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Research paper

Automated Derivation of Building Envelope Thermal Performance Based on BIM for Building Energy Analysis

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Abstract

Building envelope performance is an important factor used to calculate the energy loads required for heating and cooling buildings. Despite the large influence that building envelope thermal performance has over the energy consumption of buildings, thermal performance evaluations are often carried out using two-dimensional CAD drawings that require much time and effort. Recently, Building Information Modeling (BIM) has been used as a tool to enhance the efficiency of manually performed building information management practices. In addition, studies in the field of energy performance evaluations that have incorporated BIM have also been conducted. In this study, a method of automatically extracting information from BIM necessary for the derivation of building envelope performance was proposed. The first step of the proposed method was to classify parts that directly or indirectly made contact with the outdoor air. The second step was to classify the parts composing the envelope to appropriately reflect the standard used for the evaluation. Third, the thermal transmittance of each component composing the building envelope was calculated. Lastly, the area of each part was calculated. A case study was performed on a multi-residential unit to verify the accuracy of the proposed method. The verification results indicated that the proposed method was applicable in practice. Further research is planned to verify the performance of the proposed method with regard to its application to various standards and types of residential buildings.

Keywords: *Building Envelope; Building Information Modeling; Energy Analysis; Industrial Foundation Classes, Thermal Performance*

1. Introduction

Energy consumed by residential and commercial buildings constitutes 30%~40% of the total global consumption of energy [1]. Energy consumption for heating and cooling purposes constitutes 34% of the total energy consumption in residential buildings and 40% in commercial buildings [2]. In the case of countries in subarctic climates such as Russia, the proportion of energy consumption for heating is higher and constitutes approximately 59% of energy consumption in residential buildings [3,4]. Furthermore, the Intergovernmental Panel on Climate Change (IPCC) has predicted that energy demand for cooling and heating will sharply increase from their 2010 levels by 179% for residential use and 183% for commercial use by 2050 [5]. As is the case, not only does energy consumption for heating and cooling constitute the largest proportion of energy consumption in both residential and commercial buildings, but it also is expected to continually rise in the future. Thus, the optimization of energy consumption required to heat and cool buildings is an important factor that must be considered to lower energy consumption levels.

A building envelope is a key compositional element of a building and serves the role of physically separating the interior and exterior environments of a building [6-9]. From the standpoint of energy, building envelopes are defined as the insular components, which include the outer walls, roof, windows, and doors, as well as the foundation located in the outside area of a building [10,11]. Due to thermal exchanges that occur between the interior and exterior of a building through the envelope, thermal loss or thermal acquisition occurs at the envelope of a building during the heating or cooling of the building [12,13]. The International Energy Agency (IEA) considers building envelopes to be a key factor used to determine energy consumption for heating and cooling [2]. In actuality, almost half of all thermal loss in buildings that occurred in subarctic climates was found to be attributable to thermal loss through building envelopes [14]. Also, various studies have repeatedly shown that the thermal performance of the building envelope is closely related to the energy consumption of the building [15-18]. In light of this, ASHRAE reported that the improvement of the insular performance of building envelopes is needed to reduce thermal loss and acquisition that occur in buildings [19]. Considering this, building envelopes have been designed mainly in the direction of restricting the transfer of heat between the interior and exterior of a building [20]. Moreover, a number of countries have required the submission of calculations of envelope thermal performance in the design standards for environmentally friendly buildings. In the case of South Korea, the design standards for environmentally friendly buildings regarding the Building Energy Efficiency Rating System and the design standard for energy conserving environmentally friendly housing require building envelope thermal performance to be included as a criterion in the energy performance evaluation.

Despite the massive impact that the building envelope has on the energy consumed by buildings, derivations of the thermal performance of a building are often carried out manually using two-dimensional CAD drawings. To derive the thermal performance of an envelope, an evaluator must classify individual building components as either directly or indirectly making contact with the outdoor air. In doing so, the evaluator must determine the total area of a building exposed to the outdoor air upon individually verifying the areas of the windows, doors, walls, and floors of a building that have contact with the outdoor air by referencing the area from a two-dimensional CAD drawing of a building. Upon doing so, the part composing the envelope must be appropriately classified according to the standard in which it is to be evaluated. Due to differences in the definition of parts that compose an envelope according to the environmentally friendly building design standard used for derivations, a process of classifying the compositional part of an envelope in a manner appropriate to the concerned definition must be undertaken. Upon completing the process of classifying the parts that compose the envelope, the heat transmittance of each part must be calculated. To calculate heat transmittance, the thermal properties of the materials constituting the individual component must be known. In doing so, the evaluator must individually check the materials constituting a component as well as the thermal properties of the concerned material by referencing a two-dimensional CAD drawing. Lastly, the area of each part must be calculated. During the calculation of the area, the evaluator must manually calculate the areas that directly or indirectly make contact with the outdoor air based on a two-dimensional CAD drawing. As expected, this requires a substantial amount of time as all processes regarding the thermal performance evaluation must be undertaken manually and even repetitively if any design changes are required. In addition, due to the subjective input of the evaluator during the derivation process, the reliability of the derivation results is decreased. There is also an issue with respect to the accuracy of the derivation results, which may be significantly impacted by the experience and proficiency of the evaluator. Such challenges are expected to become more pronounced in the cases of the following events: the type of building to be evaluated becomes more varied, the number of buildings to be evaluated increases, or the building to be evaluated increases in size.

