Civil Engineering and Architecture 10(4): 1280-1292, 2022 http://www.hrpub.org
DOI: 10.13189/cea.2022.100404

Investigation of Energy Saving Using Building Information Modeling for Building Energy Performance in Office Building

Heni Fitriani*, Muhammadiya Rifki, Mona Foralisa, Ahmad Muhtarom

Department of Civil Engineering, Universitas Sriwijaya, Indonesia

Received December 17, 2021; Revised March 22, 2022; Accepted April 21, 2022

Cite This Paper in the following Citation Styles

(a): *[1] Heni Fitriani, Muhammadiya Rifki, Mona Foralisa, Ahmad Muhtarom , "Investigation of Energy Saving Using Building Information Modeling for Building Energy Performance in Office Building," Civil Engineering and Architecture, Vol. 10, No. 4, pp. 1280-1292, 2022. DOI: 10.13189/cea.2022.100404.*

(b): *Heni Fitriani, Muhammadiya Rifki, Mona Foralisa, Ahmad Muhtarom (2022). Investigation of Energy Saving Using Building Information Modeling for Building Energy Performance in Office Building. Civil Engineering and Architecture, 10(4), 1280-1292. DOI: 10.13189/cea.2022.100404.*

Abstract With increased demand for energy and the simultaneous awareness of the environmental impact of building construction, there is an urgent need to consider the issue of sustainability in the design phase. This paper investigates the potential of Building Information Modeling (BIM) for building energy performance assessment, especially in Indonesia, and provides a framework and overview of the application of BIM related to building energy assessment. This paper used Revit software integrated with Green Building Studio as a BIM tool to analyze energy performance. The results showed that the best scenario for energy use reduction was shown by the last (8^{th}) scenario by combining all possible options covering a 12/5 operation schedule, high efficiency VAV HVAC type, efficient lighting, efficient plug load, instalment of control equipment daylight and occupants, Triple LoE for window glass and solar panels installation. The use of BIM in energy analysis is very useful to measure the amount of energy consumed at the design stage. The findings can be used as a guideline for the potential of BIM related to energy use analysis.

Keywords Building Information Modeling, Environmental Impact, Energy Performance

1. Introduction

Energy consumption and sustainability have become major concerns all over the world. Given that emissions related to energy use are major contributors to climate change, there exists a need for enormous effort to conserve energy in many aspects of our lives. Buildings consume a large amount of energy, accounting for about 40% of total energy consumption [1]. For this reason, buildings are a target for energy saving and CO_2 emissions reduction. According to Kim et al. [2], there are several factors that influence building energy consumption, such as the specific technologies used, building materials, and occupant presence and behaviors. One of the current leading technologies in construction sectors is Building Information Modeling (BIM).

BIM has been recognized as a powerful tool for improving many dimensions of construction. BIM is a digital model that provides project information for architecture, engineering, and construction (AEC) professionals to better manage, plan, and design the building [3]. One of the current issues is related to environmental impact and global warming. Integrating BIM with building energy performance currently is necessary for achieving low building energy consumption during the life-cycle of a project.

Research on building energy performance using BIM has been emerging [4-7]. Aljundi [4] highlighted the use of BIM for energy analysis using Revit and Energy plus as well as presented the advantages and disadvantages of using energy software tools that enable decision makers to save time and money for achieving sustainable and efficient buildings. BIM as a digital model corresponds to the project information in terms of geometry, spatial information, quantities, material properties, etc. BIM tools and energy analysis software have the potential to simulate thermal insulation and thermal mass throughout the building lifecycle. Natephra et al. [6] studied thermal building performance by producing 4D models modified from the thermal data of the building envelope. The data collected such as thermo graphic images, air temperature, and humidity were exported to BIM models. Heat energy performance and the thermal comfort of the existing buildings were then analyzed. Hasan et al. [5] investigated the energy performance of an office building using Revit and Green Building Studio. Optimization was also performed to check the electricity consumption, resulting in a 9% energy reduction.

Many studies have shown how BIM can be integrated with building energy analysis. Oh et al. [8] used a genetic algorithm and Pareto to define the best design for glazing systems. Bazjanac [9] developed the interoperability of IFC using BIM and Energy plus. Venkataraman and Kannan [7] also performed energy simulation using 3D BIM under six different climate zones in India, resulting in energy patterns as performance indicators of energy use. Compared to other current approaches of energy analysis [10, 11], BIM makes the process easier to perform, cheaper, and less time consuming. Yu et al. [12] divided the data input for energy analysis into three types: general, architectural, and mechanical. This method could enable architects and engineers to process data effectively and efficiently. Moreover, an Entity Relationship Diagram (ERD) was also developed to show the relationships among project data.

As a developing country, Indonesia is expected to be very concerned about sustainability issues, which means that there is a need to focus on low-carbon and climate-resilient infrastructure. One of the ways to minimize the environmental impact of infrastructure growth is to optimize the building design for low-energy use. Green infrastructure concepts were introduced to Indonesia in 2012, but currently such concepts are not widely adopted, due to obstacles such as budget constraints, policy, and economic benefit analysis [13]. However, research related to energy modeling using BIM is not widely known in Indonesia. Therefore, this paper aims to investigate the potential use of BIM related to building energy assessment in Indonesia. It is important to link the energy analysis tools with BIM to better achieve energy sustainability. This paper used Revit software integrated with Green Building Studio as a BIM tool to analyze energy performance. The findings can be used as a guideline or a framework about the potential of BIM related to energy use in Indonesia.

2. Literature Review

As the construction industry faces major challenges regarding the development and promotion of sustainable construction, there is a need to adopt green innovation and technology. Building Information Modeling (BIM) is defined as “a digital representation of the physical and functional characteristics of a facility” [14], enabling different stakeholders involved during a project’s life-cycle to share data and information to facilitate the achievement of sustainable buildings. BIM has played an important role in delivering a facility by providing the data-rich that helps for decision making [15]. BIM provides a way to analyze and simulate different types of building components such as wall, window, door, etc. By using BIM for simulation at the pre-construction stage, decision makers will be able to select the building characteristics with the least environmental impact [16].

Research on building energy consumption related to BIM has been evolving due to issues of sustainability and the energy crisis. Cheung et al. [17] focused on assessing building energy consumption and optimizing the use of different technologies to find the most economical ways for energy reduction. Shoubi et al. [16] applied BIM to analyze the energy consumption of a single residential house. According to the Minister of Environment Life and Forestry Indonesia [18], energy analysis is a part of a green building concept that has been implemented in Indonesia since 2012 as an effort to improve the low-efficient energy buildings. It is expected that carbon emissions will reduce up to 40% by 2030. While as stated by the Green Building Council Indonesia [19], the use of green building can minimize utility costs up to 30-80% compared to the cost of common buildings. Buildings in Indonesia consume approximately 30% of total national energy consumption and it is likely that energy consumption will increase up to 40% by the year 2030. Therefore, it is important to reduce the energy consumption of buildings.

