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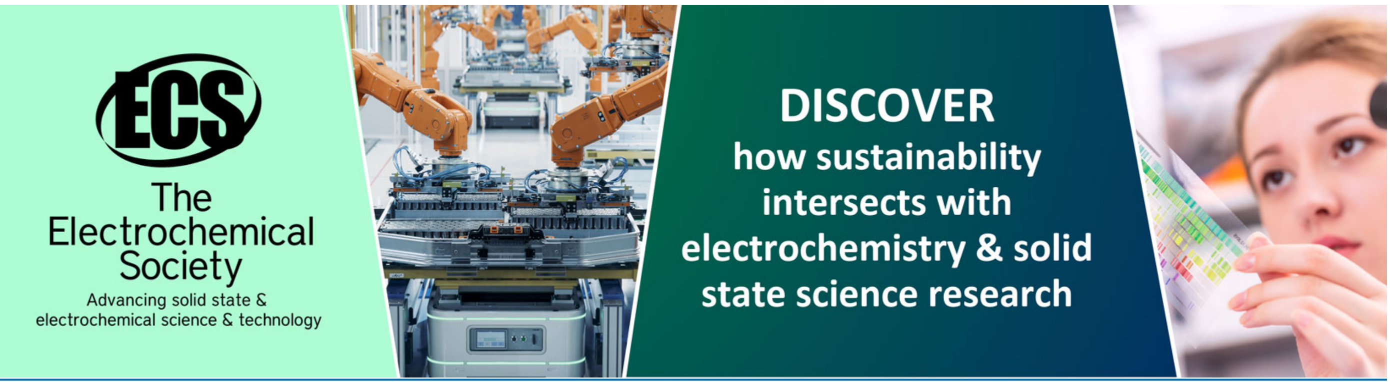

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Enhancing Building Energy Efficiency with Aluminum Composite Material Facade: A Performance Simulation Study using Building Energy Modeling and Building Information Modeling

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Abstract. Building facade is an integral piece to the overall design of a building, which not only ensures adequate interior thermal comfort, minimizing cooling load rate but also lowering overall building energy consumption. In recent years, aluminum composite material wall (ACM) is a new decorative material that is increasingly being used by developers, designers, and architects, which led to many innovative building facade designs. It is a straightforward and versatile product that provides a weather-resistant, sound-insulation, heat-insulation, earthquake-resistant, and shock-resistant façade that is simple to install. As a result, this study proposes a perfomance of energy simulation with ACM material applied in building design using Building Energy Modeling (BEM). Energy simulation in buildings using a Building Information Modeling (BIM) system is proposed to reduce the Energy Use Intensity (EUI) and energy cost of building in its construction process. The results of this study are expected to assist architects and building managers in improving and enhancing the energy efficiency of buildings. These significant findings demonstrate the potential of using ACM wall to improve building energy efficiency.

1. Introduction

Energy consumption in buildings is reported to be rapidly rising in urbanization and industrialization context. The construction industry consumes nearly 30% of the total energy used annually worldwide [1]. In the United States, commercial and residential buildings consume 40% of the total energy used, and in Europe, it accounts for 40% of total energy consumption and 36% of total CO_2 emissions [2]. In Vietnam, the total energy demand and CO_2 emissions from the housing construction sector are approximately 30% and 35% of the country's total, respectively [3]. Moreover, energy consumption in Vietnam is exceeding the supply capacity, leading to increasingly frequent energy shortages.

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Additionally, as most of Vietnam's energy sources are produced from coal and gas, increasing energy consumption will contribute to worsening climate change. Therefore, designing buildings for efficient and effective energy use is crucial in minimizing further increases in energy consumption and CO_2 emission [2].

In addition, the process of energy consumption in buildings has a direct and indirect impact on the lifespan of the structure [4]. Increasing energy efficiency in building construction is becoming a priority in the design criteria of a construction project [5]. Factors that affect the energy consumption model in a building include the type of structure, location and climate characteristics, building materials, and surface factors [6]. Establishing energy-efficient buildings requires interdisciplinary research in multiple stages of the project life cycle, specifically in the design, construction, and operation phases [7]. Currently, simulating and calculating energy models in buildings has been studied by experts through Building Information Modeling (BIM) [8]. Building Information Modeling (BIM) is a tool that has been widely used by experts to simulate and calculate energy models in buildings. BIM allows for a more accurate analysis of the energy consumption model in buildings by providing a three-dimensional representation of the building and its systems. This enables designers to identify potential energy-saving measures and optimize building performance before construction begins.

The use of BIM in construction management is currently an essential trend in the construction industry. Many research directions have been proposed by scientists around the world on how to use BIM, especially in the transition to 6D BIM, which incorporates Building Energy Models (BEM) to solve energy simulation problems for actual projects. 6D BIM is a development step that integrates energy parameters inside and outside the building. Architects often use 6D BIM to calculate energy indices, which can help optimize energy design for construction projects. Research on 6D BIM and building energy models still faces many limitations, both globally and in Vietnam [8].

In this study, the authors propose a research direction for simulating energy for a BIM 3D model of an office building in Hanoi city, Vietnam. Additionally, the research aims to simulate the energy consumption of the building and evaluate it based on architectural design factors and wall materials to choose the most appropriate solution. Particularly, the study also proposes analyzing and simulating a new type of wall (ACM wall) that is being used worldwide to evaluate and propose its use in Vietnam. With the results of the analysis, the study hopes to provide a basis for architects and managers to select the appropriate materials that meet the energy-saving needs of the building.

2. Literature review

2.1. Building Information Modeling (BIM)

Building Information Modeling (BIM) is a new technology that has emerged in the construction industry. This technology uses a three-dimensional (3D) model to create, analyze, and transmit information about a construction project [9]. BIM facilitates the exchange and sharing of project information by digitizing it. Design consultants and construction contractors can use BIM software to create a computer model of the construction project, which will closely resemble the actual project on the construction site. This enhances communication among team members throughout the project life cycle, reduces rework, manages risk, and enables more efficient maintenance and operation of the construction facility [10]. The 3D space model is linked to the project's information database and shows all spatial relationships, geometric information, dimensions, quantities, and materials of the project components [11].

BIM is a powerful tool that can be used to represent the entire life cycle of a construction project, from design and construction to operation and maintenance. By providing a shared 3D model of the project, BIM can help identify potential conflicts between team members earlier in the process and enable them to make any changes. BIM is closely related to project stakeholders, including architects, engineers, contractors, owners, and equipment managers, who all have access to the shared design models. This makes it easy to make changes to the project and ensures that all stakeholders are informed of any updates or modifications. With BIM, even small changes can be quickly updated and shared with all parties involved in the project [12].