Recently, Building Information Modeling (BIM) has been utilized as a tool across all fields of construction to efficiently manage the building information that was manually undertaken in the past. Studies regarding the utilization of information extracted from BIM for the automation of various practices most representatively include studies on construction progress management [21-24], safety management [25,26], quality management [27], cost estimation [28-30], and evacuation regulation checking [31]. Following the introduction of BIM, multiple studies have been carried out to develop the means of automatically inputting property and geometric information extracted from BIM to energy simulation programs used to perform building energy performance evaluations [32-36]. This information can be extracted from the BIM and automatically entered into the simulation for the energy performance evaluation, which can reduce the re-entering time which takes a long time [37]. In addition, this can provide reliable information by preventing human error during the re-entering process [38]. As a result, studies are being performed to link BIM with energy performance related derivations using standard data schema such as Industry Foundation Classes (IFC) [39]. However, no studies have been performed to automate the entire process of evaluating the thermal performance of the building envelope.

The purpose of this study is to propose a method to automatically calculate the thermal performance of the envelope, which can be used for analyzing the energy performance of buildings based on BIM. In particular, a method that can be utilized in apartment houses among various buildings was sought. This paper is composed as follows. Chapter 2 reviews studies regarding the extraction of property and geometric information from BIM for energy performance evaluations. Chapter 3 proposes a method to automatically extract and calculate information related to the envelope thermal performance from the BIM. Chapter 4 verifies the accuracy of the proposed method based on a case study. Finally, Chapter 5 presents the results of the study along with future research directions.

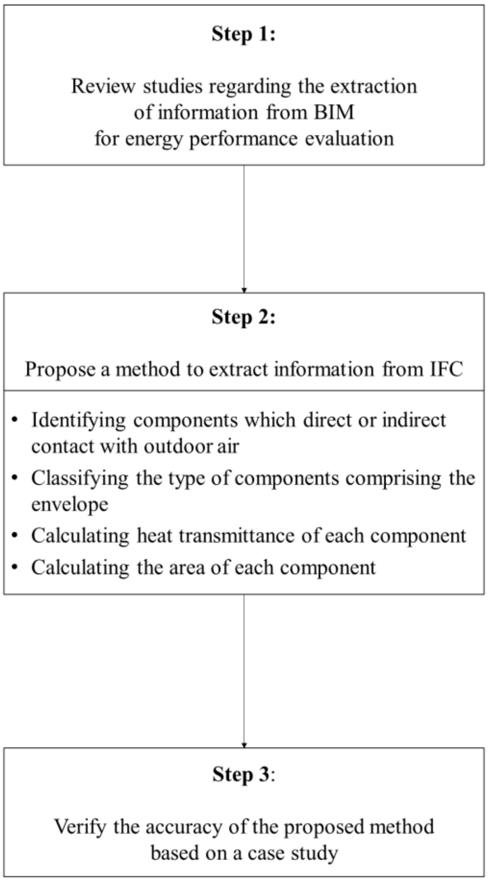


Fig. 1: Research process

2. Literature Review

The simulation program to evaluate the energy efficiency of a building requires the input of a number of variables by experts. The actual process of calculating and inputting the concerned variables requires a significant amount of time and money [32]. In particular, long durations of time are required to model the geometric information of the components that compose a building. In addition, expert knowledge and experience regarding the program of concern are required to undertake the simulations. In light of the expanded utilization of BIM design that includes building information due to such issues, BIM has become recognized as a tool to save time and money spent on performing energy performance evaluations of buildings [34]. This has resulted in the undertaking of various studies aimed at extracting information from BIM for the purpose of evaluating the energy efficiency of buildings.

Fazio et al. (2007) proposed a framework to extract necessary information from BIM to evaluate the thermal performance of a building envelope. To this end, a user interface used to extract geometric and material information from CAD drawings and IFC models was developed. The extracted information was then configured to be linked to programs, such as HOT200 and MOIST 3.0, used to evaluate the thermal performance of envelopes. A prototype system was developed using the proposed method, and the application of the system to BIM building thermal performance evaluation was proven possible through a case study.

Kim & Anderson (2013) proposed a method of extracting the geometric information of components composing a building from Industry Foundation Classes Extensible Markup Language (ifcXML) for use in DOE-2, a program used to run building energy simulations. The geometric information necessary to run energy simulations included story elevation, direction ratios, relative origin, depth, and location coordinates. In addition, a method of converting the geometric information extracted from ifcXML based on the proposed method for use in DOE-2 by converting the information into an INP file compatible with DOE-2 was proposed. Through the case study, the proposed method was verified as being capable of extracting geometric information from BIM as required by a building energy simulation program.

Ahn et al. (2014) proposed a method of extracting geometric and material information from BIM to be inputted as variables in EnergyPlus, another type of building energy simulation program. Both geometric and property information for the simulation were extracted from BIM and the extracted information was converted into an IDF file. Variables excluding geometric and material information were inputted upon being classified as default values or user-inputted values. Through the proposed method, it was possible to reduce the time required to input geometric information for the energy simulation.

