesk GBS which is the cloud-based building performance analysis system [16]. The simulation results can use to optimize energy efficiency in the design stage. The Autodesk GBS applied the DOE 2.2 dynamic thermal whole building energy simulation engine to predict building energy consumption and operating costs; which are based on the effects and interactions of building parameters and weather data. Fig. 3 depicts an interface of the GBS in which multiple combinations of building parameters were generated and performed energy simulations.

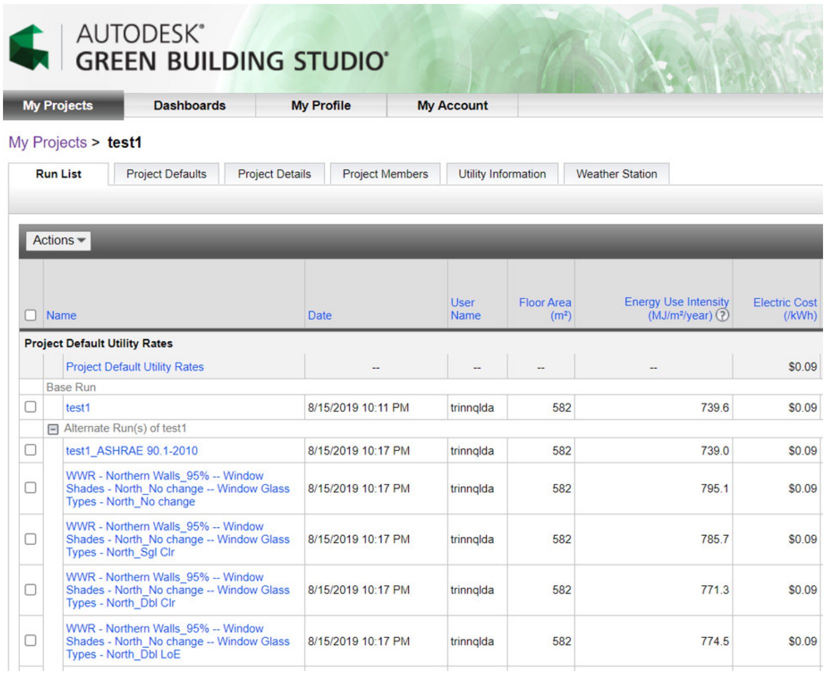


Figure 3. Energy simulation in Autodesk GBS

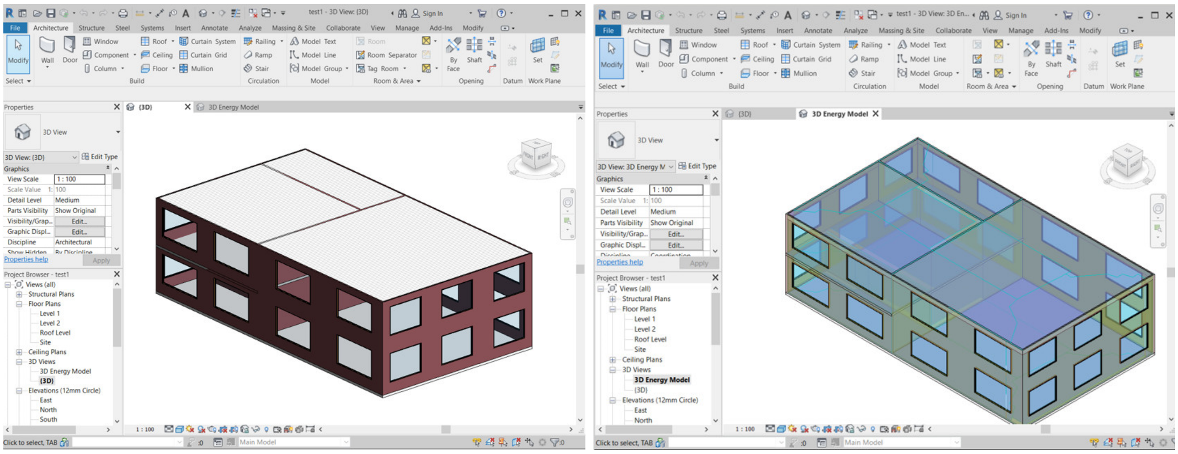
The Autodesk Insight was used to visualize and interact with the simulation results of energy consumption and costs in buildings. The results exported from Insights were used to analyze the influence of building parameters on building energy use and costs. Building parameters considered in this study include building orientation, wall construction, window-to-wall ratio (WWR), lighting efficiency, daylighting and occupancy controls, and, heating ventilation, and air conditioning system.

