

Article

A Study on the LEED Energy Simulation Process Using BIM

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Abstract: In the domestic and international environmentally friendly certification system, energy-related credit occupies a high ratio in the total distribution of certification score. Leadership in the Energy and Environmental Design (LEED) system is a certification system developed by the US Green Building Council (USGBC) in order to assess the environmental friendliness of buildings. The energy-related credit is approximately 30% of the total and also the energy simulation ratio specifically is the highest among the single credits as it is 20%. In this research, the energy simulation process using Building Information Modeling (BIM) based on the energy simulation case performed at the A-Tower, LEED certification was proposed. It places an emphasis on the verification process which was short in the previous research. The architectural geometry modeled through the BIM tool is converted to the gbXML, and in this process the geometry is verified through the interference check functions, the gbXML Viewer and the FZKViewer. The energy simulation is performed after the verification procedure. The geometry verification process in the A-Tower project is presented throughout this paper. In conclusion, an improved process is proposed for the productivity and reliability of energy simulation.

Keywords: Building Information Modeling (BIM); building energy simulation process; Leadership in Energy and Environmental Design (LEED); green building XML (gbXML)

1. Introduction

“Green Building” and “Energy Consumption Reduction” have become the major challenges of the whole building industry. In particular, the energy consumption from the building sector by countries is 45% in the US and 42% in the UK, while the average of 31% is accounted for in Organization for Economic Cooperation and Development (OECD) countries in comparison with the total energy consumption of the entire industry. In Korea, however, the energy consumption of the building sector is 24.5% compared with the industry total [1]. Energy consumption for buildings in Korea does not reach the average consumption of OECD countries. However, following the interests and demand for comfortable indoor environmental quality depending on higher income level, the energy demand of the building sector is expected to sharply rise. Therefore, it is very important to achieve the challenges of a “Green Building” and “Energy Consumption Reduction” within the building sector. In spite of the increase of building energy demands, the Kyoto Protocol enforces nations to reduce carbon dioxide emissions to 26.69% or below compared to 2006 through the reduction of the buildings’ energy consumption. The general interests for buildings’ energy consumption reduction have been spread throughout the globe. It can be found to cause many challenges in several countries; the United Kingdom has targeted building new homes with zero energy by 2016, Germany aims to build

all new construction as passive houses after 2015, France has set a target to achieve a reduction of 38% for house energy consumption by 2020, Denmark has planned to reduce 50% of all buildings' energy consumption by 2015 compared to 2006, and the United States have proposed to build carbon-neutral buildings by 2030 [1].

As a regulatory method to reduce buildings' energy consumption, numerous domestic and international green building certification programs are made and already in operation. Green Standard for Energy & Environmental Design (G-SEED) in Korea, Leadership in the Energy and Environmental Design (LEED) in the US, Building Research Establishment Environmental Assessment Method (BREEAM) in the UK, Green Star in Australia, and Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan are all representative examples. Most of the building certification programs have requested to implement a building energy simulation in order to evaluate the buildings' energy performance.

The traditional method for energy simulation is either to input architectural information by using numerical data or to make a two-dimensional model using an integrated user interface in the simulation software. The traditional modeling method is more of a disadvantage as it consumes a lot of time and effort to actually put the architectural information into the energy simulation software. However, introducing the Building Information Modeling (BIM) had enabled the three-dimensional model, and therefore the actual time needed to model the architectural geometries is dramatically reduced.

The National Institute of Building Science (NBIS) defines BIM as "a computable representation of the physical and functional characteristics of a facility and its related project/life-cycle information using open industry standards to inform business decision making for realizing better value." Building Information Modeling is the development and use of a multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. One of the fields which makes use of such BIM information is the analysis for the performance of buildings.

BIM data is able to be integrated with building performance simulation programs such as Green Building Studio, Ecotect, Project Vasari, VE, *etc.* This integration enables them to be powerful decision-making tools for the design of a high energy performance building.

In this paper, a method that utilizes the architectural geometry model generated by the BIM tool through an energy simulation process will be presented. The purpose is to evaluate the energy performance from an A-Tower case following the requirements of LEED, representing the other certification systems which will need to implement an energy simulation and provide an efficient process to get a more reliable result from the energy simulation.

The target building is modeled using BIM; having gone through the process of modifying the format of the model and verifying it, the energy performance of the building is then assessed through the energy simulation program. Throughout the evaluation of the energy performance, the limitations of the existing energy simulation method using BIM are deduced. We are going to propose a more efficient method to determine the building's energy performance.