Cheng and Das (2014) proposed a framework to extract necessary information from Green Building XML (gbXML) to perform environmentally friendly building energy simulations and code checks. To do so, information was extracted from BIM and the extracted information was created as a variable capable of being inputted into the code checker and building energy simulation. The proposed framework was applied to Service Oriented Architecture and the utilization of information extracted from BIM was proven to be possible.

Kim et al. (2016) proposed a method of extracting geometric and material information of the components composing a building from BIM to be utilized in a building energy simulation program known as DOE-2. The geometric information included location, space types/sizes, and thermal zones. The material information initially regarded only the extraction of the name of the material from the BIM. Thereafter, the name was matched to a pre-established material database to identify information on the material properties, including its conductivity, density, specific heat, and resistance. Through the proposed method, geometric information extracted from the BIM was converted to an INP file for use in DOE-2. Using the method proposed through the case study, the utilization of information extracted from BIM to perform building energy simulations was proven to be possible.

As indicated in the various studies above, the reduction of costs expended for the purpose of undertaking building energy performance evaluations by extracting geometric and material information from BIM was proven to be possible. However, only the information that was possible to be directly extracted from the BIM was used in the energy performance evaluations. In addition, studies regarding the extraction of information necessary for the entire process of undertaking the thermal performance evaluation of a building envelope are currently lacking.

Recently, Choi et al. (2018) proposed a framework for the automation of the thermal performance evaluation of building envelopes. The study not only summarized the challenges that may occur when applying BIM to the thermal performance evaluation of building envelopes, but also proposed a framework to overcome such challenges [40]. This study proposed a specific methodology based on the framework proposed from an existing study. In addition, upon implementing a case study based on an actual building, the performance of the methodology was verified.

Table 1: Literature review results

Reference	Extraction
Fazio et al. (2007)	Geometric and material information
Kim & Anderson (2013)	Geometric information
Ahn et al. (2014)	Geometric and material information
Cheng and Das (2014)	Geometric information
Kim et al. (2016)	Geometric and material information
Choi et al. (2018)	-

3. BIM based Automated Derivation Method of Envelope Thermal Performance

This study proposed a method based on BIM to automatically evaluate the thermal performance of a building envelope. The framework of the developed BIM-based automated envelope thermal performance evaluation method is presented in Figure 2. The method entails four stages that are necessary to evaluate the thermal performance of a building envelope.

First, the parts that directly or indirectly make contact with the outdoor air were classified. Generally, BIM for the energy performance evaluation of a building necessitates the input of the values ‘True’ or ‘False’ as the ‘IsExternal’ property value according to whether contact to the outdoor air exists [41]. However, for the thermal performance evaluation of an envelope, exposure to the outdoor air must be discerned. Specifically, the following must be determined: whether the exposure constitutes direct or indirect contact with the air and whether exposure exists. Considering this, a method of utilizing the relationship between the geometric information and the building component connected to the space was proposed.

Second, the part composing the envelope was classified in a manner appropriate to the standard used for derivations. The means of classifying the components that compose an envelope differ according to the standard used to evaluate the energy performance of a building. For example, some standards classify an envelope as side walls, outer walls, windows, front entrance doors, roof, and floors. Other standards classify an envelope as a wall, roof, floor, window, and door. In this study, a method of classifying the parts was proposed upon making note of the characteristic regarding the non-existence of openings in the side walls of the multi-residential building.

Third, the thermal transmittance of each component composing the building envelope was calculated. When developing designs using BIM writing tools, heat transmittance is automatically calculated according to the materials that constitute the component. However, the calculated heat transmittance value is a value that that does not consider interior surface thermal transfer resistance and exterior surface thermal transfer resistance (equation (1)). This study proposed a method of calculating heat transmittance of each component that considers interior and exterior surface thermal transfer resistance using a material name database.

$$U = \frac{1}{R_i + \sum R + \sum R_a + R_o} \tag{1}$$

U: heat transmittance in W/(K·m^2)
R_i: Interior surface thermal transfer resistance in (K·m^2)/W
R: Thermal resistance in (K·m^2)/W
R_a: Air gap resistance in (K·m^2)/W
R_o: Exterior surface thermal transfer resistance in (K·m^2)/W