2.2. Building Energy Modeling (BEM)

Today, most construction projects tend to simulate and evaluate energy consumption before construction in order to achieve energy-efficient and cost-effective buildings, especially for high-rise buildings. Initial energy simulation helps investors save costs in operation, reduce energy consumption in the building while still ensuring the necessary facilities inside the building [13]. Energy simulation allows predicting how much energy a building will consume using specialized software. In order to accurately quantify and validate design solutions with detailed data, one of the primary and crucial tools to support integrated design is Building Energy Modeling (BEM). BEM involves a comprehensive process of simulating the entire operation of a building, which includes all thermal data related to building materials, indoor spaces, human activities, lighting systems, equipment systems, and the entire HVAC system (Table 1). By utilizing this tool, designers can gain an in-depth understanding of the energy performance of a building and evaluate the impact of various design choices on energy efficiency [14]. This, in turn, allows for the identification and implementation of effective energy-saving strategies and the optimization of building performance. In short, BEM is an essential tool for any designer seeking to achieve high-performance building design and sustainability goals.

BEM is simulated under the input factors of the Building Information Modeling (BIM) model, along with weather conditions, construction location, surface materials, and HVAC systems to provide energy assessment values [15]. A BEM model combines BIM input factors with local weather information and uses physics equations to calculate heat loads, and energy system reactions to these heat loads, and provides energy usage indicators, as well as related indicators such as the comfort level of occupants and energy costs. Many different building energy modeling (BEM) tools are capable of importing data files from BIM to perform energy simulations, aiming at the criterion of energy-efficient buildings [16]. However, these tools still have various limitations and need to be properly selected for the most effective use for each construction phase and different design experts.

Table 1. Statistics research articles on BEM published in reputable international journals.

TT	Journal	2016	2017	2018	2019	2020	2021
1	Ain Shams Engineering Journal	0	1	0	1	2	3
2	Applied Energy	2	2	1	2	3	5
3	Archives of Computational Methods in Engineering	0	0	1	2	3	3
4	Automation in Construction	0	0	1	2	2	7
5	Building and Environment	0	1	1	1	2	4
6	Energy and Buildings	0	0	1	2	3	6
7	Energy	3	2	1	2	2	4
8	Journal of Architectural Engineering	1	0	1	0	1	2
9	Journal of Building Engineering	0	1	0	1	3	5
10	Journal of Building Performance Simulation	1	1	1	1	1	3

Simulation and prediction of energy consumption levels through BEM of buildings have become important in energy management, improving the efficiency of lighting systems, equipment, and HVAC systems, as well as the collaboration between utility managers and power providers (16). However, predicting energy consumption levels for buildings is often complicated and affected by factors such as weather conditions, building characteristics, building technical systems, and resident behavior. There are three widely used approaches to predict energy consumption levels in a building: physical modeling, statistical modeling, and combined modeling [1,17].

Many researchers have applied combined models in their studies. E. Elbeltagi and H. Wefki [18] used EnergyPlus software through the integrated DIVA tool in Rhino/Grasshopper software to generate energy consumption data in residential buildings in Egypt with many design parameters and then used ANN algorithm to build a model predicting the level of energy consumption in this building during the design phase. KW. Mui et al. [17] combined EP software and ANN algorithm to build a model predicting the annual cooling energy consumption for a residential building in Hong Kong. Y. Liu et al. [19] proposed an approach model using DB software combined with an RF algorithm to build a model predicting energy consumption for an educational building in China. B. Dong et al. [20] developed a combined model by integrating statistical methods and a physical model in predicting the energy of residential buildings. They also combined it with five different ML algorithms such as ANN, GPR (Gaussian process regression), SVR, GMM (Gaussian mixture model), and LS-SVR (Least Squares Support Vector Regression). Both studies showed that the accuracy of the prediction model was significantly high [1].

It is important to understand the significance of energy simulation in building design and construction. Energy simulation involves modeling and analyzing the energy usage and thermal performance of a building, which helps architects and engineers optimize their designs to reduce energy consumption and costs. Besides, the input data for energy simulation is very large, in other words, it consists of all the data related to the thermal and energy parameters of the building. These data are interdependent through physical thermal simulation algorithms, and these interactions are tracked and recorded in detailed spreadsheets and graphs. This is a complex and time-consuming calculation process, which can take several days for large projects. In return, the extracted data from energy simulation results are also extensive, including information about temperature, humidity, CO_2 concentration, solar heat gain, heat transfer through door walls, and electricity consumption of air conditioning systems in each occupied space. Therefore, energy simulation models for buildings are currently being developed and implemented on cloud-based databases and many software applications run on servers of large providers to reduce the scale of simulation machines and energy analysis time [21].

BEM based on design factors to create energy information models for buildings is becoming an increasingly popular research direction. There were over 553 research studies related to Building Energy Modeling (BEM) for energy simulation in buildings published worldwide in 2020 [22]. Building energy modeling based on design factors, such as geographic location, building materials, orientation, and window size, is a popular research direction in the field of BEM [23,24].

Overall, the use of BEM energy models in building design and construction is becoming increasingly widespread. It helps to reduce analysis time, provide reliable energy indices, and provide a basis for decisions by architects, engineers, and building managers. As a professional, it's important to keep up with the latest trends and developments in this field to stay competitive and make informed decisions in your work.

2.3. The architectural design factors affect the energy consumption of the building

Identifying the factors that affect the energy consumption of a building is a broad and important topic in designing energy-efficient buildings. With the initiation of BEM modeling, determining the design factors of a building plays a crucial role in the output of the model. Previous studies have shown that energy consumption in buildings can be influenced by weak factor groups such as weather conditions, building characteristics, building service systems, and characteristics of the occupants.

As part of the design factors of a construction project, designing the façade of a building is an extremely important task in the architectural design process, as it reflects the aesthetics and artistry of the construction project. Therefore, the necessity of a visual calculation method to find building materials that optimize the impact of solar energy on the building is a new trend that has received a lot of attention in the professional community [15].

The initial shape design of a building in urban areas is usually not flexible, so this mainly depends on the planning and architectural criteria allowed. The use of multiple different shape options to select the best shape for using energy is usually only applied to buildings located outside the city. Therefore, the focus will be on designing the exterior, the vertical façade of the building, and the materials of the walls and glass coverings [25]. In addition, designing the vertical façade of the building is a top factor related to the quality of the indoor environment of the building, but not only that, the vertical façade is also directly related to the capacity of the ventilation and air conditioning system and the investment cost for this system [26]. This is also why designing a proper vertical façade and its surface covering panels are decisive in the energy cost of the construction project [27].

Nowadays, designers are mostly paying no attention to the tools which can evaluate the impact of different materials such as the external wall system, on energy efficiency and flexibility in the overall facade design of the building. Most current simulation tools require complex manual processes with large computational workloads to achieve optimal design results. Many studies have discussed the limitations and integrated solutions for simulation into the construction design process [28,29]. Therefore, changing the surface design of the building and changing the cladding materials to minimize energy consumption in the building is a research direction that many scientists are interested in.

