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BIM-based Building Energy Load Calculation System for Designers

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Abstract

In addition to the global awareness regarding green buildings, there is growing interest in Building Energy Load Calculation (BELC). The BELC process, however, has several potential problems, including the fact that the required data are input manually through subjective engineer choices and, during the BELC process, a designer must wait for feedback from the engineer regarding the BELC results. This paper addresses these problems by proposing a BIM-based building energy load calculation system for designers. To that end, the required data for BELC are divided into four types: general, space, material, and element. According to the required data, input methodologies are categorized as either automatic type-A or manual type-M data. The proposed system for BELC is developed with four key functions: type-A data input, type-M data input, material-property matching, and calculation functions. To validate the proposed system, two designers with more than seven years of practical experience and a BELC engineer using the eQUEST and EnergyPLUS programs applied the model to the current and proposed approaches. The proposed system contributes to increasing the efficiency of the BELC process by facilitating self-check by the designer and by reducing the need for engineering input during the BELC process.

Keywords: *BIM, building energy load calculation, designers, data input system*

1. Introduction

Along with global awareness regarding green buildings, there is a growing interest in the concept of Building Energy Load Calculation (BELC). BELC is necessary to analyze building performance, and concurrently, Building Information Modeling (BIM) technology is also becoming increasingly important for collaboration in architecture. The use of BIM for green projects is expected to grow dramatically in the near future, and 78% of BIM users not currently employing BIM for green projects are expected to be doing so within three years (Harvey, 2010).

Most architects who design buildings using BIM technology import a model thru an Industry Foundation Class (IFC) standard file format. Since 1994, the IFC format has been a standard data format set by the International Alliance for Interoperability (IAI). This IFC format can be used by any BIM-based computer program in the world. Most BIM-based programs can be read and written in an IFC file. The IFC file can then be changed into an industry Foundation Class Extensible Markup Language (IFCXML) file by using an Extensible Markup Language (XML). IFCXML is also a standard format that was developed by IAI in 2007. The latest release, IFCXML4, was developed using the same rules and configurations as the IFC 2×4 release. The basic structures of IFCXML are based on an IFCXML schema (Thomas and Matthias, 2013), and the elements and attributes of the IFCXML schema are derived from the standard IFC schema. The IFCXML schema is easier to use on the web than the IFC schema.

The most popular BELC engines in the world are DOE-2 and EnergyPlus. Currently, these BELC engines are unable to use IFC files directly. For this reason, users who want to perform BELC using BIM must change the model's file format from IFC to a native file format, such as an INP file for the DOE-2 engine or an IDF file for EnergyPlus. BELC has been a technology used in the construction industry for some time, and there are many BELC programs even some for adopting BIM. However, there are some potential problems when adopting BIM for BELC.

The first is in regard to limits in the BELC process when done in a series, since a BELC engineer has to participate in the current BELC work process, and consequently the designer must wait for feedback from the engineer regarding the BELC results. Instead, in an optimal scenario, BIM-based information transfer would be seamless, and data transfer would occur back and forth without a loss of information (Kumar, 2008). In many BELC programs, however, it is necessary to have a BELC engineer input specific information. This makes it difficult to analyze building energy performance during the conceptual design phase. In addition, when BELC engineers input specific information into BELC programs, subjectivity can become an issue. Human mistakes can be made during the input data process when there is any miscommunication between a designer and a BELC engineer.

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This decreases efficiency and introduces delays in the cycle time for the BELC process.

To address and solve these problems, this paper proposes a BIM-based building energy load calculation system for designers. To that end, the required BELC data are divided into four types: general, space, material, and element. According to the required data, input methodologies for the required data are categorized as either automatic or manual. The BELC automation system is developed with four key functions: 1) type-A data input function, 2) type-M data input function, 3) material-property matching function, and 4) a calculation function.