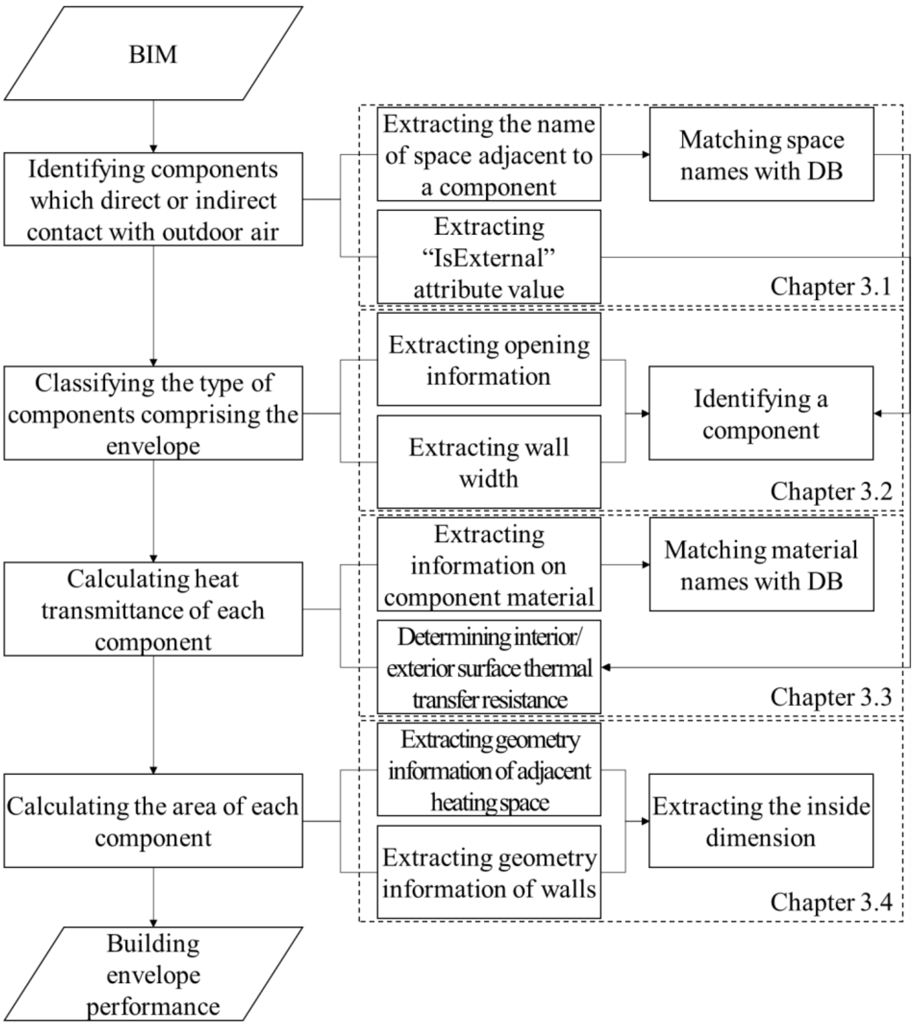


Fig. 2: BIM based framework for derivation of envelope thermal performance (adapted from Choi et al. 2018, © 2018GV School Publication)

Lastly, the area of each part was calculated. BIM includes centerline dimensions. However, due to the necessity of area measurements according to the inside dimension required in certain standards (Figure 3), this method proposed a method of area calculation based on inside dimension.

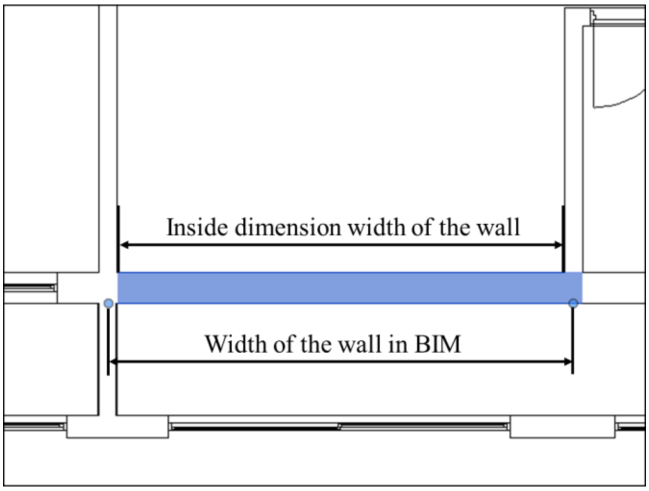


Fig. 3: Comparison of width of wall dimensions (adapted from Choi et al. 2018, © 2018GV School Publication)

3.1. Automated identification of each component contacts the outdoor indirectly

The components indirectly contacting the outdoor air are defined as those components that are adjacent to the non-heating space that do not directly contact the outdoor air. Consequently, the study proposes the use of information on space adjacent to the components that indirectly contact the outdoor air. Based on the BIM, indirect walls are classified as follows. Above all, objects comprising the envelope such as walls, windows, and doors are selected. When the selected object is window or door, information about the wall containing the window or door is extracted. Then, the names of all the spaces adjacent to the wall are extracted. Figure 4 shows an example of the process used to identify whether the components have indirect contact with the outdoor air based on the BIM. The walls including the window or door concerned can be identified with reference to IFCRelFillsElement, IfcOpeningElement, and IfcRelVoidsElement. Subsequently, the name of the space adjacent to the wall can be extracted with reference to IfcRelSpaceBoundary and IfcSpace related to the space.