The construction industry is becoming more aware of the importance of enhancing the energy efficiency of building due to needs related to global warming and sustainability. The combination of the BIM and energy models simplifies the energy modeling simulation; however, problems in transferring data from BIM tools to energy software occurred. Therefore, it is important to improve the integration of energy modeling with BIM in order to produce an optimal design. The lack of building information creates uncertainties in energy simulation and modeling at the design stage.

Pezeshki et al. [20] divided the application of Building Energy Modeling (BEM) into different categories such as prediction, estimation, consumption, design, evaluation, efficiency, management and optimization. This paper also explored the possibilities of BIM database as related to BEM throughout the project life-cycle. To respond to challenges connected with global warming and sustainability, the use of BEM for building energy assessment and performance is required. Marzouk et al. [21] presented a framework of a Building Information Modeling approach using optimization and stochastic models to find the best alternatives for building material selections to obtain the low life-cycle cost for sustainable buildings. It is evident that the selections of building materials are also determined by budgetary constraints. Thus, designers and construction managers tend to choose the materials based on their own experience and information availability in the construction market. However, given the low cost achieved in the beginning of project phase [11], sustainability issues are often ignored by the decision makers, which leads to an increase in total life-cycle costs of the projects [21].

Liu et al. [22] developed an algorithm to optimize the building designs of an office building in Hongkong combined with the BIM model. Particle Swarm Optimization (PSO) was used to search for the best costs and carbon emissions life cycles. This paper presented a more economic and environmental building design, emphasizing the importance of design optimization towards sustainability while taking advantage of the use of BIM to improve the building design. Multi-objective optimization methods are expected to improve solutions and strategies for building design.

The construction industry is the third largest contributor of greenhouse emissions (GHGs). Buildings contributed more than 40% of GHG to the environment [23]. Therefore, it is essential to pay more attention to opportunities to minimize construction's impact on global warming and carbon emissions. According to Rebitzer [25], design contributes around 70% of environmental impacts throughout the building lifetime. When designing a building, requirements to consider include building structures, materials, equipment, climate information, energy source, active or passive hearing and cooling systems, etc.

Natephra et al. [6] used the BIM model to calculate the overall thermal transfer value (OTTV) of an office building by extracting the thermal and physical properties from BIM databases. The results can help decision makers improve the energy efficiency of building design. This paper highlighted the advantages of using BIM as an automatic model to measure the thermal performance of the building envelope as compared to manual methods. According to Yu et al. [12], energy building use falls into seven categories: 1) climate characteristics; 2) building characteristics; 3) user; 4) building system; 5) occupant behaviour and activities; 6) social and economy; 7) indoor environmental quality. Fang and Cho [26] conducted an optimization for a building design process to evaluate energy performance, and verified the results using office buildings in different climate zones in the US. It was found that optimization can increase the performance metrics. Sensitivity analysis was also performed to look at relationships among variables.

Touloupaki and Theodosiou [27] developed a design workflow for a Zero Energy Building using an optimization algorithm to evaluate the energy performance. This research also discussed the current opportunities and limitations of the developed approach. Mora et al. [28] proposed tools and approaches for cost efficiency and carbon emissions optimization focusing on a case study of building renovation. The tools offered different packages that can be used for decision making about optimal costs. This paper also highlighted the importance of establishing the energy performance targets of a building to define the building codes for making cost-effective energy and carbon emissions policies. Table 1 summarizes previous research related to building energy performance. Based on the review findings, this paper concluded that none of the optimization design tools can fully address the needs of designers during the design stage. Therefore, more research into optimization is required to provide a more comprehensive analysis.

Table 1. Previous Research

No	Researcher (Year)	Variables	Types of building & Project stage	Results	Software used
1	Stumpf & Kim [29]	roof configuration, window placement, thermal zones, and orientation on the site	Commercial and residential buildings (conceptual design phase)		Green Building Studio Revit and ArchiCAD
2	Sadeghifam et al. [30]	walls materials, climate data, temperature, humidity and airflow, user number, working hours of user, type of activities, cooling system and operation hours of system	Public building: library in Malaysia (Existing building)	Modification most optimized wall materials and energy analysis indicated 9347 Wh in Per meter square of electrical energy saving.	Revit Architecture software, Autodesk Ecotect
3	Venkataraman & Kannan [7]	climatic zones, glazing, wall, roof, building orientation, air exchange, shading, set point for cooling and heating temperature	Office building (conceptual design phase)	Derivation of energy simulation patterns for different climatic zones in addition to the performance indicator, luminous intensity and other energy related factors	AutodeskTM Revit® 2013
4	Shoubi et al. [16]	various combinations of materials (wall, window, floor, door, ceilings, indoor temperature)	single, residential, house (operational energy use of the building)	Building Information Model (BIM) should be taken into account as a comprehensive simulation method that can be used to create opportunities to assess and improve the performances of buildings	Revit Architecture 2012 and Autodesk Ecotect Analysis
5	Hasan et al. [5]	building plan, materials properties, HVAC system	Office building (operational energy use of the building)	After optimizing the energy system, annual electricity consumption reduced by 9% and annual carbon dioxide emission reduced by 3 tons per year	Revit and Green Building Studio
6	Fikar et al. [31]		Office/university building	The results of the month's insolation data were lowest in June at 94 kWh/m^2 to the highest in March, which was 146 kWh/ m^2. From this data in one year, the DTNTF building can produce PV electricity of around 1,422 kWh/ m	Revit 2018

3. Methodology

This paper examined the use of BIM software to perform a building energy analysis during the design phase. The aim is to integrate the use of BIM for energy analysis during the design process for sustainable development optimization. Revit and Green Building Studio (GBS) were used as a cloud-based energy analysis program that allows architects and designers to perform an entire building analysis, optimize energy consumption and work on a carbon neutral building design early in the process. Autodesk Revit in combination with GBS can perform an energy analysis of a structure and analyze design alternatives that could lead to a more energy efficient structure.

The revit application is used as software to model the building as a whole by entering all the data of the building material so that general information about the building can be determined. While, for energy analysis, the integration between software of GBS and Insight was conducted. GBS displays data acquisition in detail, while Insights displays data for visualization.

The results of the simulation with software BIM could produce an Energy Use Intensity (EUI) value estimation based on ASHARE 90.1 and ASHARE 2030 benchmarks. Revit might be useful as a design tool at the conceptual stage to predict building design performance for determining the lighting and ventilation system design with the most efficient electrical energy. The expected energy use (fuel and electricity) were measured based on the building geometry, climate, building type, envelope properties, and active systems (HVAC and lighting). The analysis takes into account the overall interdependence of buildings to reduce building energy use.

Building modeling was conducted with BIM Revit software, using some inputs such as weather data and building information which includes specifications and materials. In addition, the simulation was also carried out with the GBS and the scenario analysis was developed using Insight 360 using the DOE 2.2 and EnergyPlus simulation engine. The maximum EUI value was obtained and then compared with the applicable ASHRAE and SNI standards as seen in Figure 1 below.