2. Research on Related Technologies to Establish BIM Energy Simulation Process

2.1. BIM Model Guide for Energy Simulation

Several organizations have published a guideline for BIM modeling on building energy simulation. On 21 October 2010, the Public Procurement Service of Korea established a fundamental guideline for the BIM ordering of buildings, and on 19 April 2012 they announced the first revision of the guideline. This guideline includes the approximate energy efficiency evaluation criteria for applicants, tenderers and contractors [2].

The US General Service Administration (GSA) had presented the BIM modeling guidelines for each category via the GSA Building Information Modeling Guide Series. In particular, the Building Information Modeling Guide Series 05-Energy Performance was established by the GSA in order to

provide a set standard for energy simulation using BIM [3]. In addition, the Industry Foundation Classes (IFC) Implementation Guide Space Boundaries for Thermal Analysis had provided a modeling methodology for each structure of the building [4]. Figure 1 shows an example of space boundary creation according to BIM geometry modeling.

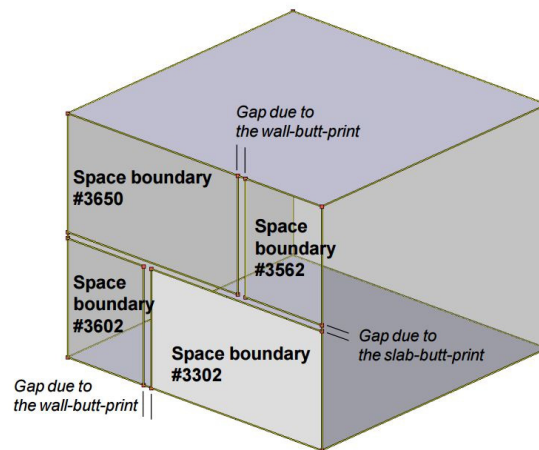


Figure 1. Guide to BIM geometry modeling example [4].

These studies are presenting the architecture modeling methods to use BIM as a tool for architectural geometry information modeling in the energy simulation process [5–7]. If a wall, roof, and floor that may constitute architecture are important factors in the general architectural BIM model, then a space boundary becomes a major issue depending on the modeling because the object of analysis in energy simulation is a space defined by objects.

2.2. Methodology for BIM Energy Simulation

BIM data creating (a format conversion in order to exchange information) and energy simulation steps at the current stage are defined in the Building Information Modeling Guide Series 05-Energy Performance of the GSA. In addition, this guide presents an energy simulation process on a case-by-case basis [3]. Figure 2 indicates part of the simulation process which is presented by the guide above. Comparing the process, generating the geometry information, and exporting the information into the energy simulation software, using a data schema file, is the common process.

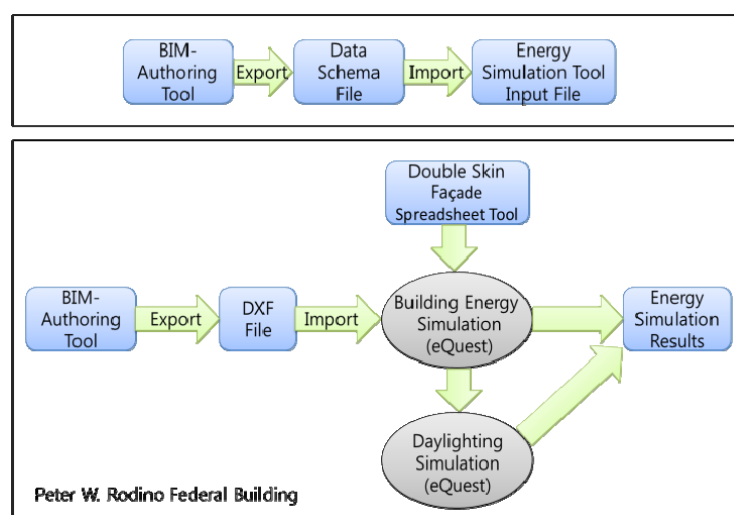


Figure 2. Cont.