3. Case study

3.1. Building description

Fig. 4 shown the 2-story office which has been used in this study as a case study. It locates in Danang city, Vietnam with a total floor area of 582 m^2. The office has an overall length of 27,432 m, a width of 15,240 m, a height of 7,925 m, including 2 floors with a height of 3,962 m each. The office building consists of 5 rooms as presented in Table 1.

Details of building components were presented in Table 2. The first floor is made of concrete with a thickness of 160 mm, combined with a metal floor with a thickness of 50 mm with an area of 424,590 m^2, the second floor is made of reinforced concrete with a thickness of 200 mm, an area of 190 m^2, 152.4 mm regular brick wall, 12 mm thick glass windows, 515 mm thick insulated steel roof



(a) Building geometry model

(b) Energy analytical model

Figure 4. A building geometry and energy anaytical models in Revit

with 4 layers: 50 mm thick Standing Seam roof, 220 mm thick hard insulation panels, 20 mm thick metal roof, and thick anti-thick scaffolding 225 mm.

After the building energy simulation was done, the cloud-based Insight generated cost charts (USD/m^2/year) for different types of materials for building components such as building walls, roofs, floors or windows, and construction-related parameters. Insight analysis results were input to Green Building Studio. The GBS continues to produce more detailed parameters of the materials used for optimal cost and maximum energy-saving.

Table 1. Room schedule of the office building

Story	Name	Area (m^2)
1	Room 1	56
1	Room 2	130
1	Room 3	232
2	Room 4	56
2	Room 5	130

Table 2. Thermal properties of building components

Component	Structural material	Thickness (mm)	Thermal resistance R (m^2.K)/W	Absorptance	Heat transfer coefficient U (W/m^2.K)	Solar Heat Gain Coefficient
Wall construction	Brick common	152	0.2822	0.1	3.5433	n/a
Roof construction	4-layers	515	6.2922	0.7	0.1589	n/a
Floor construction	Concrete	200	0.1912	0.1	5.2300	n/a
Window	Pilkington single glazing	12	0.2177	n/a	3.6886	0.8600

3.2. Results

The building energy analytical model was generated based on the building geometry model. After the building energy simulation was done, the cloud-based Insight generated EUI and energy cost for different scenarios of building materials, lighting, building orientations, window-to-wall ratio. Fig. 5 presents the building energy analytical model in the Insight. This is an interactive interface that provides users with multiple options such as section analysis, object measure, and camera interactions. The number of 10.1 USD/m^2/year on the upper-left corner reveals the energy cost per area unit in a year in this building. The location of the building is connected with the map at the lower-left corner.

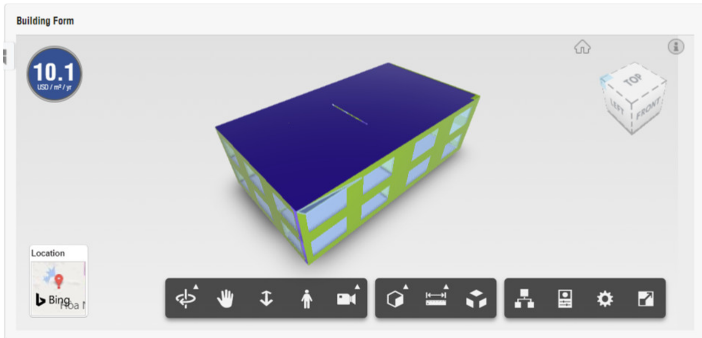


Figure 5. Building energy analytical model in the Insight

Fig. 6 reveals the change of EUI and cost with different scenarios of building orientations. There are nine scenarios which are building degrees of 0° (the North), 45° (the Northeast), 90° (the East), 135° (the Southeast), 180° (the South), 225o (the Southwest), 270° (the West), 315° (the Northeast), and the original orientation. The comparison results revealed that the office building obtained less energy use intensity and energy cost as the building degrees were 0° (the North) or 180° (the South). The building orientation of the Northeast obtained the biggest increase in energy consumption and energy cost. Particularly, the increase in energy consumption and energy cost and were 19.05 kWh/m^2/year and 1.72 USD/m^2/year, respectively compared to the original orientation of the building.