Although previous studies have made efforts to identify factors affecting energy consumption in buildings, there are still few studies inside and outside the country focusing on identifying factors in the design phase, an important stage of the project that can determine the success of the building in terms of energy-efficient use. Therefore, this study continues to inherit the factors from previous studies and uses simulation software to identify the important factors affecting the energy consumption of the project in the design phase, especially determining the influence of common types of walls in Vietnam on the selected project.

2.4. The impact of exterior walls on the energy consumption of the building

One of the important surface design factors of a building that is evaluated to have a significant impact on energy consumption in the building is the building's external walls. Proper design and selection of the exterior wall construction and its components are effective methods to save energy in the building [30,31]. In particular, according to Hosamo et al. [32], in the field of building surface design, the exterior wall plays a very important role in the heat transfer of the building, which greatly affects the energy consumption in the building. Many studies have also chosen the exterior wall as the object of analysis and optimization to reduce energy consumption in the building [33]. The exterior wall with insulation materials is considered an important part of the building surface that determines the energy consumption of the building. They protect the indoor space in suitable weather conditions and reduce large fluctuations in outside temperature. Therefore, exterior walls have been studied extensively in recent years to save energy consumption in buildings [34].

Especially with modern technology today, many types of exterior walls with multi-layered structures, including insulation layers, have been studied and proposed in the world [35]. Exterior wall types are evaluated with different materials, especially the variation of the construction layers of the building's external walls to aim for energy savings in the building [36]. In particular, many researchers not only analyze the impact of the wall material layers but also aim to optimize the thickness of the wall construction layers to aim for optimization in the energy use of the building. Some studies on composite walls related to energy can be listed in Table 2.

Table 2. Studies on the impact of composite walls on energy consumption in the building.

Topic	Content of studies	Citations
The thickness of composite walls	The determination of the optimal thickness of insulation materials in the building envelope and its impact on energy consumption	[30]

Topic	Content of studies	Citations
Optimizing the insulation layer of multi-layered walls	Analysis of the impact of insulation location in the external cladding wall and optimizing the thickness of the insulation layer toward energy-efficient use	[37]
Evaluation of multi-layered walls for a construction project	Evaluation and study of multi-layered walls and insulation walls for a real construction project in Ireland based on the government's energy-saving program	[36]
Optimizing the insulation layer of composite walls	Optimizing the insulation capacity of external walls of buildings in different climatic regions in Libya towards energy-efficient use	[38]
Optimizing the insulation layer of the exterior wall	Energy simulation and optimization of the insulation layer thickness of walls using energy management strategies	[39]

Based on current trends and research worldwide, it is evident that analyzing and optimizing the energy performance of building external walls is becoming increasingly important. In particular, optimizing the layers of the wall structure has attracted a lot of attention from scientists and has achieved certain achievements in energy research. However, analysis and optimization of wall types and layers remain largely underexplored in the context of Building Information Modeling (BIM) and Building Energy Modeling (BEM). Most of the research conducted to date has been carried out using software platforms such as Matlab or traditional mathematical methods. Numerous factors and barriers hinder the optimization process, leading to various difficulties [40]. Energy simulation to evaluate wall types and layers of materials will help designers and construction managers save time in material selection and optimize the structural layers. Therefore, in this study, the authors aim to develop an energy evaluation method by changing the wall type and wall structure layer through the BIM and BEM environment to increase energy efficiency in construction.

In the field of modern architectural design, there has been a shift away from ornate decoration towards a more minimalist and energy-efficient approach to building design. As a result, architects and designers have increasingly recognized the value of multi-layer walls made from metal composite materials, particularly those featuring aluminum metal panels. These walls, known as Aluminum Composite Material Walls (ACM Walls), offer superior durability, refined aesthetics, and excellent thermal insulation properties (Figure 1). They have become a popular design and construction trend for numerous projects in developed countries such as the US, Canada, and the UK.

Despite the many advantages of ACM walls, there remains a significant gap in our understanding of their performance in Building Energy Modeling (BEM) and Building Information Modeling (BIM) environments. Currently, limited studies and simulations are exploring the characteristics of these walls in BIM environments that can help to optimize energy evaluation processes for construction projects.

To address this issue, researchers have begun collecting data from real-time designs incorporating ACM walls, using it to construct models and declare parameters within BIM environments. These models are then fed into BEM simulations to evaluate energy performance and optimize the wall layers of the ACM walls. By conducting these evaluations, we can gain a more comprehensive understanding of the effectiveness of ACM walls in improving the energy efficiency and overall performance of modern building designs.

In this study, the author successfully simulates the energy consumption of a building using ACM walls and compare it with the use of other traditional walls in Vietnam, demonstrating the superior energy-saving performance of ACM walls. Through energy simulation and analysis, the study helps evaluate the changes in the level of energy consumption in buildings when using different types of walls, using the BIM-BEM platform. This allows designers and managers to make informed decisions during the design and operation of buildings.

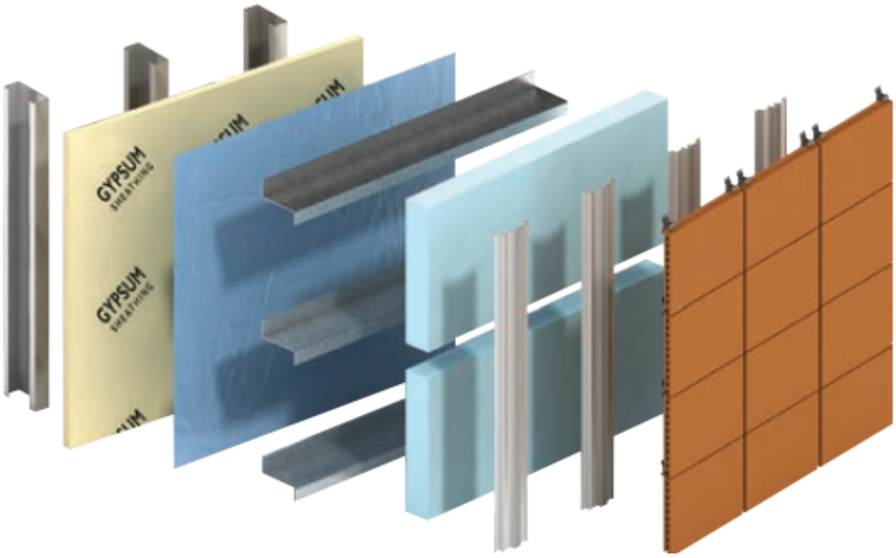

Figure 1. 3D model of multi-layered ACM wall

3. Methodology

3.1. Simulation and analysis tools

This study was carried out using various simulation and analysis tools, including Autodesk Revit software and two other energy modeling tools (Autodesk Insight and Green Building Studio-GBS). Based on the initial data collected, such as operating schedules, wall, roof, and window materials, and the percentage of open windows on different building facades, the author created an energy model in BIM. Through simulation on the Autodesk 360 cloud system, these tools proposed recommendations on the use of materials and designs to achieve the most energy-efficient results.