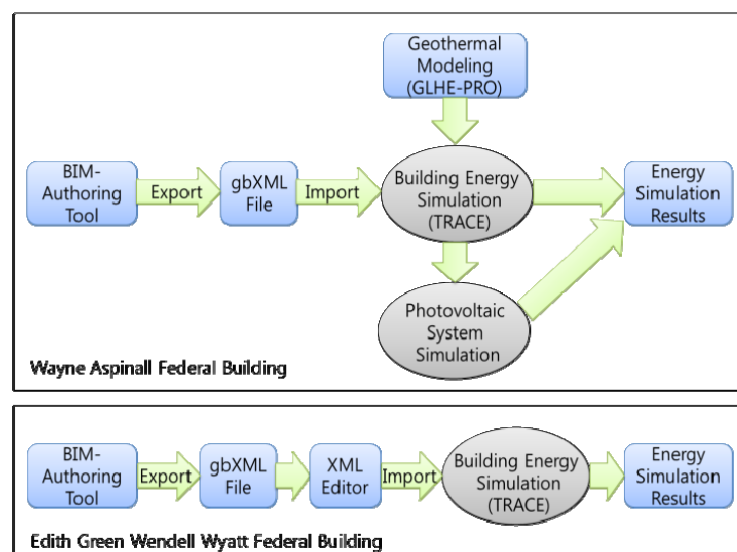


Figure 2. BIM based energy simulation process example.

The data schema files for exporting BIM information to the energy simulation software include gbXML, IFC, ifcXML and ecoXML files, as presented in Azhar *et al.* [5]. The process of exporting information to Ecotect, IES VE and GBS, which are building simulation tools, through gbXML is proposed in Azhar *et al.*

In addition, it can be notified that the processes are varied by each project's particular characteristics as well as the energy simulation software used. One of the studies on the BIM-based energy simulation process and geometry verification is that of Ryu *et al.* [8]. Figure 3 shows the geometry verification method proposed by Ryu *et al.* In the process of converting architectural geometry information created through the BIM tool into gbXML for energy simulation, architectural geometry verification methods are introduced.

Case.	Revit Geometry.	Revit Interference Check.	gbXML Viewer.	FZKViewer.	Effect of Energy Modeling.
Errorless.					
Duplicated Object.					Wall Area Error.
Interference between Objects.					Roof Area Error.
Space Setting Error.					Wall/Roof Area Error.

Figure 3. gbXML geometry verification process.

In this paper, to obtain an accurate geometry model, the process of checking errors through the interference check function on Revit, gbXML Viewer and FZKViewer are used, and any errors are then modified [9].

2.3. LEED Energy Simulation

LEED has total of 110 points, which consists of six points for Innovation in Design and six points for Regional Priority, with a base of 100 points. Using LEED New Construction (NC), the total achievable points for energy simulation is a maximum of 19–21 points based on the type of building, and there is also a comparison of which has the highest possible points compared to other credits. Furthermore, it is necessary to achieve a minimum energy cost reduction of 10% in order to get LEED certification.

A study which utilizes BIM for a LEED assessment is that of Alwan *et al.* [7]. The methodology of assessing LEED credits through Revit Architecture, Revit MEP, IES or Project Vasari is proposed in his study. This study is mainly focused on the geometry verification in the energy analysis process, which differentiates it from Alwan's study.

3. LEED Energy Simulation Using BIM

3.1. A-Tower Design Overview

The targeted building for energy simulation is an A-Tower located in Seoul. The A-Tower is a building that consists of eight basement floors and 24 ground floors with a common area and a sales facility in the lower level. It also has a business facility of two blocks in the higher level of the building.

Sources of energy used for this tower are electricity, gas, and district hot water. There are photo voltaic panels installed that produce electricity. A source of geothermal power is used with a geothermal heat pump. Heating and cooling energy is produced through a centrifugal chiller, an absorption chiller-heater, a geothermal heat pump, and an electric heat pump, and heat is stored with an ice thermal tank, which is used to distribute the peak load during the summer months. As an air conditioning method, the Variable Air Volume (VAV) and Constant Air Volume (CAV) air handling unit is used and, in a perimeter zone, a fan coil unit is responsible for the load.

As for energy conservation methods, passive technology in Low-e double glazing and active technology in the oval coil of the air handling unit, an occupancy sensor, dimming control, renewable energy and the enthalpy control of energy recovery ventilation are used. The A-Tower architectural and mechanical design overview is shown in Figure 4.