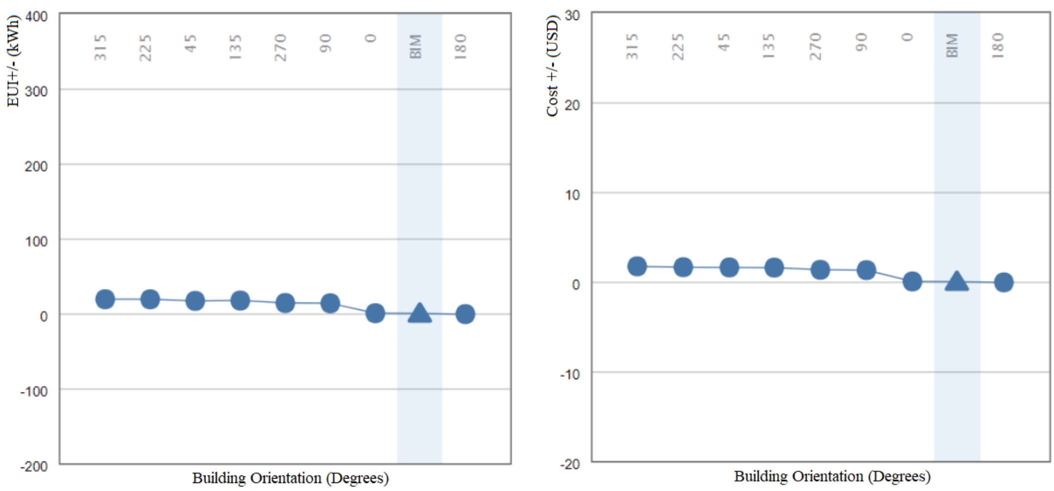


Figure 6. Energy use intensity and costs with different building orientations

From input data, the Insight and Green Building Studio produced the following scenarios of wall construction as shown in Fig. 7. Using materials with poor thermal conductivity in wall construction can reduce heat rise and counteract energy loss. The simulation results depicted that the wall construction with metal mesh panels R10 + R13 was a good choice because this option can reduce 0.26 USD/m^2/year in energy cost and 3.38 kWh/m^2/year in EUI compared to the original BIM model. These mesh panels are heat resistant, non-conductive, reduce the pressure exerted on the foundation, are reusable, especially relatively low cost.