The specification of building material envelope is shown in Table 2. The roofs are made of bitumen, light brick walls in paint-finishing plaster, ceramic floors, gypsum ceiling, and 1/8 single type plankton window glass. The value of heat transfer (U) indicates a function of heat conductivity, in which the smaller the U value, the greater the heat resistance and the potential for cooling energy savings. The Solar Heat Gain Coefficient (SHGC) value of glass material indicates the quantity of a glass plane continues permitting the heat transmission of sunlight into the room which ranges from 0 – 1. The value means the smaller the value, the less heat radiation transmitted through the glass. The SHGC value of window glass is 0.860.

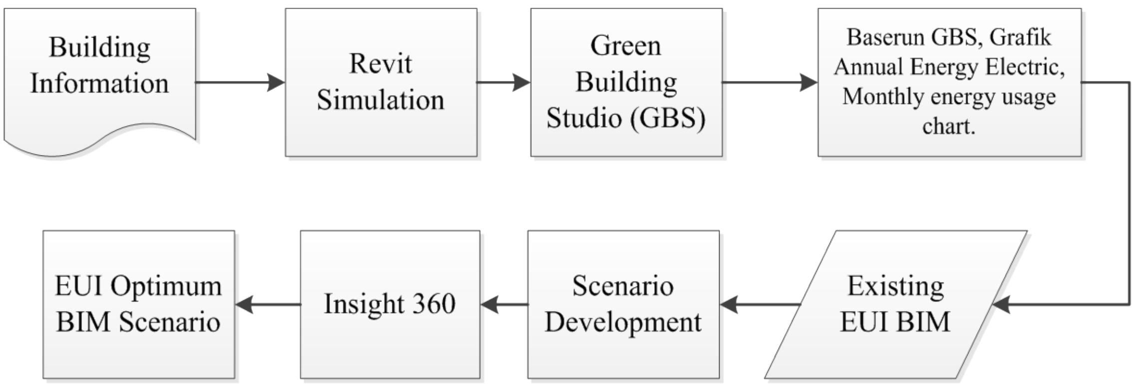


Figure 1. Research Methodology

Table 2. Building envelope material information

Building materials	**Total thickness (mm)**	**Heat transfer coefficient (U) (W/m^2.K)**	**SHGC**	**Information**
Roof	505	0.057	-	Structure Steel with insulation and Roof Bitumen
Wall	144	1.329	-	Finishing with light brick
Floor	210	5.012	-	Ceramics
Ceiling	135	0.516	-	Gypsum
Glass window	3.6	3.689	0.860	Plinkton 1/8 single

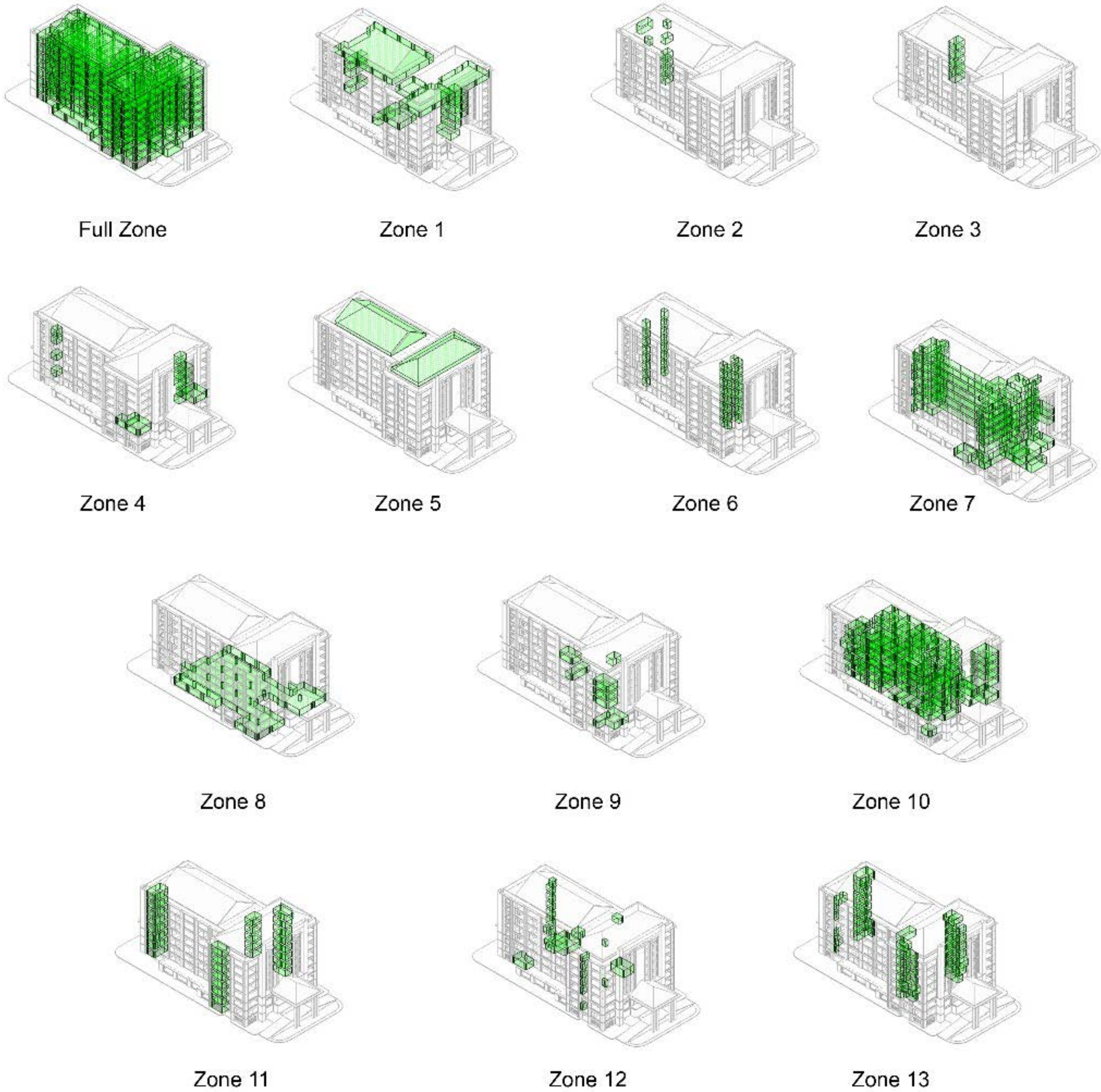
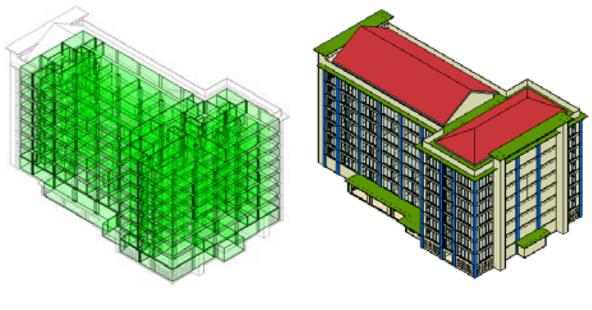


Figure 2. Zone Divisions

The project was located in Palembang, South Sumatra Province. The structure consists of reinforced concrete and light brick walls with a total area of 14,179 m^2 with 50 years of service life. The office building consists of 8 (eight) floors in which the area of the ground floor is 2117 m^2, consisting of a number of rooms with their respective functions such as car park area, corridor, lift, lobby, generator room, driver's waiting room, pump room, transformer room, transit room, stairs, toilets for the disabled, men's toilets, women's toilets.