Project Name	A-Tower		
Building Site	Seoul, Korea		
Number of Stories	B8~24F, 2-Tower	6F~24F	
Site Area	7,022 m ²		
Building Area	4,149 m ²		
Gross Floor Area	105,486 m ²		
Heat Source	Electricity, gas, district hot water, photo voltaic panel, geothermal loop	B2F~5F	
Heat Plant	Ice thermal storage, centrifugal chiller, gas boiler, geothermal heat pump, district hot water	B7F~B1F	
Air Handling System	VAV, CAV, OHU, FCU		

A
Tower
Office

B
Tower
Office

Retail

Common
Facility

Figure 4. Mechanical design summary of A-Tower.

3.2. Energy Modeling Process for A-Tower

The A-Tower energy simulation process, the process provided by Ryu *et al.*, is used [8]. Through Revit, architectural geometry is modeled. Object duplication and interference between objects are

checked through Revit's Interference Check function. Through the gbXML Viewer, the space height error is checked. The Revit modeling that went through these two processes is exported to gbXML and the modeling errors are finally checked and modified through the FZKViewer. [10] Accurate building geometry information created through this process is imported to the energy simulation program.

3.3. BIM Modeling

In 2013, Revit was used for building geometry modeling. Building zones are modeled according to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1, Table G3.1 [9]. After that, each of the rooms was assigned to spaces, and each space was assigned to the same air conditioning unit by using the MEP zoning function. Color schemes classify each zone assigned to each air conditioning unit. The MEP zones are modeled through geometry verification as shown in Figure 5.

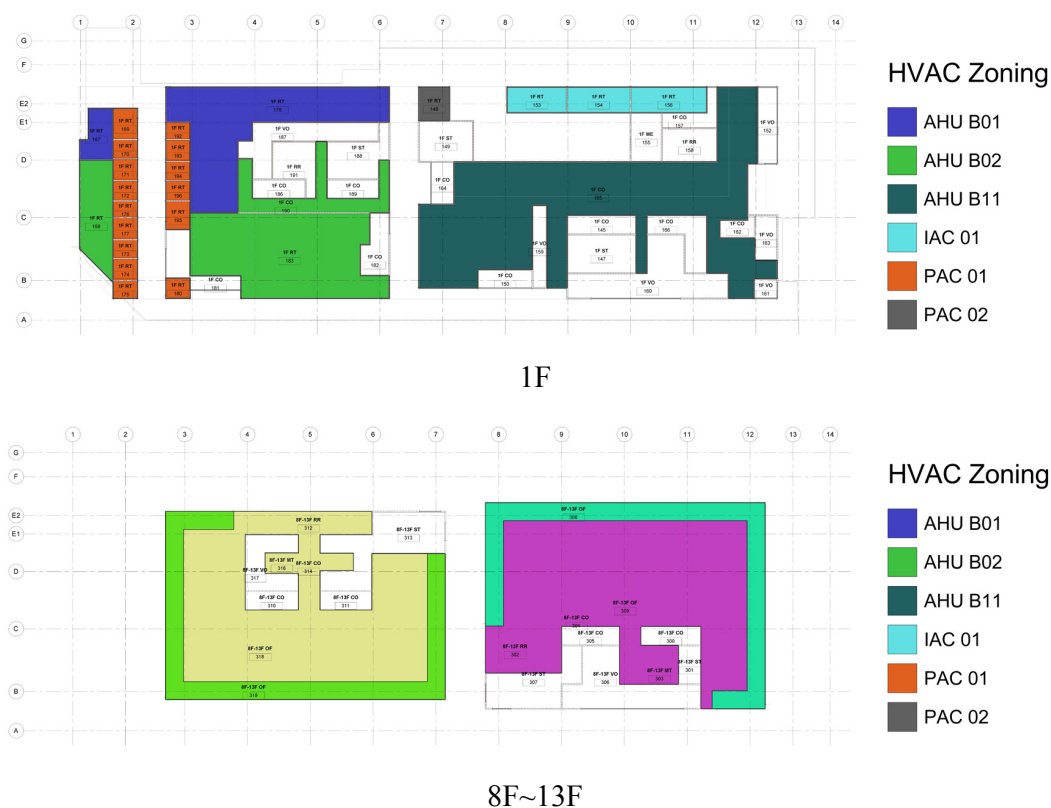


Figure 5. Building geometry modeling and mechanical zoning by Revit.

3.4. Exporting into Energy Modeling and Verifications

The architectural geometry information generated by Revit undergoes the modeling verification process after being converted to the gbXML file. Firstly, with the Revit's Interference Check function, check interference and the duplication of building objects is used. Interference and duplication may occur during the modeling process because of the modeler's mistakes and lack of actual understating of building spaces.