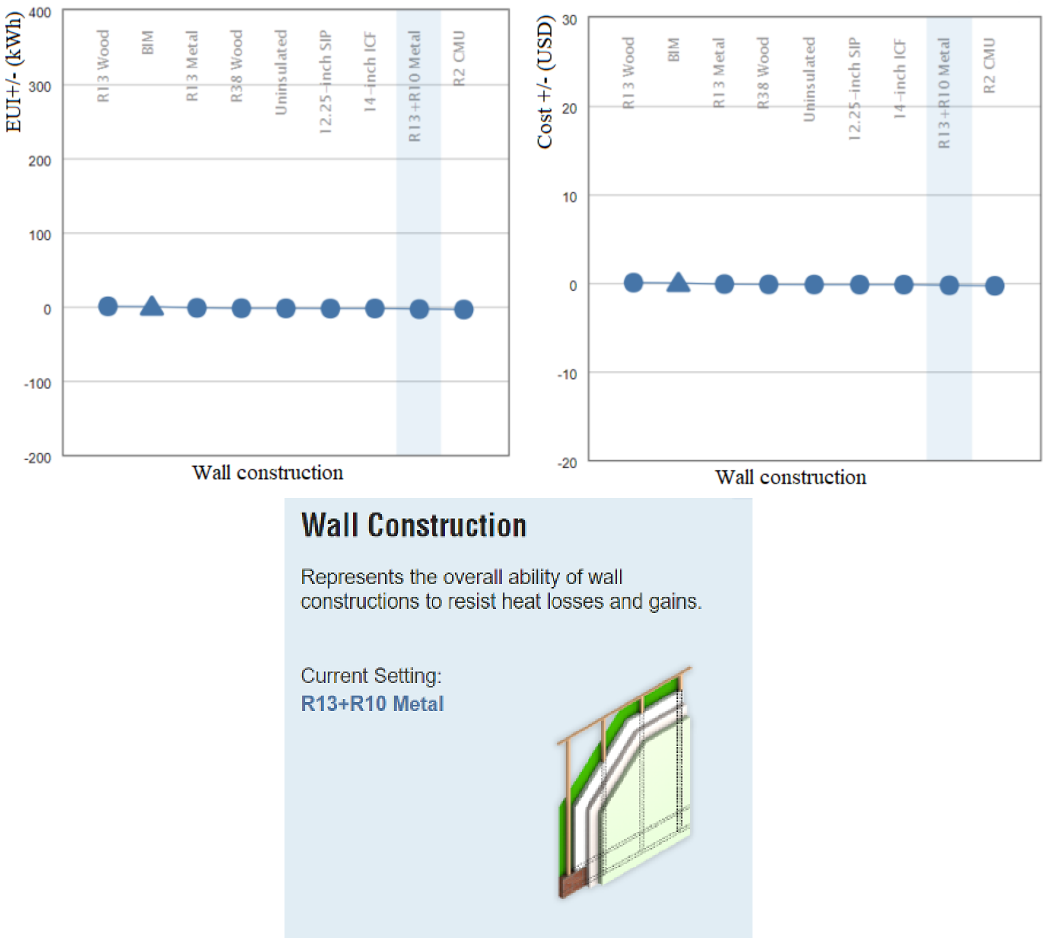


Figure 7. Materials of wall construction

Fig. 8 depicts the trend of EUI and energy costs with the corresponding lighting density in the building. Selecting effective lighting in the building can potential reduce heat rise and power consumption. The lighting density was set as 7.53 W/m^2 as shown in Fig. 8. The more natural light to use, the lower the energy use for lightings. Therefore, using the design for maximum natural light is an energy efficiency strategy that is widely applied in green buildings. Besides, the preferred paint color has high brightness in order to enhance lighting efficiency and reduce excess lights. Tungsten, halogen lamps, and electronic ballasts should be replaced with fluorescent lamps, and LEDs because they can save energy. Energy cost and EUI can reduce 1.25 USD/m^2/year and 13.09 kWh/m^2/year, respectively with the lighting density of 7.53 W/m^2.