The Building Energy Analysis (BEA) process is a green building analysis by zone using the eQUEST, ECOTECT, DOE-2, or EnergyPLUS programs. The BEA result includes the energy consumption of the building model by specific BEA engineer specialists. They have to enter the specific required data for BEA into the BEA system, including the HVAC system, and the BEA result is also needed in order to interpret data to provide feedback to the designers. On the other hand, the Building Energy Load Calculation (BELC) process calculates the energy load of the envelopes on the building model by each spaces using BEA engines such as DOE-2 or EnergyPLUS. During the BELC process, in general, information of the HVAC system is not necessary, and the architectural information is required, even for a BEA engineer conducting the BELC process. In this paper, since the BEA process can't be conducted without a BEA engineer, the scope of the green building analysis is limited to the BELC process. This paper only considers the DOE-2 based BELC process, which is limited to calculating building energy load. As such, this paper considers the required data for representation and the placement data of building elements and spaces, material data, and some energy load input data for a building. This required data can be extracted from the IFC-based BIM data and manually input as a generic default value. In addition, since the IFCXML 2×3 schema is the most popular in the BIM-based design phase, we used it to create the building model as a case study.

2. Literature Review

2.1 Previous Research

Many researchers have studied the input of data for the BIM-based BEA. Gupta *et al.* (2014) presented a conceptual framework for developing IFC-compliant BEA tools using a multi-model concept in which the IFC data model provides partial input data required to run BEA simulation models. They developed an application for data exchange from an IFC file format to an input data requirements file format for a solar photovoltaic simulation. However, since the solar photovoltaic process is conducted by specific BEA engineers, a designer can't use the presented application in the early design phase without specific data requirements. Attia (2010) surveyed the selection criteria of building performance simulation tools between various stakeholders on a construction project. The final result indicated a wide gap between the priorities of designers versus engineers. For this reason, the designers have to ask for specific help from the BEA engineers. This introduces inefficiencies into the design process by increasing time and cost. Sullivan and Keane (2008) proposed a graphical user interface to input the data of an HVAC system into a BIM-based building energy simulation using an IFC file. This demonstrates the possibility of data exchange between a BIM model and BEA tools that employ a user interface. However, when a designer adopts the result of this application, they have to wait for the completion of the BEA engineer's work when using the proposed application. Kim *et al.* (2011) suggested some necessary steps to develop a data mining approach with a case study of an ongoing design project. They presented steps showing how energy analysis was used early in the design process. However, some problems arose in applying data mining technology to the BEA process, such as with the work process in the series between CAD and BEA tools. Ahn *et al.* (2014) proposed an automated conversion of geometric information within the interface and investigated the validity of automated conversion and simulation. In the proposed interface, since the required data must be input by BEA engineers without using the default and library data, the system can only be used by BEA engineers. Without BEA engineers the required data cannot be entered into the system. Samguinetti *et al.* (2012) provided a system architecture for tailoring design models for specific analysis applications. This proposed system can reduce the designer's effort by post-processing the subject building model. However, the data input process is unclear when using a BIM-based building description. In addition, because the BEA is processed by a specific BEA engineer, subjective BEA engineer decisions still represent a limitation. Bazjanac (2008) described the methodology and the interoperability of an IFC file and BEA tools. In this methodology, geometry data and HVAC data are re-used in EnergyPlus for BEA. However, this methodology also needs intervention in the design process from a BEA engineer. Lagüela *et al.* (2014) presented an automated methodology for the generation of an as-built building model using a thermo-graphic camera scanning in a gbXML file format. However, even the gbXML-based building model can be automatically generated using the proposed approach, a construction material of the building element can't be identified by a user without additional works. Ham and Fard (2015) proposed an automated approach for updating the thermal properties of the building elements in gbXML using 3D thermography scanning. However, the proposed approach can be adopted on an existing building with the BIM-based building model, and the actual thermal properties should consider the constructability by contractors. Overall, most of the studies considered the data input process using specific BIM-based BEA tools in the design phase. However, since an increase in the efficiency of the designer's work process should also consider the performance of the building during the early design phase, the results of the BEA or BELC process should provide feedback to the designer as soon as possible. Thus it is necessary to develop a BELC process