In terms of room arrangement and zoning, the total space is divided into 364 spaces and 13 zones, with each zone representing a variation in the energy performance of a particular space. The area above the ceiling is assumed to be only on the roof floor and is configured as an unoccupied zone. Figure 2 shows the general configuration for calculating heating and cooling loads including all grouped rooms and zones.

The energy simulation was conducted with several inputs, such as geographic location, climate data, thermal envelope, space, and operational characteristics and spatial work. The building model simulation was first created using the data obtained from the contractor using Autodesk REVIT. Autodesk Revit provides several features that can help with energy performance processes in building. After the architectural model is built, the building's thermal envelope characteristics and the operational arrangement of all the rooms are configured to obtain an energy model as seen in Figure 3. The air conditioning system was set based on the building energy regulation. Furthermore, simulation and energy analysis were carried out using simulation tools integrated with REVIT, namely the Green Building Studio and Insight 360 based on the internet network (cloud). For orientation, climate, and external temperature, this study used facilities that have been arranged in Revit and Green Building Studio which are integrated with google maps for locations and weather data that have been recorded on the GBS web.



(a) (b)

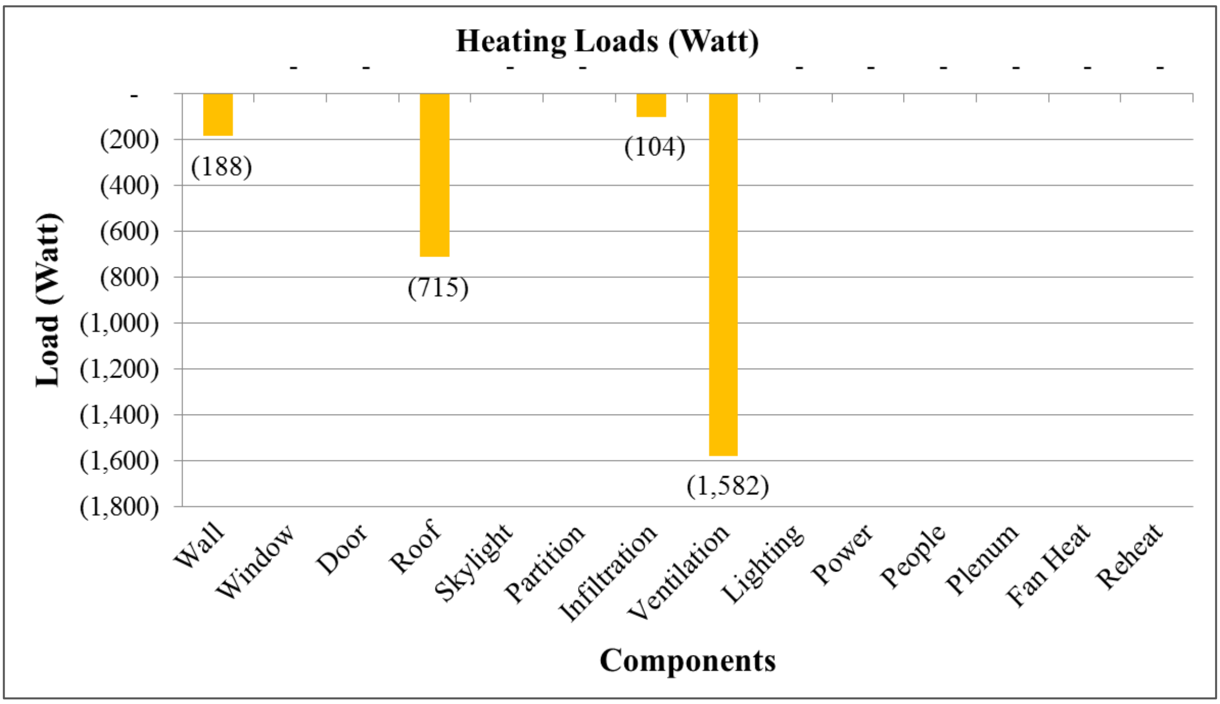
Figure 3. (a) Building model (b) Architectural models of buildings

4. Results and Discussion

In this section, annual energy consumption was obtained from the energy simulation using BIM tool software. Furthermore, the building behavior from an energy and environmental point of view was also optimized, also from the BIM software platform, analyzing various possible alternative improvements for buildings using Insight 360.

4.1. Heating and Cooling Load

The heating load is the amount of heat energy added to a room to keep the temperature within an acceptable range. The cooling load is the amount of heat energy removed from the chamber to maintain the temperature within an acceptable range. Cooling load is affected by the thermal properties of the material, heat from lamps and electrical equipment, occupancy rate, outdoor air load, and casing load as seen in Figure 4. The minus sign on the heating load indicates the energy lost or reduced by the elements of the wall, roof, infiltration and ventilation, while the cooling load is the energy generated in the elements of the wall, roof, infiltration, ventilation, lighting, power, people and fan heat.