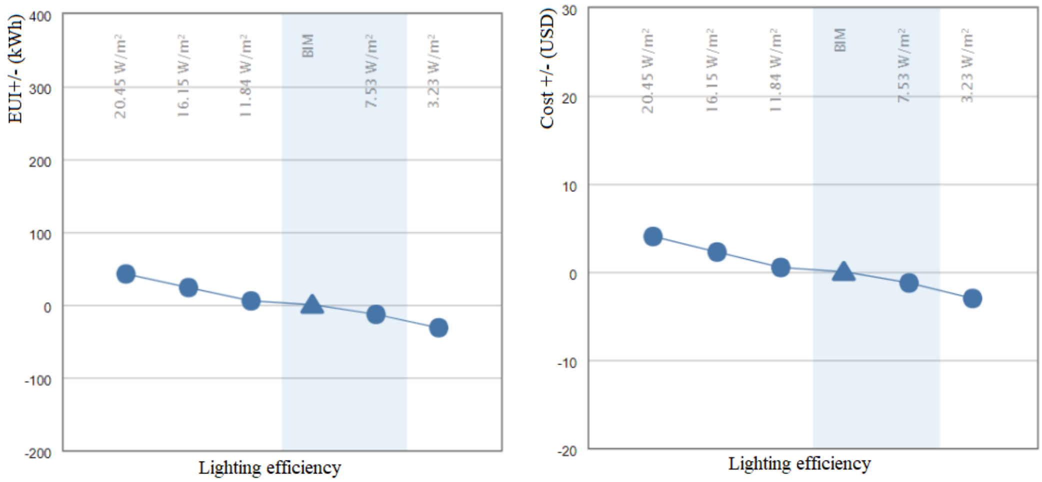


Figure 8. Lighting efficiency

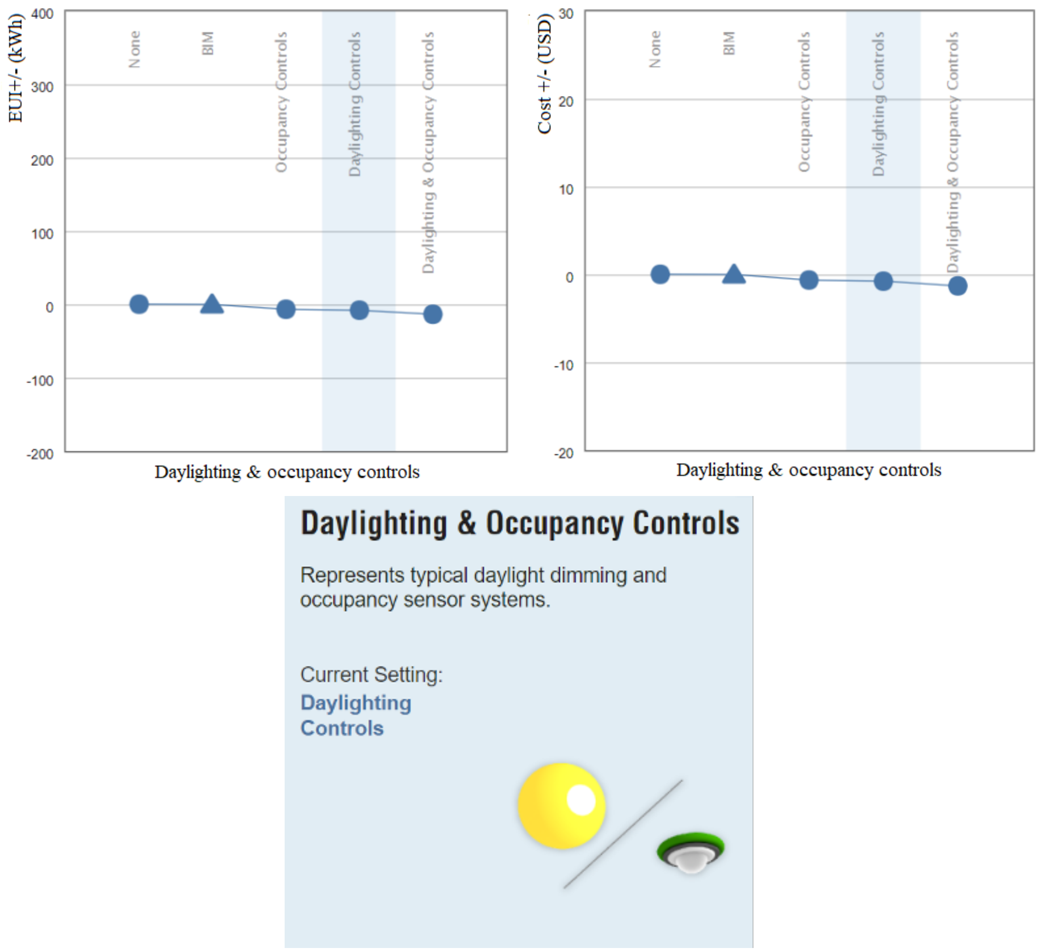


Figure 9. Daylighting and occupancy controls

Fig. 9 presents the daylighting and occupancy controls. Natural light is abundant but people still waste energy. As shown in Fig. 9, the option of daylight controls or daylighting and occupancy controls can save energy consumption and cost in buildings. The new solution for energy saving is digital daylight control. It will automatically reduce the level of artificially electric light through building windows or skylights of apartment buildings and high-rise buildings. For example, in dimmer and optical machines, 40% of energy consumption can be saved. The trend of energy cost and EUI in Fig. 9 revealed that the daylighting and occupancy controls have a small influence on energy use and cost in the building.

The ratio of the glazed area to the total wall area in accordance with the window properties was determined to minimize the house effect and to help control the solar energy and heat of the building. As shown in Figs. 10 to 13, from the analysis on the BIM application, the window-to-wall ratio (WWR) of the investigated building was set as 30% for southern walls. Building designers can change the WWR to investigate differences in EUI and energy costs in buildings. The properties of