Table 1. Summary of the Literature Reviews Related BEA

Category	Authors	Contents	Limitations
Propose a process for BEA	Bazjanac (2008)	The author described a methodology and the interoperability of an IFC file and BEA tools.	This methodology also needs intervention in the design process by a BEA engineer.
	Attia (2010)	The author surveyed selection criteria of building performance simulation tools between various stakeholders on a construction project.	Since the final result indicated a wide gap between the priorities of designers versus engineers, the designers have to ask for specific help from BEA engineers.
	Kim *et al.* (2011)	The authors suggested some necessary steps to develop a data mining approach with a case study of an ongoing design project.	There were some problems in applying data mining technology to the BEA process, such as with work process in series between CAD and BEA tools.
	Lagüela *et al.* (2014)	The authors presented an automated methodology for the generation of an as-built building model using a thermo-graphic camera scanning in a gbXML file format.	Even the gbXML-based building model can be automatically generated using the proposed approach, a construction material of the building element can't be identified by a user without additional works
	Ham and Fard (2015)	The authors proposed an automated approach for updating the thermal properties of the building elements in gbXML using 3D thermography scanning.	The proposed approach can be adopted on an existing building with the BIM-based building model, and the actual thermal properties should consider the constructability by contractors
Develop an application for BEA	Sullivan and Keane (2008)	The authors proposed a graphical user interface to input the data of an HVAC system into a BIM-based building energy simulation using an IFC file.	When a designer adopts the result of this application, they must wait for the completion of the BEA engineer's work when using the proposed application
	Samguinetti *et al.* (2012)	The authors provided a system architecture for tailoring design models to reduce the designer's effort by post-processing the building model.	Because BEA is processed by a specific BEA engineer, subjective BEA engineer decisions might be included into the process.
	Gupta *et al.* (2014)	The authors developed an application for data exchange from an IFC file format to an input data requirements file format for a solar photovoltaic simulation.	Since the solar photovoltaic process is done by specific BEA engineers, a designer can't use the presented application in the early design phase without specific data requirements
	Ahn *et al.* (2014)	The authors purposed an automated conversion of geometric information within the interface and investigated the validity of automated conversion and simulation.	Since the required data must be input by BEA engineers without using default and library data, the system can only be used by BEA engineers

where the designer can proceed without waiting on the BEA engineer's process.

BIM data can be converted into a text-based building model, and include an INP or IDF file (Ahn *et al*., 2014). However, since subjective BELC engineer contributions place a limit on the required data input procedure for the BEA or BELC process, the proposed systems do little to actually improve work efficiency. Therefore, it is necessary to improve the BELC process from a practical perspective using BIM-based data conversion technologies.

Currently, the required data for BEA already exist in a BIM-based standard file format, such as IFC and gbXML. In the ideal BIM adoption into a construction project, various engineering analyses can be conducted using an integrated building model which is generated using an open standard file format such as IFC. For this reason, this study used IFCXML as a file format, which was directly generated by a designer without an engineer, as opposed to gbXML which is a specific file format for green building analysis. Moreover, in general, when the designer exported a building model by gbXML, the designer has to enter information regarding the BEA zone considering the BEA engineer's help. On the other hand, since IFC/IFCXML can be exported only with spaces except for the zone, IFC/IFCXML can be directly used to calculate building energy load by spaces by designer. To address this limitation, this paper used the IFCXML file to extract the required data for the BEA process. An IFCXML file can be adopted for other processes, such as estimation, scheduling, and maintenance of processes. There are several studies that use the IFCXML file within the BEA process. Kim and Yu (2012a) proposed a method to extract BIM data from IFCXML using a temporary BEA project DB. This approach contains some algorithms for the extraction of BIM data using the IFC schema including a data-mapping table between IFC and INP for a DOE-2 based BEA process. Moreover, Kim *et al*. (Kim and Yu 2012b; Kim *et al*., 2012) suggested an approach for the concurrent BEA data collection through data authorities. Project, space, and material data can be entered into a BEA tool concurrently and automatically using the required data input method. Yu *et al.* (2011) proposed a material name-matching process for BELC using ontology technology. A standard material name can replace the thesaurus name of each material to exactly recognize the specific material name. Kim and Anderson (2013) developed an energy modeling system using an IFCXML file. The energy modeling system works with the SketchUP program to generate a BEA INP file. The variable data of this system, however, only consider the placement and representation data of the building elements. There is additional required BEA data that need to be entered by BEA engineers, such as material properties and occupant schedules.