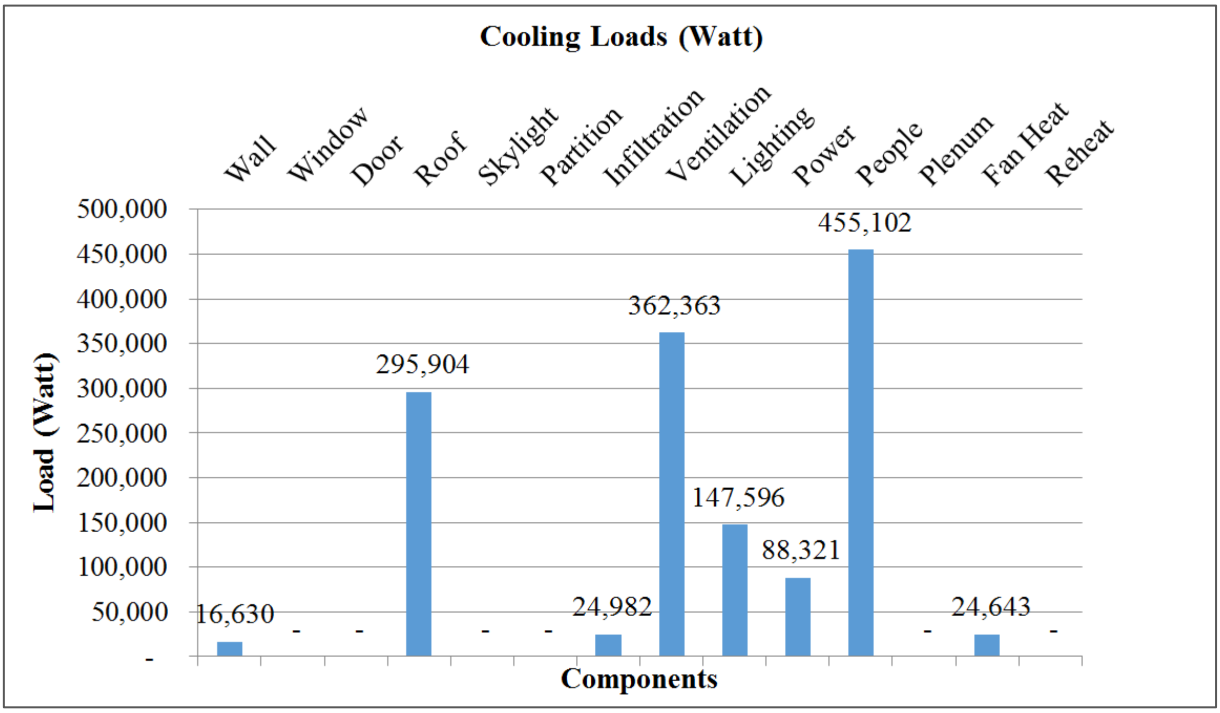


Figure 4. Heating load and Cooling load

4.2. Energy Use Intensity (EUI)

The energy analysis was carried out using the Green Building Studio (GBS) to identify the total energy use in the existing building when the BIM model has been built. The results show that the energy consumption was spent for HVAC electrical energy by 72.3%, lighting by 17.3%, and others such as electronic equipment by 10.5% as seen in Figure 5.

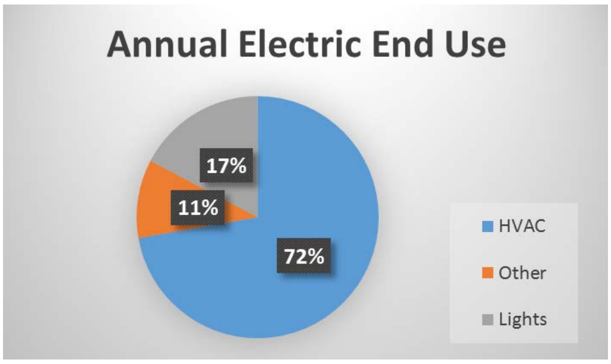
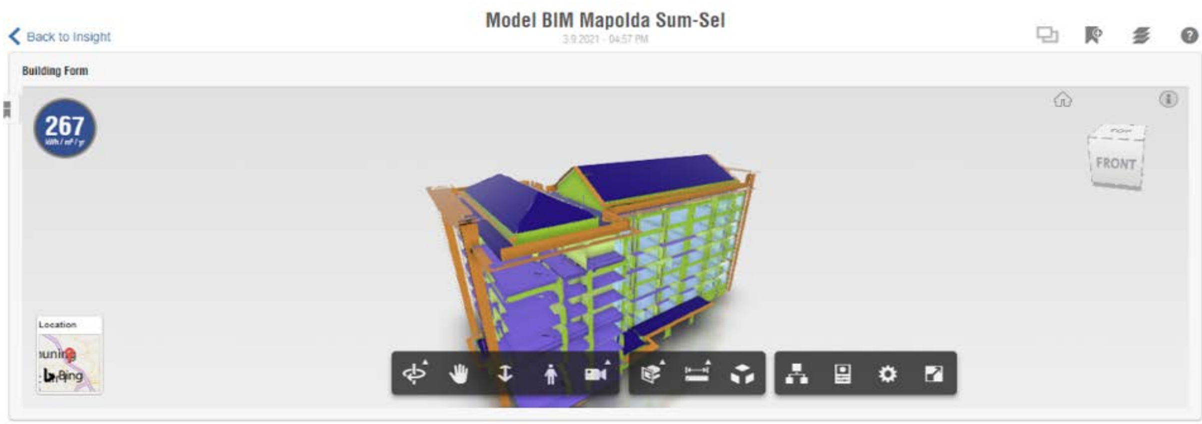


Figure 5. Annual electrical energy use

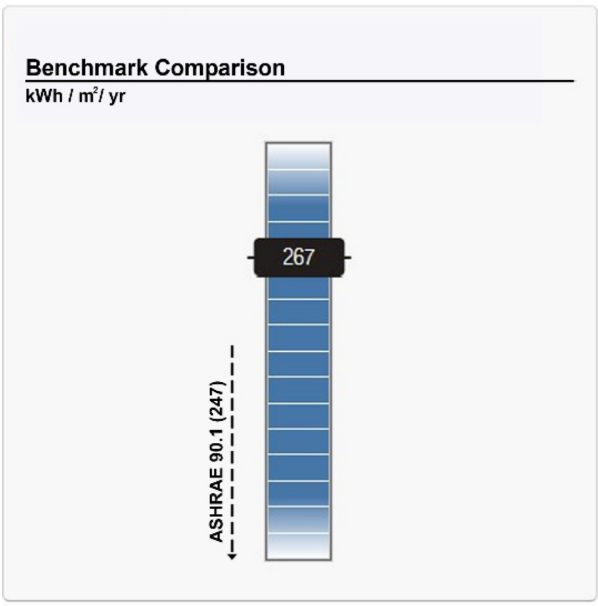
4.3. Insight 360 Analysis Results

Insight 360 analysis was used to identify the value of energy consumption (EUI) as well as the costs incurred in the building. Furthermore, the scenario analysis was carried out to find the most efficient EUI value (the smallest EUI). After the data was entered into the Revit program, the analytical calculations on Autodesk Revit were then exported to the gbXML file, and calculated using the cloud-based Green Building Studio (GBS) program. The detailed calculations from existing building data using GBS take into account the data of location, weather station, and climate data. The results also show that the electricity and fuel costs were around 0.06 USD/kWh and 0.11 USD/term respectively. Furthermore, the estimated total energy use intensity (EUI) is around 1,152 Mega Joules per square meter per year, including consumption of electrical energy and fuel sources. Meanwhile, the total electricity consumption is 3,657,868 kWh equivalent to 236 kWh/m^2/year, and for energy from fuel is 4,656,210 MJ, which is equivalent to 84 kWh/m^2/year.

The analysis using Insight 360 with DOE – 2.2 and Energy plus engines was conducted to identify the EUI value. Figure 6 shows the Insight 360 view and the EUI value of the existing building where the results obtained in the energy simulation are 267 kWh/m^2/year. The EUI value of the related buildings is known to be higher than ASHRAE 90.1, which is 247 kWh/m^2/year.