Secondary verification is made by using the gbXML Viewer in the export function of the Revit. The left side of Figure 6 reveals the geometry verification through the gbXML Viewer. The main goal of this verification is to understand the object expressed as an "air gap". An "air gap" may be generated by "space separation lines" used to divide a space or by an error in setting the space height. An error in the setting of the space height and objects modeled that are duplicated will cause errors and inadequate results in the energy simulation, so all these sorts of errors shall be corrected.

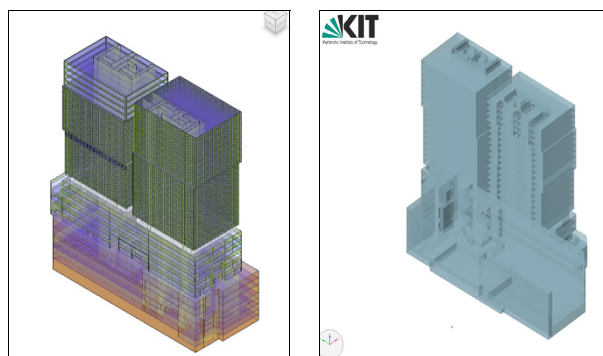


Figure 6. gbXML modeling quality check. (Left) Revit gbXML Viewer; (Right) FZKViewer.

Finally, verification is made using the FZKViewer. The right side of Figure 6 reveals the geometry verification through the FZKViewer. The FZKViewer has an advantage that allows it to check the information generated using gbXML by each hierarchy and element. gbXML-AIR and gbXML-SHADE objects which are in relation to the duplicated model and setting for the space were arranged to be verified.

3.5. LEED Energy Simulation

Energy simulation for the LEED version 3.0 follows the ASHRAE standard 90.1-2007. Energy simulation shall be implemented with the proposed model as an actual designed building and baseline model following the guidelines of ASHRAE 90.1-2007, Appendix G. The improved performance of the proposed building is calculated with the following formula:

$$\text{Percentage improvement} = 100 \times (\text{Baseline performance} - \text{Proposed performance}) / \text{Baseline performance}$$

By comparing the proposed and baseline model simulation results, the actual evaluation of the relative energy cost-savings rate shall be assessed.

The ASHRAE Standard 90.1 presents the requirements for the envelope, the standard for the Heating, Ventilation and Air-Conditioning (HVAC) equipment and lighting power density for the baseline model.

The first step for creating a proposed case is entering the location information and the weather data. As for weather data, the data provided by Weather Analytics are used. The Department of Energy (DOE) is encouraging us to use weather data from more reliable sources if there is no data on the applicable data among the weather data provided by the DOE and one of the agencies that the Weather Analytics are presenting in the DOE. Weather data is applied to both the proposed case and the baseline case.

The next step is the creation of a template. Through using a template, the purpose-specific occupancy density, lighting load density, and the instrumental load density as well as each load-specific schedule are then set. Furthermore, thermal properties such as infiltration, room temperature, and the envelope are prepared. All conditions are combined to finally create a template.

After creating a template, the gbXML that went through the verification stage is imported to Trace 700 for an energy simulation. Templates created prior to each of the room facts are applied to match the room-specific information. As the air volume in the air supply, ventilation, and exhaust is changeable for each room, individual room properties should be entered rather than using a template. If the room-specific variable being entered is finished through the previously mentioned process, enter the information into the duct system. Select the same system as that from the design documents and set the same control method. Furthermore, set the heating and cooling supply air temperature and relative humidity, fan consumption power, along with the heating and cooking capacity identical to the actual design, and connect the rooms applicable for each conditioning equipment.

The next step is the equipment-setting stage. In this step, we first make a model of the accessories in the applicable heat source equipment and pump as well as the connection equipment. Then we enter the detailed information on capacity, efficiency, and partial load efficiency on all equipment and set the operating conditions; then we match the applicable heat source to the conditioning equipment that is connected. The final step is the energy rate entering stage. This is applied to both the proposed and baseline models identically. It can be entered so that the rate system on gas and electricity is by season or time zone in order to calculate the energy price depending on the use of energy.

The baseline case is prepared based on the information from the proposed case. In the baseline template, occupancy density and instrumental load density are set equally. However, lighting load is entered with a space by space method in the ASHRAE Standard 90.1 and all schedules are set equally to those in the proposed case. For the performance of the building envelope, enter the performance of the envelope that is applicable to climate zone 4A. Additionally, information such as the thermal properties of a building envelope, the lighting power density, *etc.* is entered in compliance with the information expressed in Table 1.