2.2 Current Tools

Many tools have been developed for BELC to measure building energy consumption. Most include an engine for detailed energy simulations and typically require simple text-based input and return output files (including peak loads, monthly loads, and

Table 2. Current BELC Tool Practices

BELC Tools	Current practices of BELC process	Characteristic
DOE-2.2 engine directly	Manually input using the specific form by an engineer	The specific form is too difficult to direct use on DOE-2 engine
eQUEST	There are 41 steps of data input using specific UI by an engineer	The data has to be collected by one person, and usage data has a limit of library
Ecotect	User creates the building model by the tool and various property data can be input by an engineer	The modeling ability is essentially required to model the building model and property data input
Green Building Studio	BIM data in gbXML can be imported to the tool and required data can be entered with UI by an engineer	The composite material set can be included to gbXML file, and gbXML has to be created separately

used energy costs) in the same text format. In order to input the required information to a BELC tool, a BELC engineer must collect all of the information prior to running a BELC tool. If any data are missing or unidentified by the BELC engineer, the BELC process cannot run, as the data input process is linear in a series. A building consists of too many elements to have only one person manually input all the associated data. Additionally, the BIM is very often applied to construction projects that have various stakeholders (Rezui *et al*., 2009). As such, it is often unclear when data are missing and who may have to create data and when. This influences the overall efficiency of the project process. The current practices of some well-known international BELC tools are summarized in Table 2. The practices are reviewed for each type of required information.

In practices with the current BELC tools, a BELC engineer has to participate in the BELC process, as it is an engineering process and the BELC tools require analysis. When a designer wants to calculate the building energy load, they have to wait for an engineer to calculate and input the data. This cycle time can be inefficient, and feedback loops can be lengthy (Bazjanac, 2008). In addition, manual data input inevitably presents the possibility of human error, such as a misunderstanding about the design or engineering information or mistakenly entered data. When a system inputs datasets systematically according to the manually entered data using a pre-established data library, the mistakes in the manual data inputs will lead to mismatched corresponding datasets in the given data library (Fleming *et al*., 2012). In addition, if any changes occur in a design alternative, these changes can't be directly or actively applied. This chain effect can result in incorrect analysis outputs. To address this, a designer needs to be able to make calculations without the input of an engineer when using a BIM-based building model, even if a BELC result is conceptual in the early schematic design phase. Thus, this paper proposed an improved approach to conduct the BELC process without a BELC engineer. The proposed approach contains four key functions: 1) import BIM data automatically as a type-A data input function, 2) enter the required data of the subject building using libraries and default data set as a type-M data input function, 3) generate material properties for the BELC process as a material-property matching function, and 4) generate the input file for the BELC engine and run as a calculation function. The four key functions are described in Section 4.

From a practical perspective, since the current tools of BELC have actually been developed as a BEA tool, an end-user must enter the whole input dataset into the tools, even if he or she wants to conduct the BELC process. Therefore, the data requirements