(a)



(b)

Figure 6. (a) Insight 360 view of analysis results, (b) Energy usage cost diagram

Table 3. EUI value according to Indonesian standards [32]

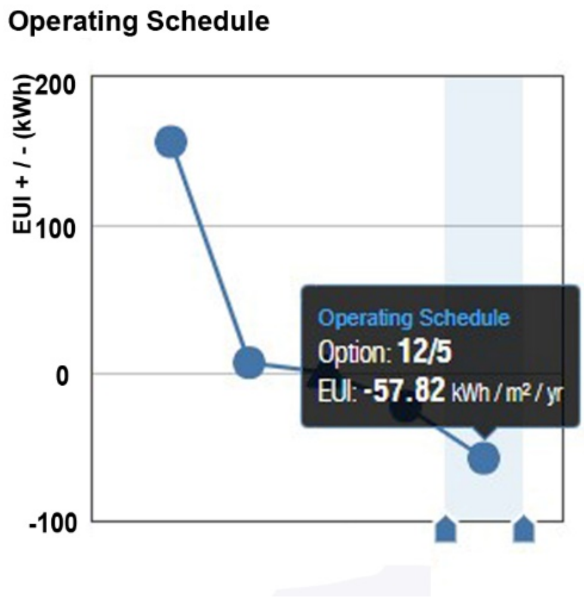
Criteria for an air-conditioned office building. ($kWh/m^2/month$)	EUI value
Very Efficient (<8.5)	-
Efficient (8.5 - 14)	-
Simply Efficient (14 - 18.5)	-
Wasteful (> 18.5)	$Wh/m^2/month$

The EUI value of existing buildings is known to be 267 $kWh/m^2/year$, while the EUI per month is 22.25 $kWh/m^2/month$. Based on the EUI standard in Indonesia for office buildings for one month, this result is categorized in the wasteful category (> 18.5 $kWh/m^2/month$). Table 3 shows the position of the EUI value of the related building, therefore it is necessary to develop a scenario to obtain a smaller (efficient) EUI value.

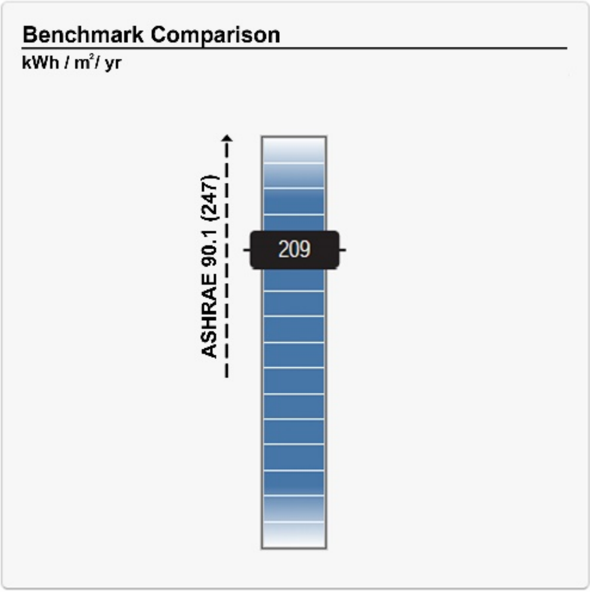
4.4. Optimization by Developing Different Scenarios

In order to determine the most efficient EUI values, it is necessary to analyze possible scenarios to achieve the minimum energy consumption value. The scenario analysis was carried out by varying the design factors using Insight 360 as seen in Table 4. To perform energy simulations, the HVAC systems provided in the simulation software are similar to those used in the actual building. In order to determine the characteristics of the operational load, work, and internal space of the BIM model, a distinction is made between air-conditioned and non-air-conditioned rooms. Due to the large number of air-conditioned rooms, it is necessary to group the rooms into four zones, namely the private zone, the public zone, the service zone and the circulation zone. The scenario development analysis for increasing energy efficiency must be selected from the scenario development factors in Insight 360 that are available in the software while the performance diagram for each factor was analyzed by the simulation software.

Furthermore, scenario development was carried out by changing the operating schedules, HVAC systems, lighting efficiency, plug load efficiency, natural lighting controls and occupants, window glass, etc. Scenario 1 was based on the selection of an operation schedule, where the operating schedule is 12/5, which means the building operates 12 hours in 5 days per week, resulting in a EUI value of 209.18 $kWh/m^2/year$ and energy savings of 57.82 $kWh/m^2/year$.



(a)



(b)

Figure 7. (a) Operating schedule design factor values (b) EUI value diagram

Table 4. The results obtained in various scenarios

No	Scenario Development	Variable	Energy Consumption (EUI) (kWh/m²/year)	Energy saving (kWh/m²/ year)	% Energy Efficiency Contribution
	Existing Building	Existing Building	267.01	-	0.00%
1	Operation Schedule	12/5	209.19	57.82	21.65%
2	HVAC	High Eff. VAV	196.03	70.98	26.58%
3	Lighting Efficiency	3.23 W/m²	230.30	36.71	13.75%
4	Plug/Miscellaneous expenses	6.46 W/m²	261.70	5.31	1.99%
5	Daylight and occupant control	Install daylight and occupant controls	257.30	9.71	3.64%
6	Glass window	Triple LoE type window glass	250.80	16.21	6.07%
7	All variables	12/5 + High eff.VAV+3.23 W/m2+6.56 W/m²+ Install daylight and occupant controls + Triple LoE type window glass	114.48	152.53	57.13%
8	All variables + Solar Panel	12/5 + High eff.VAV+3.23 W/m2+6.56 W/m²+ Install daylight and occupant controls + Triple LoE type window glass + Solar Panel	103.57	163.44	61.21%