The baseline air handling system is modeled with a variable air volume method in accordance with the ASHRAE Standard 90.1, and the capacity of the heating and a cooling coil is entered by adding a 15% safety factor to the maximum load in case of cooling capacity, and the heating capacity is entered by adding a 25% safety factor to the maximum load. In addition, other detailed input conditions are modeled depending on Appendix G.

Baseline modeling on heat source equipment was modeled with a chiller and a boiler, respectively. Operating conditions are set and efficiency is entered in accordance with Appendix G.

Table 1. Baseline and proposed case envelope, lighting and process load input.

Category		Baseline	Proposed	Category	Baseline	Proposed								
Envelope	Roof	0.273 W/m²K	0.187 W/m²K	HVAC Type	Variable Air Volume (VAV) with Reheat	Constant Air Volume (CAV)/VAV								
			0.148 W/m²K			Fan Coil Unit (FCU)								
	Exterior Wall	0.365 W/m²K	0.352 W/m²K			Packaged Termianl Air Conditioner (PTAC)								
			0.363 W/m²K			Cooling Capacity	10,512 kW	14,327 kW						
	Exposed Floor	0.214 W/m²K	0.238 W/m²K			Heating Capacity	3749 kW	9695 kW						
						Fenestration	2.84 W/m²K Solar Heat Gain Coefficient (SHGC)-0.4	1.437 W/m²K SHGC-0.218 Visible Light Transmittance (VLT)-0.59	Air-Side Heating, Ventilation and Air-Conditioning (HVAC)	Supply Airflow	11,081,291m³/h	1,330,030 m³/h		
	Outdoor Airflow	307,904 m³/h	Economizer							Not Required	Applied			
												Supply Air Temperature Reset	2.8 °C	-
												System Fan Power	891.8 kW	695 kW
	Lighting	Elec./Mech. Room	1.50 W/ft²			0.4 W/ft²	Chilled Water-Side	Chiller Type	Centrifugal	Centrifugal				
Corridor		1.5 W/ft²	0.17 W/ft²	Absorption										
Office		0.5 W/ft²	0.54 W/ft²	Chiller Capacity	2242 tons	2860 tons								
Conference Room		1.10 W/ft²	0.77 W/ft²	Efficiency	6.1 Coefficient of Performance (COP)	1.08~5.83COP								
Retail		1.70 W/ft²	1.34 W/ft²	Primary CHW Pump Power	0.175 kW/L/sec	0.408~0.714kW/L/sec								
Storage		0.30 W/ft²	0.60 W/ft²	Secondary CHW Pump Power	0.253 kW/L/sec	Not Applied								
Restroom		0.90 W/ft²	2.04 W/ft²	Cooling Tower Fan Power	3.23LPS/kW	22 kW								
Parking Garage		0.20 W/ft²	0.09 W/ft²	Condenser Water Pump Power	0.310 kW/L/sec	0.462~0.767kW/L/sec								
Lounge		1.02 W/ft²	0.54 W/ft²											
Gymnasium		0.90 W/ft²	0.28 W/ft²											
Total		0.82 W/ft²	0.50 W/ft²											
Exterior Lighting		51.66 kW	45.42 kW											

Table 1. Cont.

Category		Baseline	Proposed	Category	Baseline	Proposed
ProcessLoad	Elec./Mech. Room	0.46 W/ft ²		Geothermal LoopCapacity	Not Required	Cooling 468 kW
	Corridor	0 W/ft ²				Heating 504 kW
	Office	2.32 W/ft ²		Boiler Capacity	4324 kW	11,912 kW
	Conference Room	0.46 W/ft ²		Hot Water Pump Power	0.310 kW / L/sec	2.2~3.7 kW
	Retail	1.86 W/ft ²				
	Storage	0 W/ft ²				
	Restroom	0 W/ft ²				
	Parking Garage	0 W/ft ²				
	Lounge	0 W/ft ²				
	Gymnasium	0 W/ft ²				
	Total	1.03 W/ft ²				
Other Process Load		659.0 kW				
Service Hot Water		2107 kW				