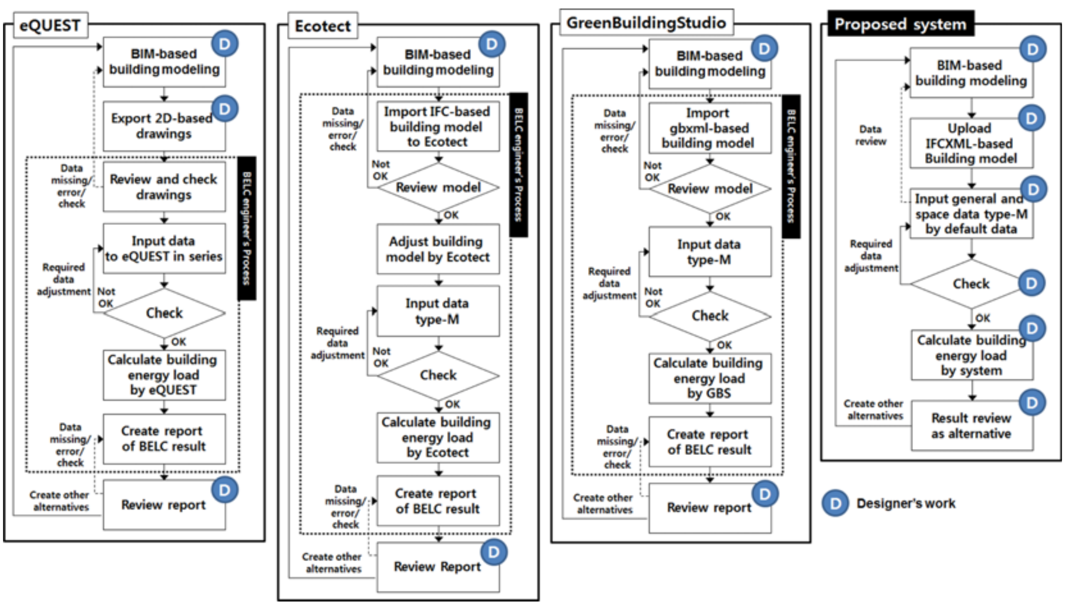

Fig. 1. Work Process of Current and Proposed Practices using BELC Tools

of the process have needed increasingly more information, such as the HVAC system or other types which are needed in the BEA process. Moreover, when the BELC engineer imports the building model into the current system, the engineer has to check the data error or omission of the model file, since the building model was not created from their own. On the other hand, the proposed system has been developed for only the BELC process, considering architectural information including spaces and enveloped elements regarding azimuth. In this regard, the architectural information can be totally extracted from the building model. Fig. 1 shows the work process of the different participants for a BELC process using the current BELC tools.

3. Required BELC Data

BELC is concerned with predicting the usage profile and cost of energy consumption within buildings (Swan and Ugursal, 2009). In this regard, to analyze building energy consumption, the building energy load is needed to determine an appropriate heating, ventilation, and Air Conditioning (HVAC) system and for alternative building designs designed in the BELC process. Various data are required for this process, depending on the building. As shown in Table 3, predefined data are required for BELC in the early design phase, such as project, site, site context, building, energy target, building stories, spaces, thermal comfort criteria, ventilation criteria, ventilation design, second-level space boundaries, building elements, material, and energy analysis zone (US GSA, 2009). These required data can be categorized into two types according to input method: type-A and type-M. Type-A data are automatically extracted and entered into the BELC system (e.g., building stories, building elements, and materials), while type-M data are entered manually into the system using an appropriate User Interface (UI) of the BELC system (e.g., thermal comfort and ventilation criteria).

The required data can be grouped according to data characteristics. There are four types of required data: general, material, space, and element. Initially, general data describe the general information of the building. General data include building location, type (e.g., office, residence) and operation strategy (e.g., schedule). Material data, the second type, includes data about material layers and material layer sets, which are made up of a set of materials in an element. Material data contain thermal properties, such as conductivity, density, specific heat and thickness. The third type is space data, which describe the area condition of thermal comfort and ventilation criteria. This includes building stories, thermal comfort criteria, and ventilation criteria. The last type, element data, consists of building elements such as architecture information. Since all element data can be extracted from a BIM file, there are no type-M data. Building elements are included not only in building elements type (e.g., wall, slab, roof, window, door), but also in element attributes (e.g., object placement, representation, relationships with the other elements).

In order to input the required data into a BELC tool, a BELC engineer must collect all of this information prior to running the BELC tool. However, if any data are missing or unidentified, the BELC process cannot run, since the data input process consists of a linear series of prompts. The BELC engineer can easily make a mistake due to the tedious nature of the task. For this reason, this paper proposes a parallel concurrent data input approach that will increase the efficiency of the BELC process.