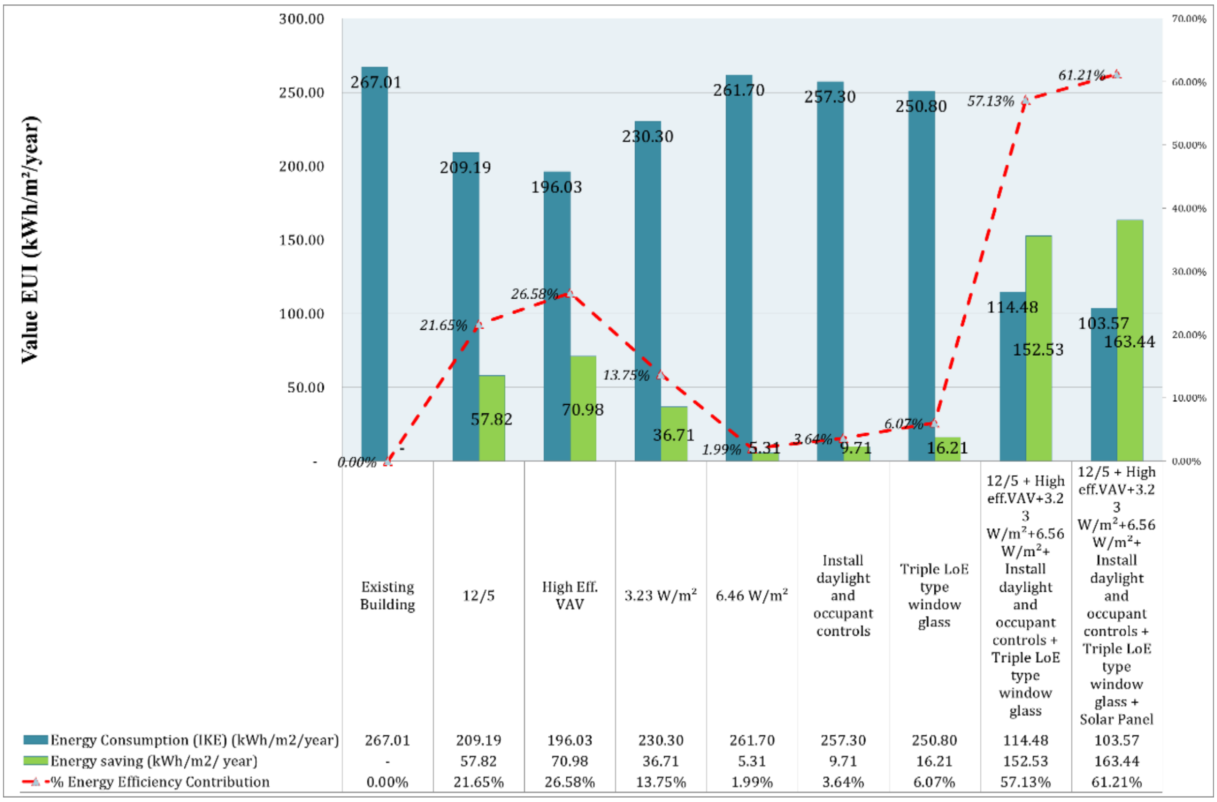


Figure 8. Energy Consumption based on different scenarios

Figure 8 shows a graph of the various improvement alternatives studied in the energy simulation, where a value of 61.21% is obtained from the result of dividing the EUI value of Scenario 8 by the EUI value of the existing building. Different scenarios were developed to find the most efficient scenarios as indicated by the lower EUI values. From a number of scenarios, it can be explained that for Scenario 1 the operating schedule is used 12/5, indicating that the building operates for 5 days per week spending an average of 12 hours. The second scenario consists of replacing the air conditioning system with a more efficient system using High VAV central air conditioning. The results showed that the EUI value and energy savings were 171.64 kWh/m^2/year and 27.38 kWh/m^2/year respectively. The third scenario used the most efficient lighting of 3.23W/m^2, using LED as an energy efficient lighting source, resulting in an EUI value of 230.30 kWh/m^2/year and energy saving of 42.02 kWh/m^2/year. The fourth scenario modified plug load efficiency resulting in an EUI value of about 261.70 kWh/m^2/year and 6.07 kWh/m^2/year in energy savings. The fifth scenario was developed using building lighting control and control systems which consists of controlling natural light and installing light sensors. It led to an EUI value of 257.30 kWh/m^2/year and energy savings of 11.11 kWh/m$^{2.}$/year. The full results can be seen in Table 4.

The seventh scenario combined 6 variables. The results obtained after implementing improvements in energy simulation are an EUI Value 114.48 kWh/m^2/year and 152.53 kWh/m^2/year in energy savings. The last scenario combined all variables as well as integrating the installation of solar panels with a surface area coverage of 90%, and with a type of panel 16% efficiency for 30 years. The results showed 103.57 kWh/m^2/year for an EUI value and 163.44 kWh/m^2/year for energy savings. There is a significant energy use reduction of 61.21% as compared to the existing building. Therefore, the 8th scenario was found to be the best scenario for achieving the targeted energy reduction. The best scenario for energy use reduction combined all possible conditions covering a 12/5 operation schedule, high efficiency VAV HVAC type, efficient lighting, efficient plug load, instalment of control equipment daylight and occupants, Triple LoE for window glass and solar panel instalment.

The use of BIM in energy analysis is very helpful for estimating the amount of energy consumed at the design stage, which can then be used as a preliminary design guiding construction. However, the major shortcoming is that the scenarios were developed based on features available in Revit software only, which should be adjusted with the typical local conditions in Indonesia. Nevertheless, the findings can be used as a guideline or a framework about the potential of BIM related to energy use in Indonesia.

5. Conclusions

This paper investigated the use of BIM software to perform a building energy analysis during the design stage to achieve sustainable development optimization. Revit and Green Building Studio (GBS) were used as cloud-based energy analysis programs that allow architects and designers to perform an entire building analysis, optimize energy consumption and work on a carbon neutral building design early in the process. Insight 360 analysis was used to identify the value of energy consumption (EUI) as well as the costs consumed in the building. Furthermore, the scenario analysis was carried out to find the most efficient EUI value (smallest EUI). It can be concluded that the best scenario for energy use reduction was shown by the last scenario (8^{th} scenario) by combining all possible options covering 12/5 operation schedule, high efficiency VAV HVAC type, efficient lighting, efficient plug load, installation of control equipment daylight and occupants, Triple LoE for window glass and solar panels instalment.

The use of BIM in energy analysis is very useful to measure the amount of energy consumed at the design stage. However, its shortcoming is that scenarios were developed based on variables available in Revit software only, which should be adjusted with the typical conditions of existing buildings in Indonesia. The findings can be used as a guideline about the potential of BIM related to energy use in Indonesia towards achieving sustainable construction. However, this research is limited to investigating the scenarios referring to the thermal resistance improvement of other components of the thermal envelope only. Further research should be elaborated in economic consideration for each scenario and carbon dioxide emissions quantifications.

Acknowledgments

The research of this article was funded by DIPA of Public Service Agency of Universitas Sriwijaya 2021. SP DIPA-023.17.2.677515/2021, on November 23, 2020. In accordance with the Rector's Decree Number: 0010/UN9/SK.LP2M.PT/2021, on April 28, 2021.

REFERENCES

[1] Cao, X., Dai, X., & Liu, J, "Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade," Energy and Buildings, 128, 198–213, 2016, doi:10.1016/j.enbuild.2016.06.089

[2] Kim, J. B., Jeong, W., Clayton, M. J., Haberl, J. S., & Yan, W, "Developing a physical BIM library for building thermal energy simulation," Automation in Construction, *50*(C), 16–28, 2015, https://doi.org/10.1016/j.autcon.2014.10.011

[3] Autodesk. https://www.autodesk.com/industry/aec/bim, 2020.