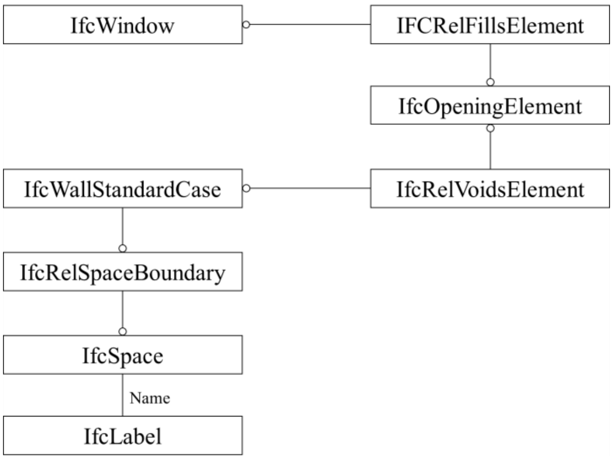


Fig. 4: Example of identifying indirect wall based on the BIM

After all the names of spaces adjacent to the wall have been extracted, the adjacent space is classified into a heating or non-heating space based on the space names. The heating or non-heating space is built as a database depending on the space names. For example, a living room and balcony are saved in the database as a heating space and a non-heating space, respectively. If a wall exists between the living room and the balcony, the wall is classified into heated and non-heated space adjacent. When the wall adjoins both the heating and non-heating space, window and door included in the wall and the wall are classified as objects that indirectly contact the outdoor air.

3.2. Automated classification of component type

A side wall is defined as the wall positioned at the side of the building that contacts the outdoor air directly or indirectly, with its length exceeding 4m. As the wall positioned at the side of a multi-residential building does not have an opening, the first criterion is the existence of openings. The existence of any openings can be verified by using the inverse order of that used to find a wall that has a window or door shown in Figure 4. If no opening is found on the wall with reference to IfcRelVoidsElement at IfcWallStandardCase, the wall is considered as not having an opening.

The second criterion is to identify whether a side wall is in direct or indirect contact with the outdoor air. If the attribute value of "IsExternal" based on the BIM is "True" among these walls, the wall is classified as a direct wall. Meanwhile, the method mentioned in 3.1 is applied to classify a wall as an indirect wall.

The third criterion to identify the wall as a side wall is to determine if the wall width is longer than 4m. To determine this, the value related to the width among the attributes of each wall is extracted. Finally, the wall without any opening and longer than 4m that is a direct wall or indirect wall is classified as a side wall. Any wall other than the side walls among the walls classified as direct or indirect walls is classified as an outer wall. Figure 5 shows the algorithm used to classify the side walls.

An exterior door is defined as a door that is positioned at the front of a building. Walls that have a door are identified first to find exterior doors and the information about the space adjoining the walls with the door is then extracted. When the extracted information identifies a space called ‘front’, the door installed on the wall of that space is classified as the exterior door.

3.3. Automated calculation of heat transmittance

Thermal resistance (which is used to calculate thermal transmittance) is calculated from the material thickness divided by the thermal conductivity. The list of the component materials is shown in IfcMaterialLayerSet while the thickness of each material is shown in IfcMaterialLayer (Figure 6). The thermal transmittance is found by matching the material list and the database. This thermal transmittance is then used to calculate the thermal resistance of the components. The method proposed in 3.1 above is applied to classify a wall as a direct wall or an indirect wall to select the exterior and interior surface thermal transfer resistance coefficient.

As the information about the window and door materials is not included in the IFC, the thermal resistance is calculated using the inverse number of the thermal transmittance. The interior surface thermal transfer resistance, the exterior surface thermal transfer resistance, and the heat resistance of the air layer are also taken into account for the calculation. For information on the thermal transmittance, the item referred to should be that with the attribute name of “Thermal Transmittance” (Figure 7). The interior surface thermal transfer resistance and the exterior surface thermal transfer resistance are determined from the direct and indirect object classification results.