Autodesk is one of the pioneering software companies leading the development of BIM (Building Information Modeling) support applications. Among them, Autodesk Revit is a powerful software that greatly supports architects and engineers, built based on the BIM information modeling approach, allowing design experts to realize their ideas by approaching a coherent coordinated model with construction material and component data [41].

Autodesk Green Building Studio is a cloud-based energy analysis software that can help designers, architects, engineers, and energy analysts to perform quicker, iterative energy analysis on multiple building designs, optimizing energy performance through design proposals [42]. In addition, Autodesk Insight is a recently developed (2018) cloud-based energy analysis tool by Autodesk that can support users in performing concurrent energy analysis and optimizing energy efficiency during the design process in a visual and automated way. Optimizing building energy performance with the Insight tool is fast, reliable, and scalable for improving energy performance by creating energy models or alternatives based on the initial architectural model in Revit through analysis steps. The results of the performance optimization are visualized and provide early decision-making for energy-saving solutions for the building [43].

3.2. The indices related to energy consumption calculation

3.2.1. Energy Use Intensity (EUI). Buildings account for a considerable portion of energy consumption during their operational lifetime and are a significant contributor to carbon emissions, which directly affect global warming. Therefore, optimizing energy use intensity (EUI) and reducing energy costs through the application of building information modeling technology (BIM) is crucial for energy analysis. Several studies on EUI (kWh/m^2/year) have been conducted, and an energy rating certificate is required for all prospective home buyers or residents [44,45].

$$EUI = \frac{\sum Site\ Energy\ Use\ \left(\frac{kWh}{a}\right) - \sum Site\ Renewable\ Energy\ Generation\ \left(\frac{kWh}{a}\right)}{Modelled\ Floor\ area\ (m^2)} \tag{1}$$

The research objective is to propose a method for simulating energy while evaluating different measures in design to reduce energy consumption by changing wall types to achieve the best energy-efficient building model in terms of EUI and energy cost.

3.2.2. The Thermal transmittance (U-Value) and thermal resistance (R-Value). The U-Value (W/(m^{2}K)) and R-Value (m^{2}K/W) are important indices used in the energy simulation process. Any type of material used in a BIM environment for energy simulation requires the declaration of these two coefficients.

The U-Value (Thermal Transmittance) of a product refers to the amount of heat lost through the building components and is calculated based on the ratio of heat loss per square meter of material. When searching for products that perform better, the lower the U-Value, the better the product is at preventing heat loss. A lower U-Value means less heat is lost, preventing unwanted heat flow and heat loss.

$$U = \frac{1}{R} \tag{2}$$

The R-Value (Thermal Resistance) represents the thermal resistance of building components, where, unlike the U-Value, the higher the R-Value, the better the product performs, meaning it reduces heat loss (the higher the R-Value, the better the insulation). All factors of a building have defined R-Values, including walls, types of glass, roof, floor, and ceiling. Especially for multi-layer walls, there will be multiple R-Values for each layer of the wall, and these are calculated to provide the total R-Value for that multi-layer wall to serve the energy simulation process [35].

$$Ri = \frac{Di}{Ki} \tag{3}$$

With: Ri: the resistance value of the i-th layer of wall or material
Di: the thickness of the i-th layer material
K or Thermal Conductivity (W/mK): a physical quantity that characterizes the heat conduction ability of the material. Each type of material has a different K-value.

To achieve high efficiency in energy simulation, selecting and declaring the R-value and U-value for the main components of the project such as cladding walls, windows, floors, and roofs is crucial. For materials with multiple layers such as walls and roofs, detailed values for each layer need to be calculated to provide the most accurate U-value.[46].

3.3. The proposed framework

This study proposes a methodology for analyzing and simulating the energy performance of a building using a combined BIM-BEM platform (Figure 2). The goal is to provide architects, engineers, and building managers with an efficient and accurate tool for optimizing building energy use.

The proposed methodology involves four key steps. In step 1, the 3D model of the building is initialized using Autodesk Revit software. The construction is defined by key parameters such as the type of main structural materials, weather and construction location, HVAC system, glass type, building type, and operation time. In step 2, the 3D model is transformed into an energy model with flat surfaces and a closed space using supporting tools. The authors proceed to divide and adjust the spaces of the construction. Any gaps and cracks that appear need to be adjusted to avoid errors in the energy simulation in subsequent steps.

In step 3, Autodesk Insight supporting tools are used to simulate and upload energy data to Autodesk 360 cloud to run the analysis. The simulation results are displayed on the Insight interface, providing users with alternative design options to change the energy consumption level. Finally, in step 4, the authors propose changing different types of walls corresponding to various types of enclosing walls to achieve an appropriate EUI index for the needs of building designers and managers.

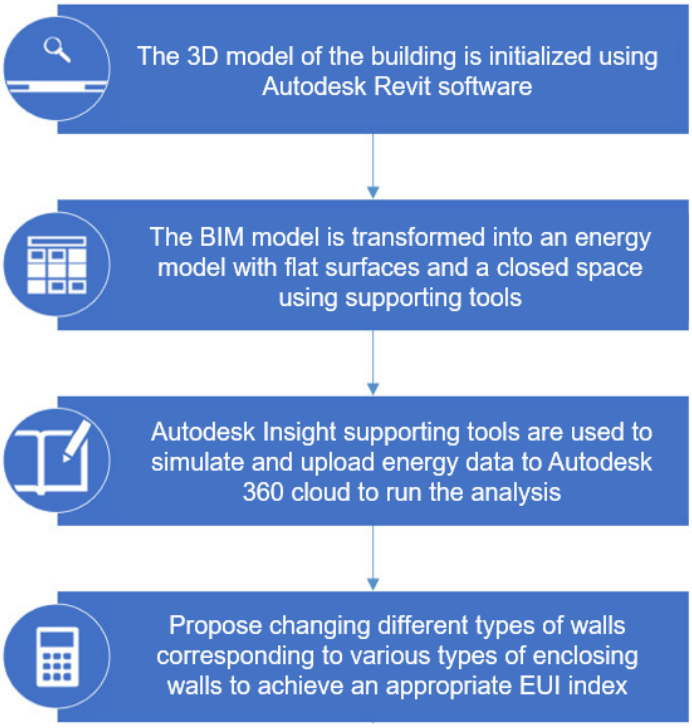

Figure 2. Flowchart of the energy performance using a combined BIM-BEM platform.

This methodology can be used to analyze and optimize the energy performance of buildings during the design phase, allowing designers to make informed decisions about the materials and systems used. Additionally, building managers can use this methodology to identify areas for energy efficiency improvements in existing buildings. Overall, the proposed methodology provides an efficient and effective tool for building professionals to optimize building energy performance.