[4] Aljundi, K., Pinto, A., & Rodrigues, F, "Energy Analysis Using Cooperation Between BIM Tools (Revit and Green Building Studio) and Energy Plus, *1º Congresso Português de Building Information Modelling*, *1*, 309–319, 2016, https://doi.org/10.5281/zenodo.166758

[5] Hasan, R., Islam, S., & Akter, J, "Energy performance analysis of an office building," *Energy and Buildings*, *7*(3), 34–53, 2017, https://doi.org/http://dx.doi.org/10.1016/j.enbuild.2017.10.030

[6] Natephra, W., Motamedi, A., Yabuki, N., Fukuda, T., & Michikawa, T, "Building Envelope Thermal Performance Analysis using BIM-Based 4D Thermal Information Visualization," *ICCCBE2016*, *August*, 1539–1546, 2016.

[7] Venkataraman, A., & Kannan, .M Ramesh, "Whole Building Energy Analysis using BIM," *International Confrence of Advances in Civil Engineering*, *September*, 2013. https://www.researchgate.net/publication/281965883_Whole_Building_Energy_Analysis_using_BIM

[8] Oh, S., Y. Kim, Y., Park, C., and Kim, I, "Process-driven BIM-based optimal design using integration of energyplus, genetic algorithm, and pareto optimality," 12th conference of international building performance simulation association, Sydney, pp. 894-901, 2011.

[9] Bazjanac, V, "IFC BIM-based methodology for semi-automated building energy performance simulation," Lawrence Berkeley National Laboratory, 2008. Available at http://escholarship.org/uc/item/0m8238pj.

[10] Roz-Ud-Din Nassar, Eka Sediadi, Fathia Elmenghawi, "Sustainable, Energy Efficient and Economical Design of Single-Family Dwellings," Civil Engineering and Architecture, Vol. 9, No. 4, pp. 1048 - 1056, 2021. DOI: 10.13189/cea.2021.090407.

[11] Mojdeh Nikoofam, Abdollah Mobaraki, "Improving Passive Solar Housing Design to Achieve Energy Efficiency; Case Study: Famagusta, North Cyprus," Civil Engineering and Architecture, Vol. 9, No. 4, pp. 1064 - 1074, 2021. DOI: 10.13189/cea.2021.090409

[12] Yu, Z., Fung, B. C. M., Haghighat, F., Yoshino, H., & Morofsky, E, "A systematic procedure to study the influence of occupant behavior on building energy consumption," *Energy and Buildings*, *43*(6), 1409–1417, 2011. https://doi.org/10.1016/j.enbuild.2011.02.002

[13] Kim, H., Shen, Z., Kim, I., Kim, K., Stumpf, A., & Yu, J, "BIM IFC information mapping to building energy analysis (BEA) model with manually extended material information," *Automation in Construction*, *68*, 183–193, 2016. https://doi.org/10.1016/j.autcon.2016.04.002

[14] Smith, "BIM implementation - Global strategies," *Procedia Engineering*, *85*, 482–492, 2014. https://doi.org/10.1016/j.proeng.2014.10.575

[15] Sadeghifam, A. N., Meynagh, M. M., Tabatabaee, S., Mahdiyar, A., Memari, A., & Ismail, S, "Assessment of the building components in the energy efficient design of tropical residential buildings: An application of BIM and statistical Taguchi method." *Energy*, *188*, 116080, 2019. https://doi.org/10.1016/j.energy.2019.116080

[16] Shoubi, M. V., Shoubi, M. V., Bagchi, A., & Barough, A. S, "Reducing the operational energy demand in buildings

using building information modeling tools and sustainability approaches," *Ain Shams Engineering Journal*, *6*(1), 41–55, 2015. https://doi.org/10.1016/j.asej.2014.09.006

[17] Cheung, C. K., Fuller, R. J., & Luther, M. B, "Energy-efficient envelope design for high-rise apartments. Energy and Buildings," 37(1), 37–48, 2005. doi:10.1016/j.enbuild.2004.05.002

[18] Minister of Environment Life and Forestry Indonesia, "Long-term Strategy on Low Carbon and Climate Resilience 2050 (LTS-LCCR 2050)," *United Nations Climate Change*, 1–32, 2021. https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf

[19] Green Building Council Indonesia (GBCI). (2019). https://gbcindonesia.org/

[20] Pezeshki, Z., Soleimani, A., & Darabi, A, "Application of BEM and using BIM database for BEM: A review, "*Journal of Building Engineering*, *23*(May), 1–17, 2019. https://doi.org/10.1016/j.jobe.2019.01.021

[21] Marzouk, M., Azab, S., & Metawie, M, "BIM-based approach for optimizing life cycle costs of sustainable buildings," *Journal of Cleaner Production*, *188*, 217–226, 2018. https://doi.org/10.1016/j.jclepro.2018.03.280

[22] Liu, Z., Osmani, M., Demian, P., & Baldwin, A, "A BIM-aided construction waste minimization framework. *Automation in Construction*," *59*(2015), 1–23, 2015. https://doi.org/10.1016/j.autcon.2015.07.020

[23] USGBC. (2021). https://www.usgbc.org/articles/how-green-buildings-can-help-fight-climate-change

[24] https://www.autodesk.com/industry/aec/bim

[25] Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Pennington, D. W, " Life cycle assessment," Environment International, 30(5), 701–720, 2004. doi:10.1016/j.envint.2003.11.005

[26] Fang, Y., & Cho, S, "Design optimization of building geometry and fenestration for daylighting and energy performance," Solar Energy, 191, 7–18, 2019. doi:10.1016/j.solener.2019.08.039

[27] Touloupaki, E., & Theodosiou, T, "Performance simulation integrated in parametric 3D modeling as a method for early stage design optimization - A review," *Energies*, *10*(5), 2017. https://doi.org/10.3390/en10050637

[28] Mora, T. D., Righi, A., Peron, F., & Romagnoni, P, "Cost-Optimal measures for renovation of existing school buildings towards nZEB," Energy Procedia, 140, 288–302, 2017. doi:10.1016/j.egypro.2017.11.143

[29] Stumpf, A., & Kim, H, "Early Design Energy Analysis Using BIMs (Building Information Models)," *Technical Report, ERDC/CERL TR-11-41 (2011)*, *217*, 426-436, 2011. http://link.aip.org/link/?ASCECP/339/44/1

[30] Sadeghifam, A. N., Marsono, A. K., Kiani, I., Isikdag, U., Bavafa, A. A., & Tabatabaee, S, "Energy analysis of wall materials using building information modeling (BIM) of public buildings in the tropical climate countries," *Jurnal Teknologi*, *78*(10), 35–41, 2016. https://doi.org/10.11113/jt.v78.7591

[31] Fikar, M. Z., Kholid, M., Widiharto, A., Teknik, D., Fisika, T., Mada, U. G., Grafika, J., & Yogyakarta, S. D. I, "Electrical Energy Analysis on Buildings Integrated with Photovoltaic using BIM," National Proceeding Seminar in Electrical Engineering, 4(4), 60-63, 2019.

[32] Regulation of Indonesian Minister of Energy and Mineral Resources No. 13 (2012) (Permen ESDM No 13 Tahun 2012.