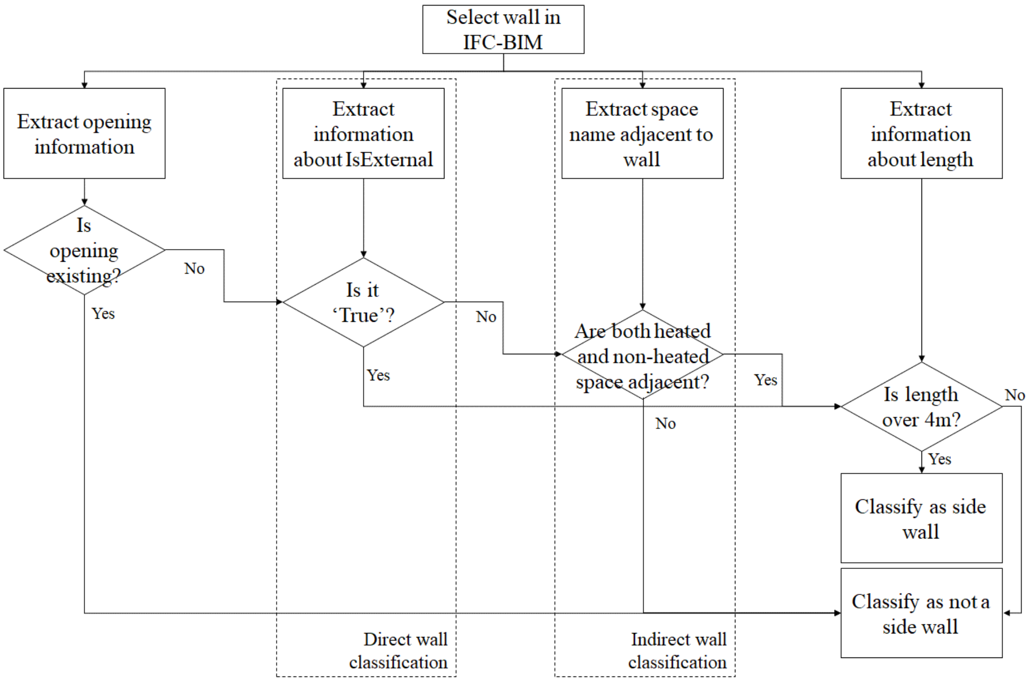


Fig. 5: Flowchart of the side wall classification

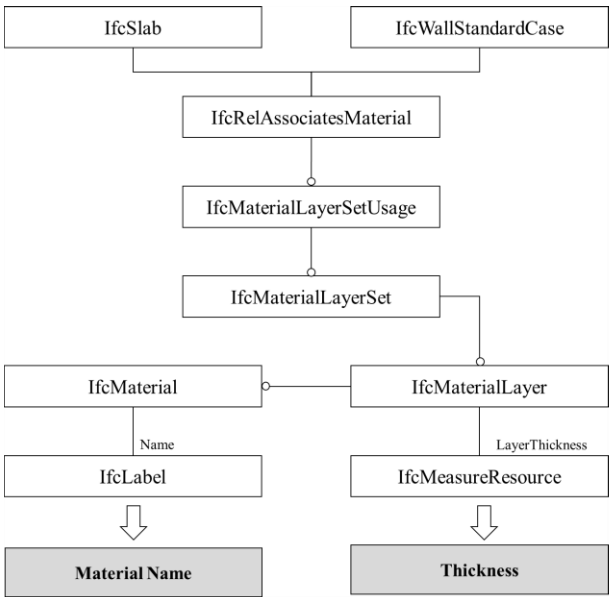


Fig. 6: Example of identifying material name and thickness based on the BIM

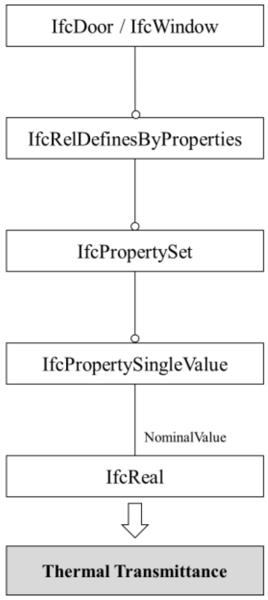


Fig. 7: Example of identifying thermal transmittance of door and window based on the BIM

3.4. Calculation of areas of each component

The thermal transmittance and area of each component are needed to calculate the average thermal transmittance. As previously discussed, in some standards, the area is calculated based on the inside dimension (the measured distance between the inner sides of two walls). As the slab area extracted by the BIM is the same as that based on the inside dimension, it can be used to calculate the average thermal transmittance. On the other hand, the roof area included in the IFC differs from the inside dimension-based roof area, since the IFC roof area includes the area contacting the wall. Considering a multi-residential building which has the same roof area and slab area, in this study, the roof area is replaced with the slab area (Figure 8).

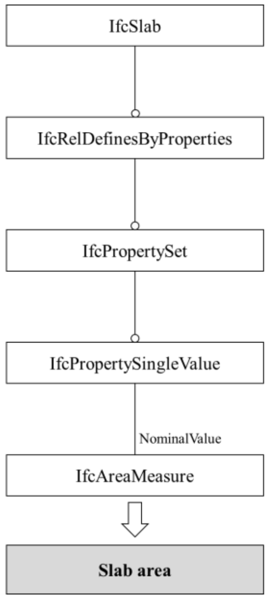


Fig. 8: Example of identifying slab area based on the BIM

The area of a wall is calculated from the inside dimension as follows. According to the definition of the inside dimension, the information on the geometry of the heating space is extracted among the space adjoining walls. Geometry of the heating space is used to determine the inner side of the walls that serve as the baseline to measure the dimension. The information on the geometry of the wall and space can be extracted with the IFC after the vertex coordinates of local coordinates are converted into world coordinates [42,43]. Figure 9 presents the example of identifying geometry of the wall based on the BIM.

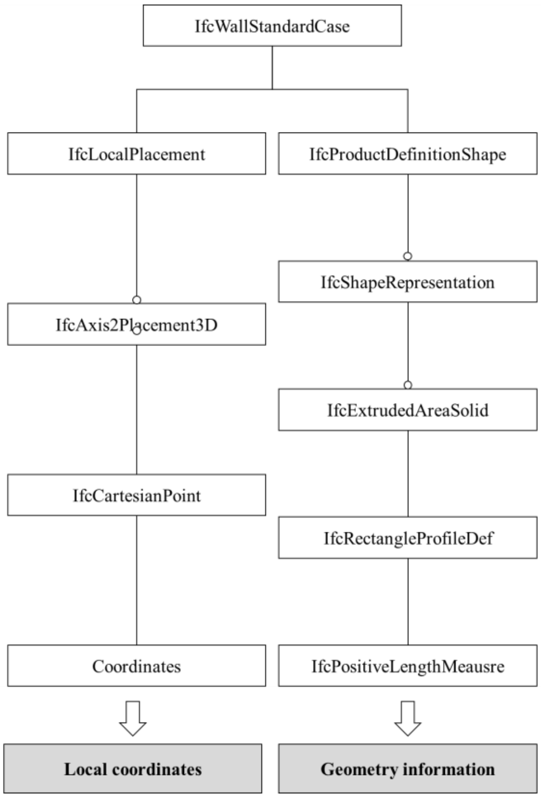


Fig. 9: Example of identifying geometry of the wall based on the BIM

Figure 10 presents the geometry of the wall and the heating space using the information included in the IFC. The red rectangle, blue line, and green cross represent the geometry of the wall, the geometry of heating space, and the vertexes that comprise the geometry of the space, respectively.