Table 3. Required BELC Data

Category		Description	Data Examples
General type-M data	Project	General data to identify the specific project including stakeholders	Owner/Client Information
	Site	Where the subject building is located including climate data	Building Address Weather data
	Building	General data to identify the specific building including usage strategy	Building type Usage schedule
General type-A data	Building Story	Stories that make up the building	Story name Elevation
Material type-M data	Material Property	Thermal and general attributes of material	Thickness, Thermal conductivity
Material type-A data	Material	Component building material including material layer set	Material name Material layer set
Space type-M data	Energy Analysis Zones	Set of spaces for energy analysis in a building	Zone type Component spaces
	Thermal Comfort Criteria	Area conditions related to thermal comfort in a space	Dry bulb temperature Relative humidity
	Ventilation Criteria	Area conditions related to ventilation in a space	Designed quantity of outside air to be provided
Space type-A data	Space	Usage area made of a building by the usage type	Space Usage Occupancy Schedule
	Second Level Space Boundaries	Relationship between space and element	Space boundary type Link to building element
Element type-A data	Building Element	The components of a building such as wall, slab, roof, window, and door	Object placement Representation

Table 4. Data Input Method of BELC Tools

Required data		Data input methods of BELC tools		
		Type-1 (e.g. eQUEST)	Type-2 (e.g. ECOTECT)	Type-3 (e.g. GreenBuildingStudio)
General data	Type-A	Manually using given menu	Automatically from BIM data in gbXML format but uncertainly	Automatically from BIM data in gbXML format
	Type-M	Systematically using given data library	Systematically using given data library	Systematically using given data library
Material data	Type-A	Manually using given menu	Automatically from BIM data in gbXML format but uncertainly	Automatically from BIM data in gbXML format
	Type-M	Some manually using given menu and the others systematically using given data library	Some manually using given menu and the others systematically using given data library	Some manually using given menu and the others systematically using given data library
Space data	Type-A	Manually using given menu	Some manually using given menu and the others systematically using given data library	Automatically from BIM data in gbXML format
	Type-M			Some manually using given menu and the others systematically using given data library
Element data	Type-A	Manually using given menu	Automatically from BIM data in gbXML format but uncertainly	Automatically from BIM data in gbXML format

Table 4 shows the data input method of various BELC tools by data type.

4. Proposed Approach

4.1 Overall Process

To efficiently use the BIM data extracted from IFCXML as type-A data, the overall process of the proposed approach consists of four key functions: 1) type-A data input function, 2) type-M data input function, 3) material-property matching function, and 4) a calculation function. First, a user has to create a new project via the type-A data input function to clarify the authority for a project by accessing the system. Then the IFCXML file of the subject building model is uploaded to the BELC system to extract type-A data from the IFCXML file via the type-A data input function. Next, type-M data are entered based on the extracted type-A data by the type-M data input function. In this regard, the material data are matched to add their property data via the material-property matching function. Before an INP file is created via the calculation function to input the INP file into the DOE-2 engine, the user has to check the type-A and type-M data in the Project Database (DB). In the calculation function, the DOE-2 engine calculates the building energy load in the uploaded IFCXML file. Finally, the user can check the graphical images of the BELC results from DOE-2.