3.6. A-Tower Energy Simulation Result

The annual energy consumption and annual energy cost derived from energy modeling are as shown in Figure 7. In the baseline case, the annual energy consumption per unit area is 125.8 kWh/m² and in the proposed case it is 97.3 Wh/m² and the annual energy generation from the solar light power panel is 221,159 kWh. In the baseline case, the percentage of energy use per purpose including solar light power production is as follows. From the entire energy consumption, the process energy is 33.9%. Process energy includes the energy consumption depending on the use of appliances, elevators and escalators. Lighting energy includes the energy consumption for indoor lighting and exterior lighting and uses 26.6% energy. Energy consumption of fans and pumps is 13.9% and that includes the conveyance energy consumed for the air conditioning and hot water supply. Cooling energy occupies 14.0% of the entire energy. The percentage of energy used at a cooling tower while cooling is 2.7%. Heating energy occupies 9.0% of the entire energy. In addition, the percentage the hot water supply energy is 2.6%.

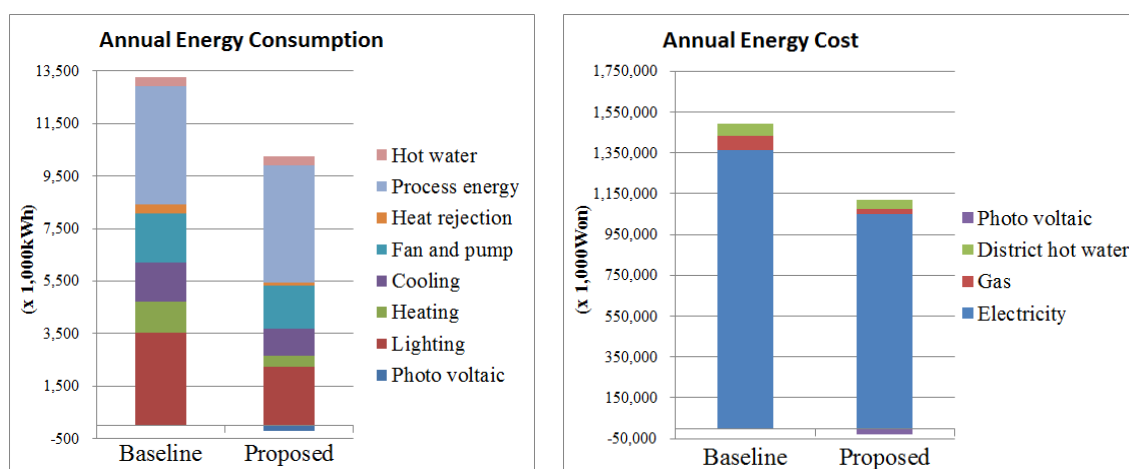


Figure 7. A-Tower annual consumption and cost (Left) energy consumption; (Right) energy cost.

In the proposed case, the purpose-specific energy use percentage is as follows. For the entire energy consumption, the process energy occupies 43.7%. Lighting energy uses 21.9% of the energy. Energy consumption for fans and pumps is 15.8%. Cooling energy occupies 11.0% of the entire energy. The energy percentage used at a cooling tower while cooling is 1.1%. Heating energy occupies 4.1% of the entire energy. In addition, the percentage of the hot water supply energy is 3.4%. When compared, the energy saving rate for the proposed case is 27.9%.

If this is converted to the annual energy cost, in the baseline case, the energy cost per unit area is 14,000 won annually, and in the proposed case it is 11,000 won annually. If this was converted into a percentage, the energy saving rate would be 26.9%. This is equivalent to eight points of 19 possible maximum points in item Energy and Atmosphere (EA) credit 1 based on the LEED NC. Solar light power production is 2.2% of the entire energy consumption.

3.7. Limitations of the BIM-Based Energy Simulation Process and Methods to Improve the Process

Energy simulation through BIM involves going through the BIM geometry modeling process and the format conversion, geometry verification and analysis process just as it is in the case of the method used in this thesis. Errors may occur due to various reasons in this process. Firstly, geometry model errors may occur due to the BIM modeler. In addition, errors may occur due to the difference between the geometry expression method of BIM and that of the gbXML in the process of exporting BIM data to gbXML. Thirdly, errors may occur due to the energy modeler's mistake(s) or his or her lack of relevant information or proficiency in the energy simulation process.

Limitations were deduced in the processes of using the Revit gbXML Viewer and FZKViewer as methods to verify errors related to the BIM model among such possible errors. Since these software programs function only as viewers, it takes quite a lot of time to check and confirm any individual errors using them visually. In addition, the working time increases because of the required process when checking for any errors, modifying the BIM modeling and double-checking for any errors through the viewers.