4. The energy performance of Exterior Wall – Case study

The authors selected a real-life project to simulate in Hanoi, Vietnam. The construction is an office building for rent with a total floor area of approximately 3,075 m^2, situated on a plot of land with an area of 750 m^2 (Figure 3). The building comprises five above-ground floors with more than 70 functional rooms. This project was chosen as a representative example of the proposed methodology of analyzing and optimizing building energy performance using a combined BIM-BEM platform. By using this methodology, the authors aim to provide building professionals with an effective tool for reducing energy consumption and improving energy efficiency in real-life building projects.

The Building program is presented in Table 3. The 3D BIM model also includes important parameters such as geographic location, building orientation, HVAC system, and building materials. The analysis requires selecting a weather station closest to the simulated project. Therefore, the authors chose a weather station with the ID code: 633598, located about 2.1 km northwest of the center of Hanoi. According to the data provided by the weather station, the highest average maximum temperature occurs in June, while the lowest temperature occurs in December.

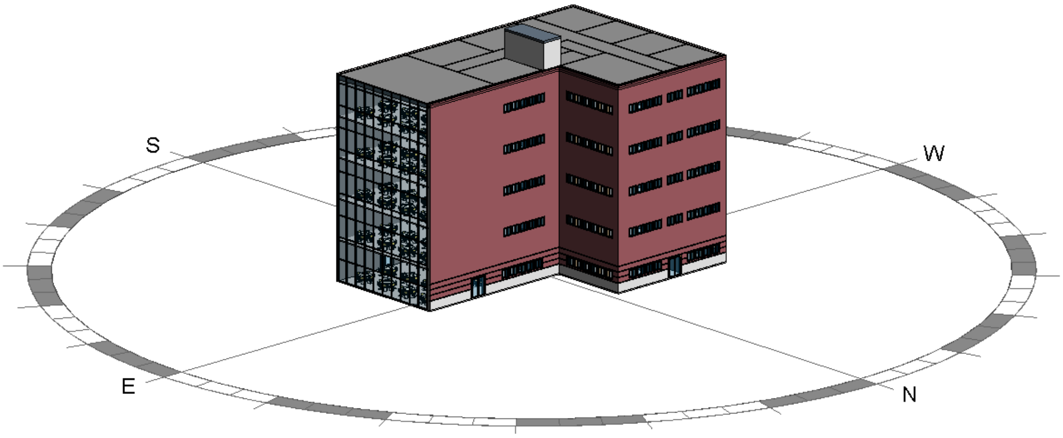

Figure 3. BIM model of buidling.

Table 3. Building program.

Attributes	**Values**
Project Type	Office - Enclosed
Location	Hanoi City, Vietnam
Total Floor area	3.075 m^2
Zones program	Office
Working hour	(8AM-5PM) 12h/6d/w
Num. of people per area	0.0565 ppl/m^2
HVAC	Central VAV, Chiller 5.96
Num. of people per area	0.0565 ppl/m^2

To carry out an analysis and simulation of energy consumption in a real construction project in Vietnam, the author proposes modifications to the types of external walls for the building (Figure 3.3). The input factors to be altered for the evaluation of Energy Use Intensity (EUI) values and energy usage costs of the project include the size, thickness, and U-Value of the wall types. Notably, introducing a new type of wall that is not yet available in the Building Information Modeling (BIM) environment to facilitate the energy simulation process, along with calculating the insulation parameters, constitutes a technical challenge and innovation in the research topic.

The study proposes to simulate four common types of walls in Vietnam and one new type of wall-Aluminum Composite Material (ACM). The author team collects information on the structural layers of the walls along with thermal conductivity data to serve the energy simulation process. The successful energy simulation of the new ACM wall type is expected to facilitate the wider application of this wall type in contemporary construction projects. While several studies have demonstrated the efficiency of the ACM wall type in energy conservation, there has yet to be a definitive comparative analysis of its effectiveness when compared with other types of walls commonly used in construction, especially those prevalent in Vietnam. This study aims to evaluate the energy of the construction project, but it does not consider the construction cost factor of the walls. However, the success of this study will provide the foundation for further research steps aimed at more specific evaluations of the energy-saving cost and material usage cost in construction. Consequently, the corresponding U-Value coefficient for each wall type is calculated to facilitate the energy simulation process. The R-Value and thickness values of the layers of the four wall types are presented in Table 4.

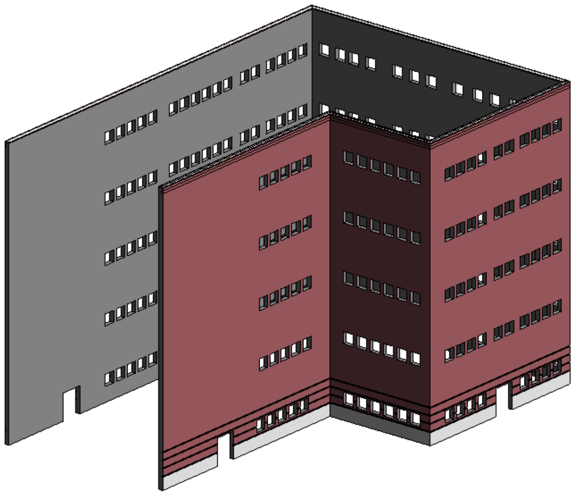

Figure 4. The building external wall of model.

Table 4. Material properties of the external walls in case study.

No.Layer	**Layer of wall**	**Thickness (mm)**	**Thermal Conductivity (W/(m.K))**
M1	**Hollow bricks wall (d= 220 mm)**		
M1.1	Cement masonry	0.015	0.93
M1.2	Hollow bricks	0.220	0.52
M1.3	Cement masonry	0.015	0.93
M2	**8 in concrete wall hollow**		
M2.1	Cement masonry	0.015	0,93
M2.2	Ground granulated blast furnace slag concrete	0.220	0.37
M2.3	Cement masonry	0.015	0.93
M3	**3D- Panel wall (180mm)**		
M3.1	Cement masonry	0.015	0,93
M3.2	3D cement panel	0.050	0.93
M3.3	Polystyrol thermal insulation layer	0.050	0.04
M3.4	3D cement panel	0.050	0.93
M3.5	Cement masonry	0.015	0.93
M4	**4 in heavyweight concrete block**		
M4.1	Heavy weight concrete	0.100	1.2
M4.2	Autoclaved aerated concrete	0.050	0.15
ACM	**ACM wall**		
ACM.1	Alumium Metal Panel	0.004	45
ACM.2	Air space	0.025	0.060
ACM.3	Rockwool insulation	0.058	0.034
ACM.4	Air Infiltration Barrier	0.001	0.060
ACM.5	Gypsum board	0.012	0.650
ACM.6	Comforbatt insulation	0.152	0.036
ACM.7	Air Infiltration Barrier	0.001	0.060
ACM.8	Gypsum Wall Board	0.127	0.650

However, the ACM wall type lacks sufficient data and models in the BIM environment. The author team resorted to the technical drawings of a sample project in the United States and the supplier's specifications to construct a 3D model and declare the material layers for the ACM wall type (Figure 5). This type of wall comprises eight basic layers of varying R-Values corresponding to different material types and thicknesses. Among the 8 wall layers, there are 2 insulation layers of considerable thickness included to enhance the insulation capacity of the ACM wall. During the actual construction process, manufacturers will modify the thickness of these 2 insulation layers to achieve the required U-Value standard as well as the construction cost. This is also the objective of the author's upcoming research into this ACM wall type.