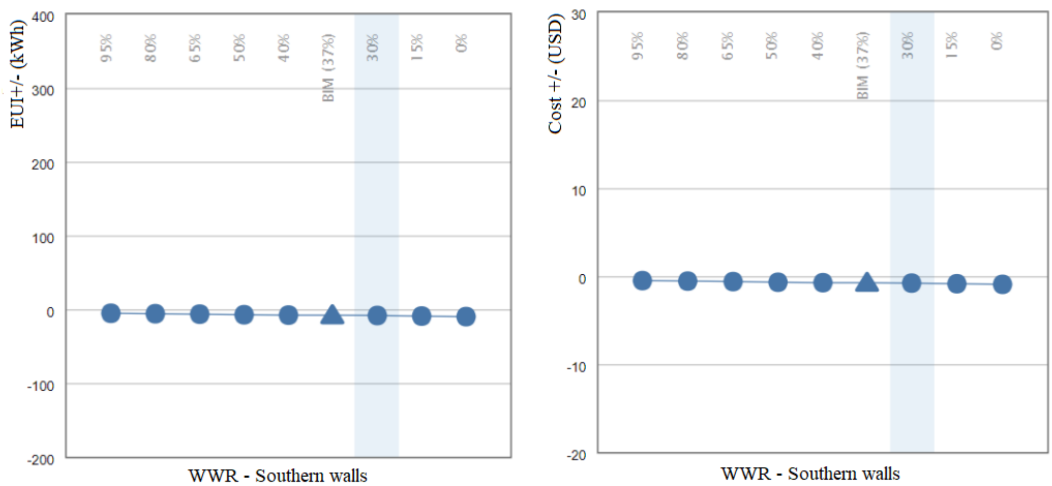


Figure 10. Window-to-wal ratio for southern walls

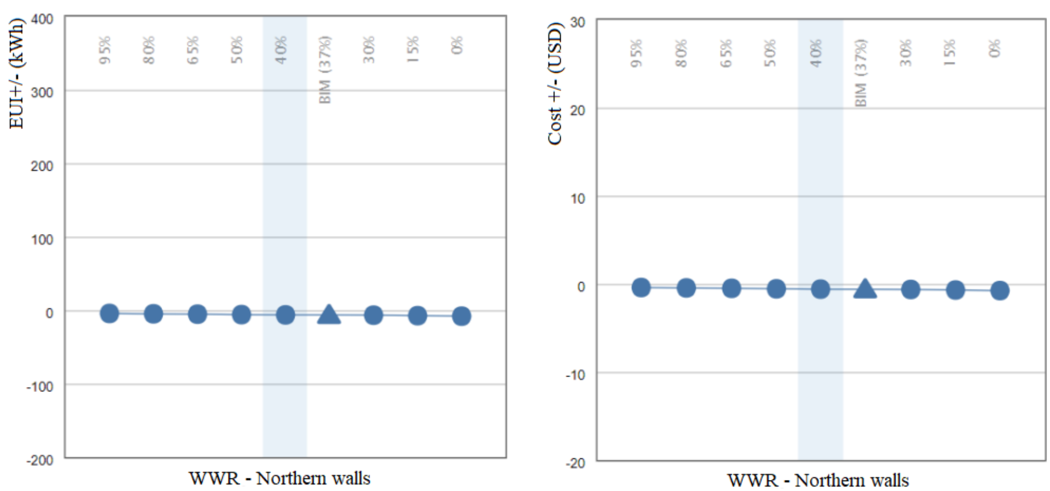


Figure 11. Window-to-wal ratio for northern walls

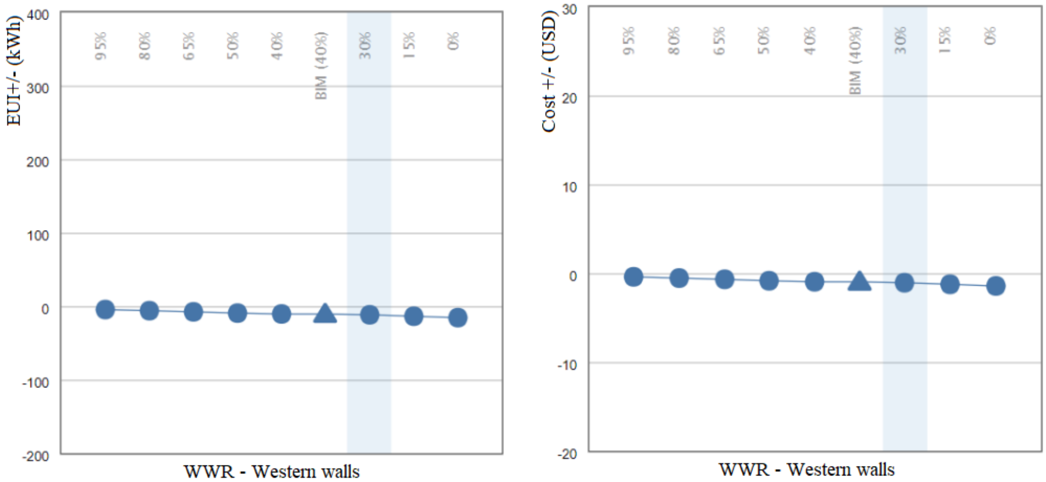


Figure 12. Window-to-wal ratio for western walls

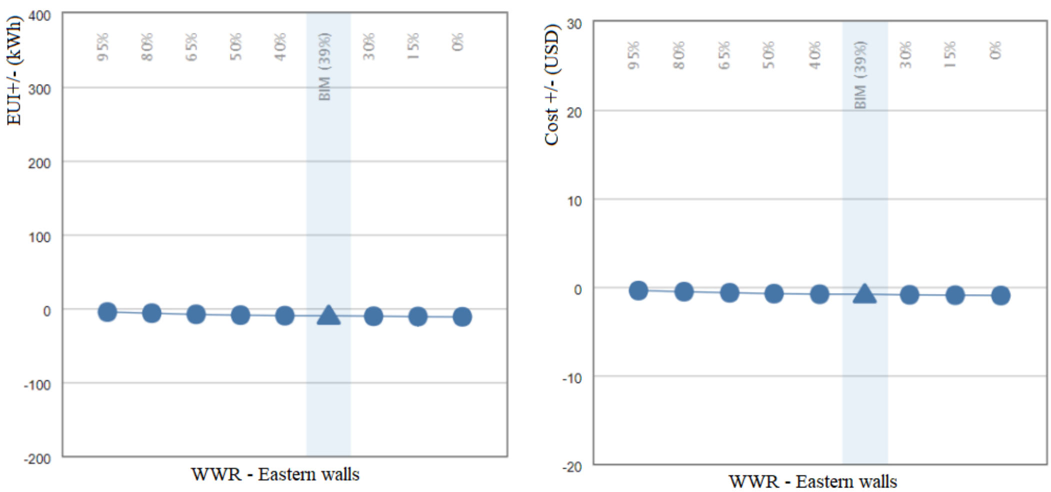


Figure 13. Window-to-wal ratio for eastern walls

glass affect the energy demand of light and heat that is transferred into the building. Insulating glass can be implemented to reduce the heat transferring from the outside into buildings. The structure of insulating glass consists of two or more different layers of glass separated by a vacuum or inert gas. Some types of insulating glass: box glass, reflective glass, low-e glass, solar control, film insulation stickers.

HVAC systems can improve air quality through large, dense, dense pipes, so during the installation process, it is necessary to strictly follow the principles of heat transfer, mechanics, and energy dynamics to avoid damage resulting in energy loss. HVAC types in this simulation consist of ASHRAE heat pump, ASHRAE VAV, ASHRAE package system, high efficient heat