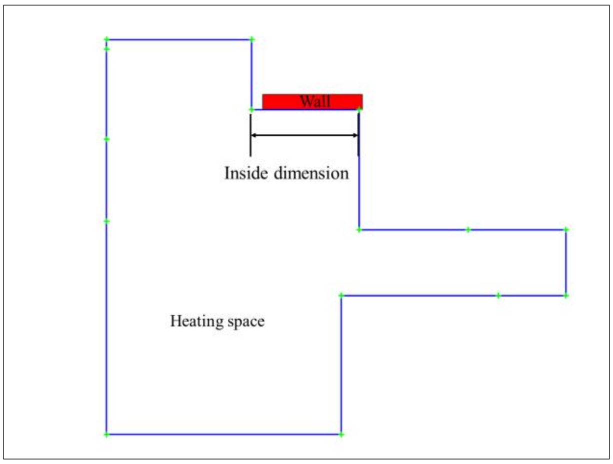


Fig. 10: Geometry of the wall and heating space

As shown in Figure 11, the inside dimension of the wall is the length of the side that includes the overlapping side between the wall and the heating space among the sides constituting the heating space. Therefore, in the study, the vertex coordinates of the walls are used as the criteria to extract the vertexes that determine the inside dimension among the vertexes comprising the heating space. Accordingly, the vertex coordinates of the walls and heating space are extracted. Then, the vertexes that equal the X coordinate or Y coordinate of the vertexes consisting of the wall among those comprising the heating space are identified. Lastly, the distance between the found vertexes is calculated as the inside dimension. When the wall width calculated with the inside dimension through the proposed method is multiplied by the ceiling height, the wall area can be calculated based on the inside dimension.

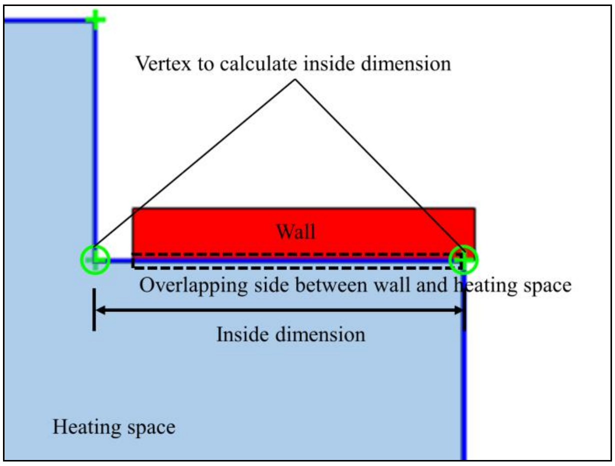
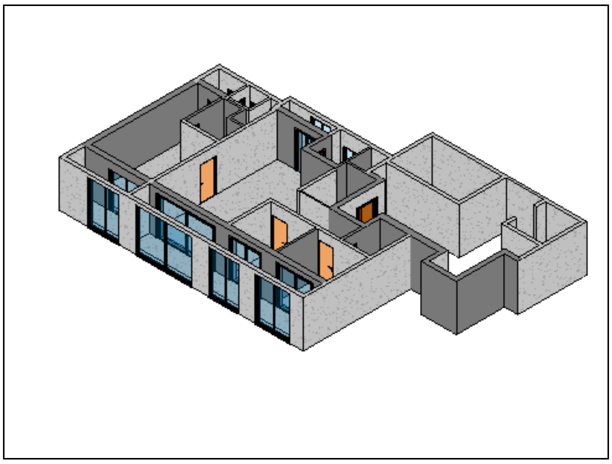


Fig. 11: Calculation of the inside dimension of the wall

4. Case study

A case study was carried out on the evaluation process of the design standard for energy saving eco-friendly houses to verify the proposed method. The household for the case study includes three rooms, a living room, and a balcony. This household was actually built and the building Information model was constructed with the same drawings. Thus, it is suitable for the performance of the standard and type of residential buildings.

Information on a house unit of a multi-residential building was extracted and converted. In addition, to verify the system accuracy, the result of automated calculation was compared with the result of a manual calculation. The result includes classification of the components that directly or indirectly contact the outdoor air, classification of the component type, calculation of each component's thermal transmittance, and calculation of the area of each component. As different components were calculated according to different unit types, a house unit in the lower part of the building was selected. Figure 12 illustrates the building information model for the case study. The lower side house unit requires derivation of the envelope thermal performance for the side wall, outer wall, windows and doors, exterior door, and slab.