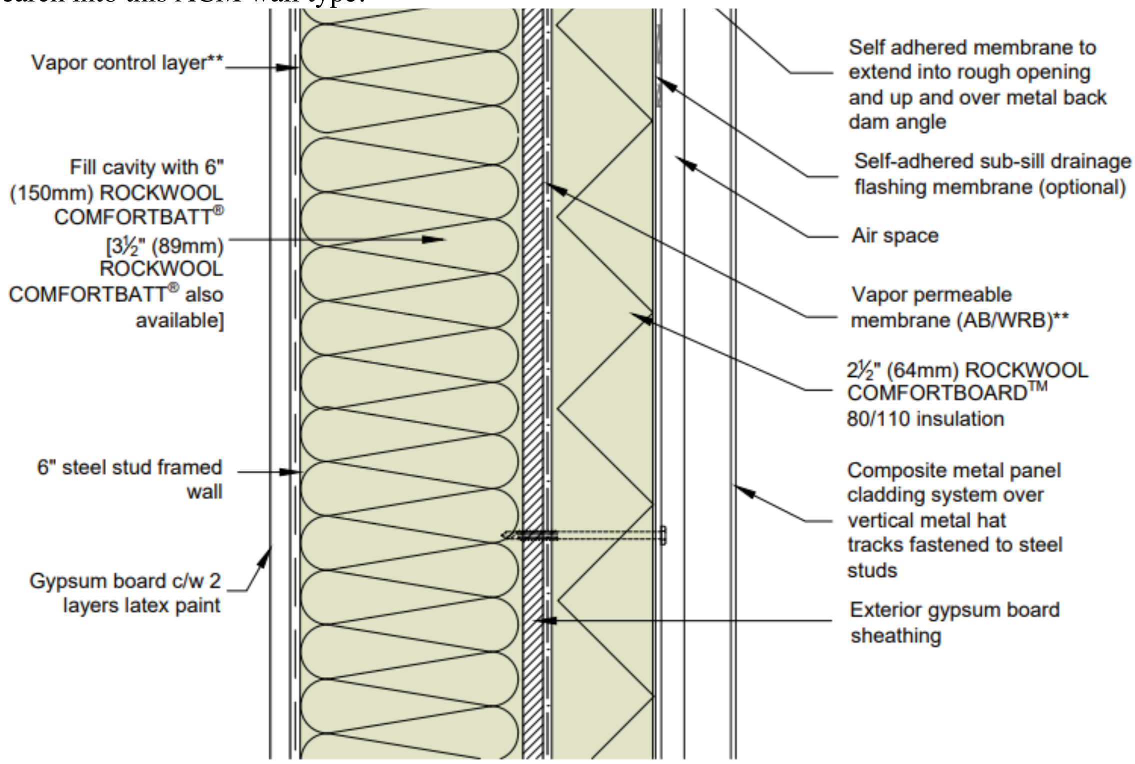

Figure 5. The layers of the ACM wall on a 2D cross-section drawing.

Notably, the ACM wall consists of several material layers and air layers, with each layer having a unique K-Value coefficient. The K-Value is an index that determines the R-Value of each material layer through its thickness index. Therefore, to accurately simulate the R-Value value for energy simulation, the wall layers of the ACM wall must be drawn precisely and data must be declared in the BIM environment.

The process of accurately modeling the ACM wall in the BIM environment poses a significant challenge, given the lack of data and models available. Nevertheless, the author team successfully created a 3D model of the ACM wall, taking into account the different material types and thicknesses of each layer (Figure 6). By doing so, they obtained accurate R-Value values for energy simulation, enabling a more precise evaluation of the energy consumption of the building.

After initializing the new ACM wall in the BIM model, the researchers conducted thorough calculations to determine the U-Value and R-Value of the ACM wall, which were found to be 0.1468 W/(m^2.K) and 6.8110 (m^2.K)/W, respectively. It should be noted that these values are subject to change as the sizes of the material layers are adjusted during the simulation process. Once the simulation is completed, the energy model will be transformed into the Building Energy Modeling (BEM) model format as gbXML and uploaded to the Autodesk Cloud (Figure 7). The parameters of the BEM model will serve as essential input data for both the Green Building Studio (GBS) and Autodesk Insight to continue the energy calculation process.

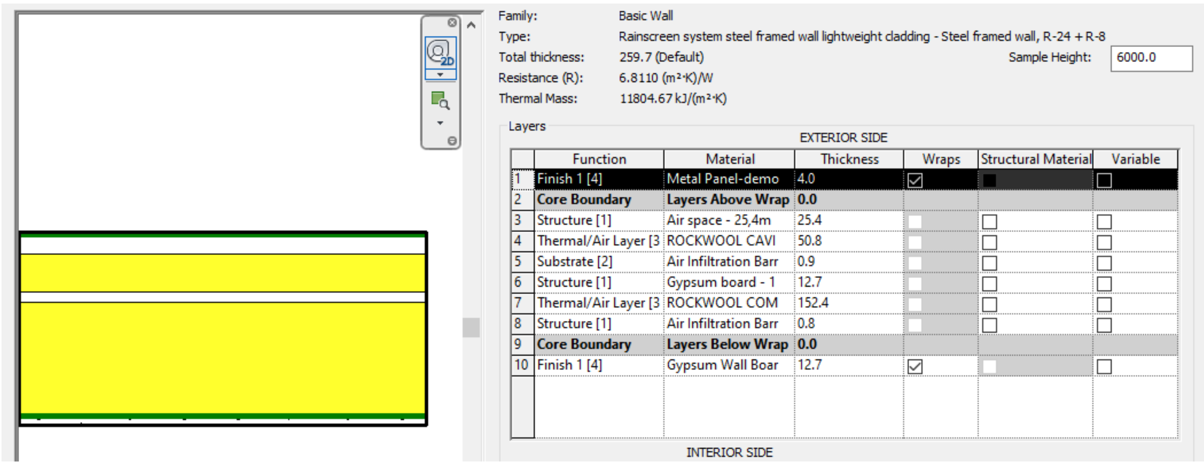

Figure 6. The initial parameters of ACM wall in BIM model.

With the available data for the 5 proposed wall types, the BEM model will generate corresponding energy simulation results along with the Energy Use Intensity (EUI) values and costs for each wall case. These findings are crucial for energy-efficient building design and will aid in making informed decisions regarding material selection and construction practices.