pump, high efficient package system, high effect VAV, high efficient package terminal AC, and ASHRAE package terminal heat pump. Energy consumption and cost for the HVAC systems were shown in Fig. 14. The results presented that the energy consumption and energy cost were changed significantly among HVAC types.

The high efficient package terminal air conditioning system or ASHRAE package terminal heat pump can achieve the lowest EUI with a reduction of 36.24 kWh/m^2/year and energy cost with a reduction of 3.17 USD/m^2/year compared to the original BIM model.

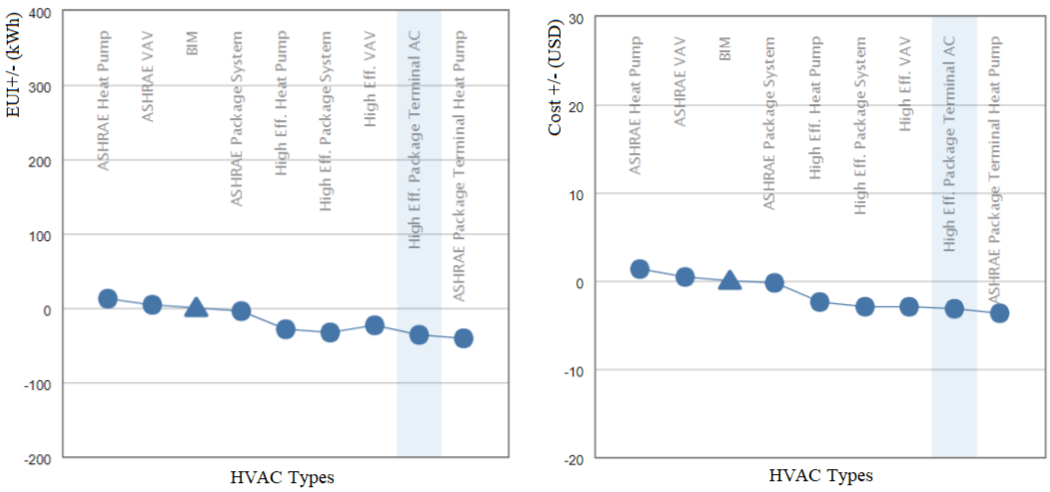


Figure 14. HVAC systems

Fig. 15 depicted the trend of energy consumption and cost regarding different types of operating schedules in the building. Based on the typical usage time of people in the building, the energy consumption in different periods can be controlled and easily detect the system's issues. These help users to promptly correct issues and reduce energy costs. Fig. 15 showed that the current setting of operating schedule obtained the lowest EUI and cost compared to others such as schedule schemes of 12/5, 12/6, 12/7, or 24/7.