(a) Bird's-eye view

(b) Floor plan

Fig. 12: Building information model for case study

Table 2 compares the results of classifying the components that contact the outdoor air both directly and indirectly under the existing manual method and proposed method. As the subject is a lower side house unit, the table shows one side wall. It is also verified that the result of the manual method for the outer wall, windows and doors, exterior door, and slab matches that of the proposed method.

Comparing the total number of the classified components shows that the same number of objects (side wall, outer wall, windows and doors, exterior door, and slab) is classified. This suggests that the proposed method allows the exact classification of the components that directly and indirectly contact the outdoor air as well as the classification of the component types comprising the envelope to meet the standard (Table 4).

Table 2: Comparing the manual and proposed method to classify the components that directly and indirectly contact the outdoor air

Type	Manual		Proposed Method	
	# of direct	# of indirect	# of direct	# of indirect
Side wall	1	0	1	0
Outer wall	0	14	0	14
Windows & doors	1	6	1	6
Exterior door	0	1	0	1
Slab	0	14	0	14

Table 3: Comparing the manual and proposed methods to calculate thermal transmittance and area of each component type

Type	Manual		Proposed Method	
	U(W/m^{2}K)	A(m^2)	U(W/m^{2}K)	A(m^2)
Side wall	0.352	15.477	0.352	15.477
Outer wall	0.502	40.557	0.503	40.545
Windows & doors	3.739	28.011	3.739	28.011
Exterior door	3.702	2.310	3.702	2.310
Slab	2.770	106.489	2.770	106.490

Table 4: Accuracy of the proposed method to classify the components that directly and indirectly contact the outdoor air

Type	Accuracy
Side wall	100 %
Outer wall	100 %
Windows & doors	100 %
Exterior door	100 %
Slab	100 %

Table 3 compares the calculation of the average thermal transmittance and area of each test component using the existing manual method with the automated calculation of the thermal transmittance and area using the proposed method. The error for the outer wall area is 0.012m^2, while the results of the other components types are the same or show an error of 0.001 W/m^{2}K; the difference is considered to have occurred from rounding. When the proposed method is applied, the envelope thermal performance can be evaluated automatically. In addition, the results show that the proposed method is applicable for actual works, given that the maximum error is 0.012m^2 (Table 5).

Table 5: Error of the proposed method to calculate thermal transmittance and area of each component type

Type	Absolute error	
	U(W/m^{2}K)	A(m^2)
Side wall	0.000	0.000
Outer wall	0.001	0.012
Windows & doors	0.000	0.000
Exterior door	0.000	0.000
Slab	0.000	0.001

5. Conclusion

This study proposed a method to automatically calculate the thermal performance of the envelope from BIM for building energy analysis. For this purpose, the challenge was analyzed when calculating the thermal performance of the envelope using BIM, and a method to solve the corresponding challenge was proposed. A case study was performed on the apartment house household to verify the proposed method. The main results of the study are as follows.

(1) When the BIM is implemented to calculate the envelope thermal performance, an automated method is needed that classifies each component according to whether it is directly or indirectly in contact with the outdoor air. In the study, the information on the space adjacent to the components that indirectly contact the outdoor air is used to classify these components. By applying the proposed method, it was possible to determine whether each component directly or indirectly contacts the outdoor air.

(2) Classification of the components type comprising the envelope varies depending on the different standards for building energy analysis. Thus, a method is needed that classifies the envelope components according to the evaluation standard. The study proposed the method to classify the wall into the side wall and outer wall. Also, the proposed method can identify the exterior door among doors with the performance evaluation on the eco-friendly house as an example. The proposed method enabled precise classification of the walls into side walls and outer walls as well as the identification of exterior doors and non-exterior doors.

(3) The thermal transmittance included in the BIM is inappropriate for building energy analysis. Therefore, the thermal transmittance for each component needs to be calculated for building energy analysis. In this study, the material names of the components were extracted from the BIM to consider the indoor surface thermal transfer resistance and the outdoor surface thermal transfer resistance. Furthermore, the thermal transmittance was calculated by considering whether the components were in direct or indirect contact with the outdoor air. Consequently, the thermal transmittance appropriate for building energy analysis could be calculated.

(4) The problem caused by the use of different standards of calculating the component areas should be addressed. For calculating areas, BIM uses the wall centerline dimensions. However, some building energy analysis standards require that the area is measured based on the inside dimension. In this study, the area of the components was calculated according to the inside dimension by using the information about the heating space adjacent to wall based on the BIM. With the proposed method, the area based on the inside dimension could be calculated using the BIM.

The method proposed in this study can increase the productivity of building energy analysis because it can automatically calculate the thermal performance of the building envelope. In addition, it is possible to improve the response of the derivation work by reducing repeated tasks that may occur during changes in design. In addition, it can secure the reliability of the envelope thermal performance calculation results, because the information contained in the BIM is used to evaluate in an objective method, while the subjective judgment of the operator is not included.

The limitations and ways to improve this study are as follows. First, to verify the method proposed in this study, a case study was performed based on the calculation of envelope performance of an energy-saving eco-friendly house among the various systems implemented in the country. Therefore, it is necessary to verify the applicability of not only a specific system but also various national standards and certification systems in the future. Second, a case study was undertaken on only one household to verify the accuracy of the proposed method. In the future, it is planned to verify the proposed method for various household types.

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