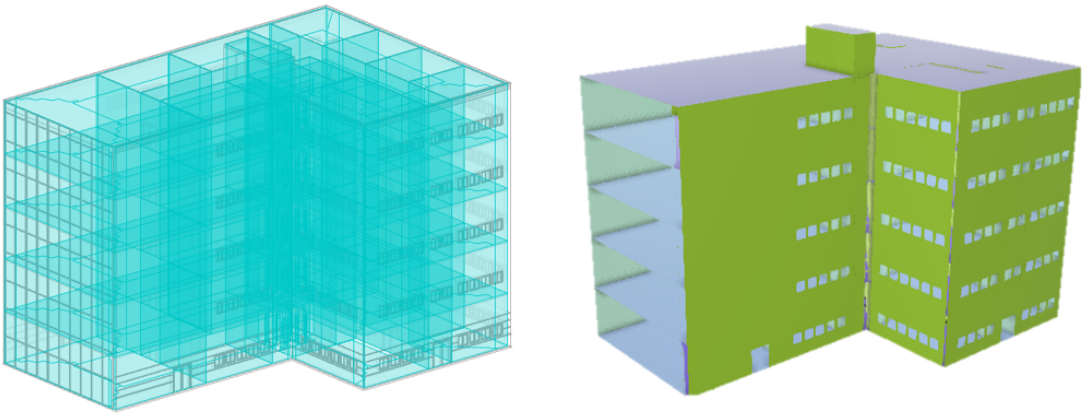

Figure 7. Conversion BIM model to BEM model.

However, the energy analysis model is created from the Room Bounding elements in the Revit model. The result is a simplified model consisting of surfaces similar to a SketchUp model. By selecting the surfaces and adjusting the display capability of the 3D Energy Model view mode, the designer can ensure that there are no anomalies before starting the simulation [43]. To obtain the most accurate energy simulation results, researchers must ensure that the surfaces are adjusted after the transformation process, to minimize the occurrence of gaps on the energy-intensive surfaces. These gaps can result in energy loss and leakage during simulation, and thus compromise the validity of the results (Figure 8).

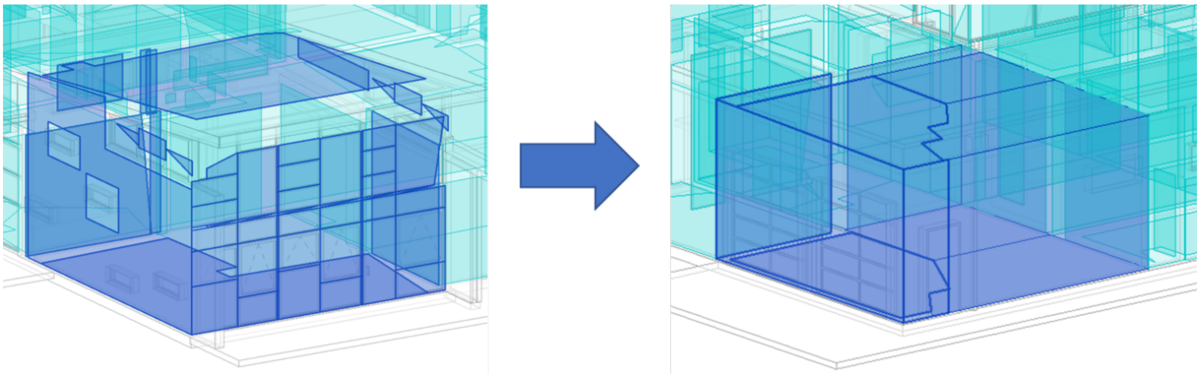

Figure 8. Adjusting the surfaces to minimize the occurrence of gaps on the energy-intensive surfaces.

In a BIM model, a non-enclosed room refers to a space that is not adequately surrounded by building elements. Such a room cannot be exported to a BEM model, which subsequently affects the building energy analysis. The default room-bounding elements in Revit include walls, roofs, floors, ceilings, columns, curtain systems, room separation lines, and building pads. Therefore, rooms must be appropriately defined in the BIM model by bounding elements, such as walls, floors, roofs, and ceilings, before converting it to a BEM model. Otherwise, rooms in the BIM model will be erroneously exported to BEM. To address this issue, users can set certain elements as either room-bounding or non-room-bounding depending on the situation. It is critical to accurately set the room-bounding elements, as Revit employs them to compute the area and volume of a room during the energy analysis.

During the process of declaring and configuring parameters before running energy simulations, researchers should limit the use of the "Use Conceptual Masses" feature, as it is no longer recommended for use. Instead, the "Use Conceptual Masses and Building Elements" or "Use Building Elements" options should be prioritized to ensure the most efficient simulation process. By employing a combination of both features, designers can complement each other and address any gaps or missing data in the declared material layers.

5. Results, analysis, and discussions

By utilizing the energy simulation process from the actual BIM model, the authors simulated different scenarios by changing the type of wall for each simulation run. Data regarding the HVAC system, building type, building structure, electricity consumption patterns, weather conditions, and envelope configuration were used as input data to initiate the energy model. The energy model simulated the calculated parameters on the Cloud and provided the necessary energy assessment index for designers and managers. With 5 simulation runs corresponding to 5 types of walls, the results were presented in Table 5.

Table 5. Results energy performance of the 5 case studies.

No.Wall	Type of wall	EUI (KWh/m^2/year)	Energy Save (%)
M1	Hollow bricks wall (d= 220 mm)	223	-2.8%
M2	8 in concrete wall hollow	217	0.0%
M3	3D- Panel wall (180mm)	184	15.2%
M4	4 in heavyweight concrete block	231	-6.5%
ACM	**ACM wall**	**149**	**31.3%**

Based on the findings, it can be observed that using ACM walls in construction yields very high energy-saving performance. Compared to the original model that uses M2 walls, the Energy Use Intensity (EUI) decreases by 68 kWh/m^2/year. In this case study, with a total floor area of 3,075m^2, proposing the use of ACM walls can save up to 209,000 kWh/year in energy consumption for the building. With the average electricity price currently at 0.08 USD ($)/kWh (03/2023), the total cost of energy consumption saved is estimated at around 16,720 USD ($)/year or 1,394 USD/month. This is a significant figure in the operating costs of a project when put into practical use. In the current trend of energy conservation and minimizing building operation costs, this is a highly effective method to consider in designing the building envelope in the early stages. Especially for large floor area buildings, the amount of EUI saved will be significant compared to the initial construction cost when analyzed over the project's life cycle.

Additionally, through simulation results, it can be seen that for conventional wall groups (M1, M2, and M4), the 8-inch concrete wall hollow is still the most energy-efficient type of wall. The M4 wall is a type of wall with a high U-Value coefficient, which in a tropical climate like Vietnam, can increase the building's energy consumption by 6.5% compared to the proposed original model. However, the advantage of these three types of walls is that their initial construction costs are low, the building materials are commonly available, and they are considered a simple construction technology suitable for small and medium-sized residential buildings in Vietnam.