In order to improve these problems, this thesis proposes the improved energy modeling process shown in Figure 8. It is necessary that the BIM-based building energy simulation process is improved with a more professional automatic modeling quality checking software such as Solibri Model Checker or Navisworks BIM quality check. [11,12] In addition, if either an individual software or an add-on function of the BIM tool is developed as not only a viewer but also an editing tool to let the user be able to modify the gbXML, which is a format to exchange the building information between software, it is expected that the energy simulation utilizing BIM will be one of the more convenient and most powerful methods.

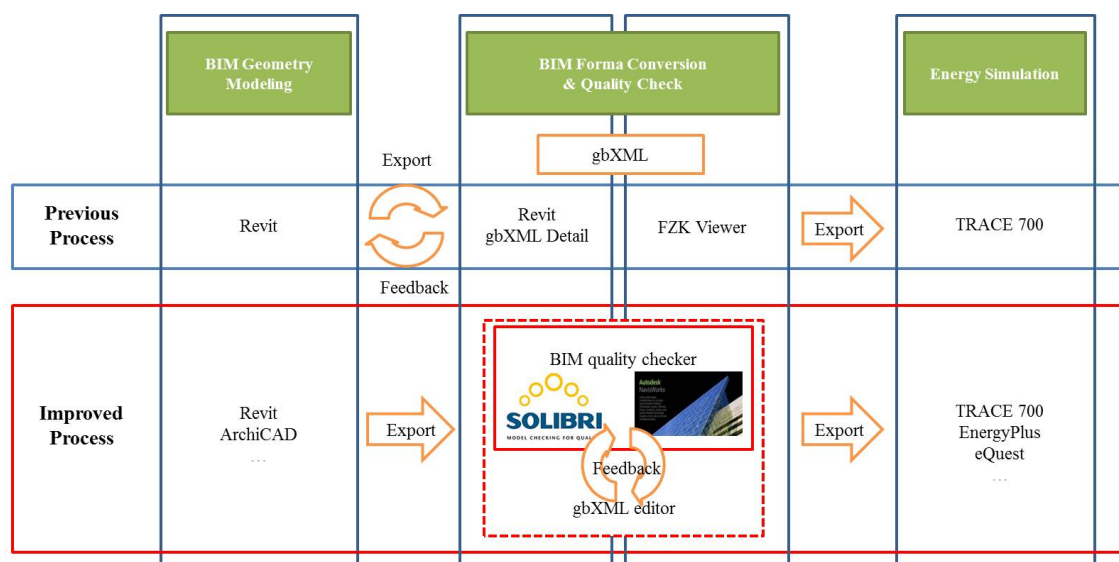


Figure 8. Improved BIM-based energy modeling process.

4. Conclusions

The energy performance for the A-Tower was done by the BIM-based energy simulation process. Entering information about the geometry of a building to take advantage of BIM saves a considerable amount of time. Furthermore, it is a tremendous advantage to quickly and easily fix numerous errors that occur during the architectural geometry modeling procedure by using the BIM modeling software, which is easy to use and has an excellent performance rate rather than the three-dimensional modeling user an interface integrated in the energy simulation software. This advantage is a more useful method for the energy simulation software without an integrated three-dimensional interface such as the TRACE 700, which was utilized in this paper.

Air conditioning zone separation using a color scheme has an advantage that lets the user intuitively understand how the analyzed building has a zoning hierarchy, and it makes the time dramatically faster during the assignment of each of the spaces, zones and air conditioning equipment including the easy finding and fixing of errors.

However, in the process, BIM modeling validation procedures for ensuring reliability were needed. The process for verifying functionality in the Revit gbXML Viewer program took advantage of the FZKViewer. Both programs perform only functions as an object viewer, so a large disadvantage is

that checking errors visually was a required effort. In addition, when an error is detected, finding and fixing the object again is another problem.

In order to improve the problems concerning the existing energy simulation process using BIM, this thesis proposes utilizing quality check programs such as Solibri Model Checker and Navisworks. Furthermore, it is necessary to develop a gbXML editor that can immediately rectify any errors found through an error checking program.

Author Contributions: Han-Soo Ryu and Kyung-Soon Park conceived and designed energy simulation process; Han-Soo Ryu performed the simulation; Han-Soo Ryu and Kyung-Soon Park analyzed the data; Han-Soo Ryu wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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