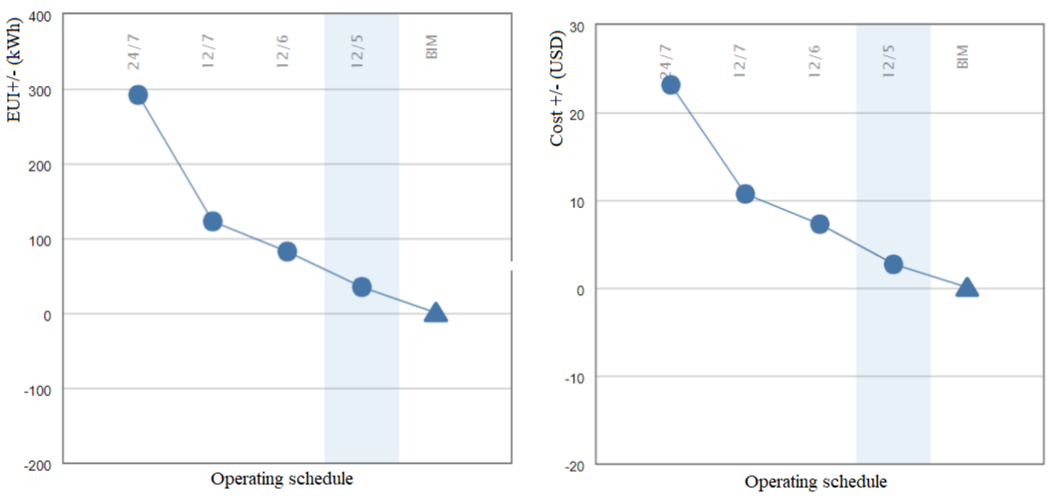


Figure 15. Operating schedule

The above analytical results presented that the building orientation, the lighting density, the type of HVAC system, building operational schedule have a large influence on the energy consumption and energy cost in buildings. The WWR values can impact slightly on the building energy use and cost. Findings can facilitate building designers or owners to fine-tune their alternative solutions regarding the building orientation, wall construction, WWR, HVAC system, and operating schedule. By obtaining the EUI and energy cost among designing solutions, building designers or owners can make a suitable decision on energy-efficient and cost-saving design for buildings.

4. Conclusions

Researching the application of BIM technology in the analysis of building parameters affecting energy use and building costs is important. This study aimed to provide energy-efficient and cost-saving designs for buildings using the cloud-based building energy simulation with various design alternatives. Particularly, the analysis of the impact of changing building parameters on energy consumption and energy cost was performed in this study. Considered building parameters includes building orientation, wall construction, window-to-wall ratio, lighting efficiency, daylighting and occupancy controls, and HVAC system.

The simulation results provided trends of EUI and energy cost with different options of building orientation, wall construction, WWR, lighting efficiency, daylighting and occupancy controls, and HVAC system. The results revealed that buildings can consume less energy as the building orientation is south or north. Wall material of metal mesh panels R10 + R13 was beneficial in saving energy and cost for building compared to others. Besides, the different values of WWR in buildings brought different EUI and energy costs.

The building orientation, the lighting density, the type of HVAC system, building operational schedule have a large influence on the energy consumption and energy cost in buildings. The WWR values can impact slightly on the building energy use and cost. The findings of the study can facilitate building designers, building owners or investors can obtain the best solution for designing the buildings. Notably, with obtained various design solutions from the analysis, building designers or owners can make an effective decision on energy-efficient and cost-saving design for buildings with the lowest EUI and energy cost.

As the first contribution of the study, the study provides an in-depth analysis of the impact of the building parameters of energy cost and energy consumption as well as energy-saving opportunities. The second contribution of this study is to contribute to the domain knowledge for promoting BIM applications toward the digital transformation in the construction industry. As a limitation, this study has not considered all building parameters such as roof and floor construction. In addition, real-world buildings should be applied in future work to prove the applicability of the proposed method.

Acknowledgements

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