Regarding multi-layer walls, the use of M3 walls (3D-Panel walls) has recently started in Vietnam. Compared to the original model's energy-saving performance, the M3 wall can save up to 15.2%. However, when compared to the ACM wall, it can be seen that the ACM wall saves 16.1% more energy than the M3 wall. Therefore, the use of ACM walls is highly valued in applying them to energy-efficient buildings. For projects with a long life cycle, the cost of energy savings may exceed the initial installation costs. This research direction is a recent development, and the authors intend to conduct further evaluations in subsequent studies to enhance its robustness and reliability.

According to the National Technical Regulation on Energy Efficiency Buildings in Vietnam (QCVN 09:2013) and the Energy Standard for Buildings Except Low-Rise Residential Buildings published by The American Society of Heating, Refrigerating and Air-Conditioning Engineers (SHRAE 90.1-2004), walls with an R-Value index of >0.56 m^2.K/W are considered to be energy-efficient construction. After comparing the results of the simulation and calculation, it was found that only M1, M2, M3, and ACM walls met the specified requirement. Among these, M3 and ACM walls had significantly higher R-Value coefficients compared to the standard requirement, indicating superior insulation performance. Further analysis will be conducted to determine the underlying factors contributing to the observed differences in R-Values among the various wall types.

Based on Figure 9, we observed that the EUI values vary when the U-Value of the walls changes. A smaller U-Value corresponds to a lower EUI value. The results indicate that the choice of external wall types has a significant impact on the EUI of the building. According to the energy, the model developed using Autodesk Insight, the EUI value for the building in this case study must be less than 210 kWh/m^2/year to comply with ASHRAE 90.1 and less than 60 kWh/m^2/year to comply with ARCHITECTURE 2023. Using ACM walls, the building achieved a EUI value of 149, which only meets the energy-saving standard of ASHRAE 90.1 but not ARCHITECTURE 2023. The utilization of virtual technology during the initial phases of the design process, as stipulated by the ARCHITECTURE 2030 challenge, has the potential to result in a significant reduction in energy consumption and facilitate the establishment of optimal energy patterns. The demands of the industry, the emphasis on the Construction 4.0 concept, the increasing digitization of the construction sector, and the requirements for environmental sustainability, such as the Green Deal, all underscore the criticality of addressing this research topic.

Therefore, to achieve all energy-saving standards worldwide, designers should pay attention to other components of the building, such as windows, roofs, window-to-wall ratios, building orientation, etc. It is difficult to achieve all energy-saving standards by only changing one factor, such as the external wall type. Regarding ACM walls, optimizing the insulation layers is considered a crucial objective in further enhancing the U-Value of the walls. The next research steps will focus on achieving this goal. Altering the thickness of the insulation layers will affect the U-Value, but it will also result in corresponding changes in the cost of construction and installation of the wall layers. Therefore, this represents a multi-objective optimization problem that the author will address in subsequent research studies

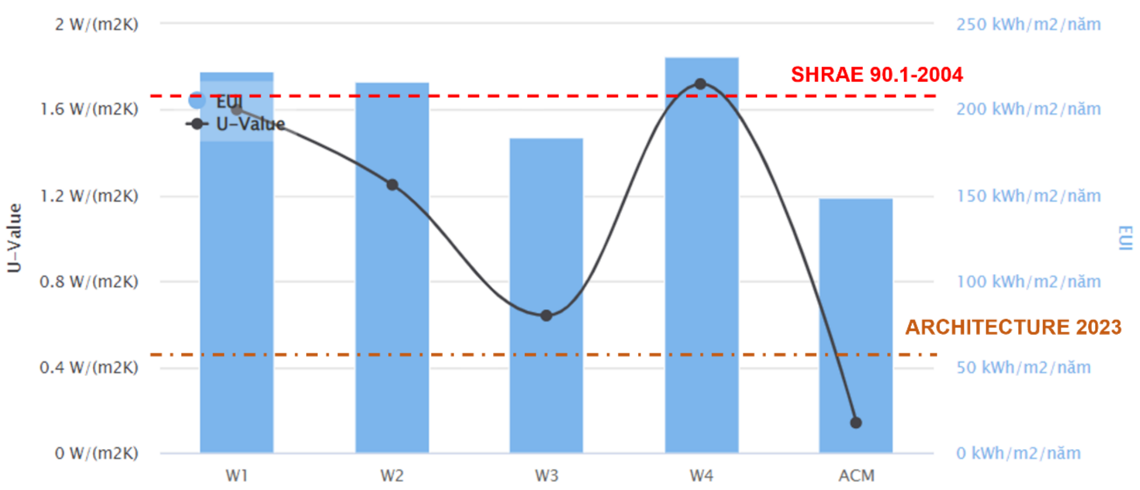

Figure 9. Comparison of results of the external walls in the case study.

The simulation of building energy performance using a BIM-BEM model with various materials, including new and commonly used ones, represents a novel area of research in Vietnam and worldwide. The results of this study provide valuable information for designers and managers who seek to make informed decisions about wall materials, including the innovative ACM wall, to promote energy-efficient building operations.

6. Conclusion

In this study, the authors proposed a simulation process for energy modeling using a 3D BIM model of a real project. The study successfully transformed an existing building into an energy model to determine the energy use intensity (EUI) of the building with different replacement scenarios. With the use of intuitive and user-friendly tools, this BIM-BEM simulation process is expected to serve as a platform for researchers to evaluate the energy performance of buildings during the initial design phase as well as after operation and occupancy.

Moreover, the research team successfully initiated and evaluated the energy performance of an Aluminum Composite Material (ACM) wall, which is commonly used worldwide. The BIM model results were used to analyze the energy performance and compare it with four common wall types in Vietnam. The ACM wall demonstrated superior energy savings compared to other wall types, and recommendations were made to designers and managers to optimize energy consumption in buildings.

The selection of spacing and thickness of layers in multi-layered walls, including ACM walls, significantly influences the U-Value and construction costs of a building. Although numerous studies have been conducted on optimizing material layers in multi-layered walls, none have employed the BIM-BEM method to simulate and run optimization algorithms for these materials. In the future, the use of BIM models in building construction will make the optimal selection process based on the BIM-BEM model for material layers or types more important. Subsequent research steps will utilize the BIM model of a specific building design to evaluate each case.

This study falls short in the selection of commonly used design parameters and their alternative materials. To address this limitation, the authors propose a novel approach that combines energy simulation modeling with machine learning optimization algorithms to automatically select variables and build a separate computational model.

In addition, the proposed model can be integrated with the LOTUS evaluation criteria, enabling designers to rapidly determine the score of Vietnam green building standards and meet investor requirements. The findings of this research will prove to be invaluable for both engineers and architects in designing, consulting, and evaluating a building's energy consumption and environmental impact.

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