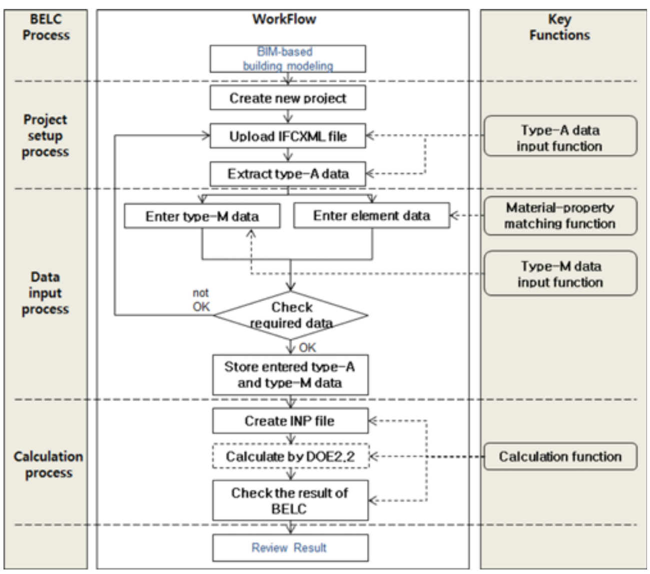

Fig. 2. Overall Workflow

The proposed system can be implemented by a designer without a BELC engineer being involved in the process by using four key functions. First, in the project setup process, the type-A data input function can automatically input the required type-A data with a specific algorithm. In this regard, the participation of a BELC engineer is not necessary to input type-A data. In addition, in the data input process, type-M data input and material-property matching functions help to input the required type-M data using generic default data from a data library. In this regard, a designer can use the generic default value as the required data, since these data can be input per the building type as a reference standard, such with ASHRAE or DOE. In this approach, mistakes from miscommunication between the designer and the BELC engineer can be avoided. Furthermore, if any information is unclear, the information can be reviewed or directly adjusted. Finally, in the calculation process, a designer can review the BELC results without waiting for the BELC engineer. This supports a more timely review of results, allowing the designer more time to create other alternatives.

4.2 Key Functions

4.2.1 Type-A Data Input Function

While the IFCXML file is being uploaded to the system, the type-A data input function runs systematically. In this regard, type-A data for general information, space, materials and elements are extracted according to the following process (see

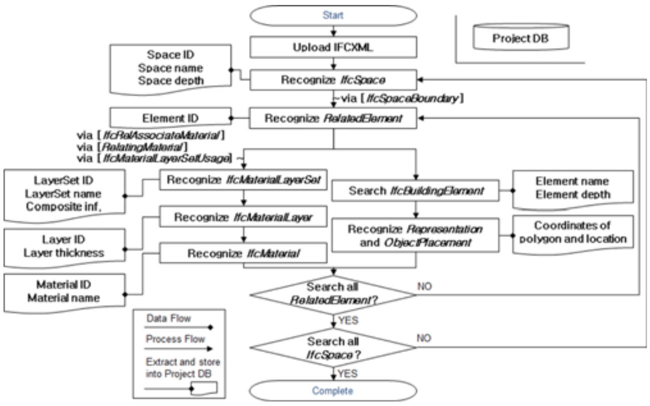

Fig. 3. Type-A Data Input Procedure

Fig. 3). To extract the type-A data, the function recognizes the *IfcSpace* entity from the IFCXML file to find space boundary information. The ID, name, and depth data of the *IfcSpace* are extracted and stored into the project DB. Then the function recognizes the *IfcSpaceBoundary* entity using the ID of the recognized *IfcSpace*. The function then recognizes the ID of related elements through the *RelatedElement* attribute of *IfcSpaceBoundary*. The function searches *IfcRelAssociateMaterial* and *IfcBuildingElement* entities to extract type-A data elements using the ID of *RelatedElement*. The function recognizes the *RelatingMaterial* attribute to find the ID of the used material, and then the material data are extracted to the project DB. The material data may be single or include composite materials related to a building element. At the same time, the function recognizes *Representation* and *ObjectPlacement* attributes of *IfcBuildingelement*. In this regard, the function extracts specific coordinates of polygon and location related *IfcBuildingElement* to the project DB. In addition, the *ObjectPlacement* has the location coordinates for whether elements are located above ground or undergrounded.

4.2.2 Type-M Data Input Function

The type-M data input function provides a systematic data input process based on the default values and the library DB to ease the input of data and increase accuracy. The extracted type-A data are first imported as a basis for entering type-M data. When type-A data are imported, users can infer which data would be entered for BELC using the extracted type-A data. In other words, some of the required type-M data for BELC is entered automatically through the extraction of type-A data from IFCXML, with the rest being entered by users. In addition, this function recommends specific data to input as a default and from the library DB. The default and library DB have various criteria and regulations according to building type and region. After the user has entered type-M data, the type-M data are also stored in the project DB.

4.2.3 Material-Property Matching Function

While type-A data are extracted from the IFCXML file by the

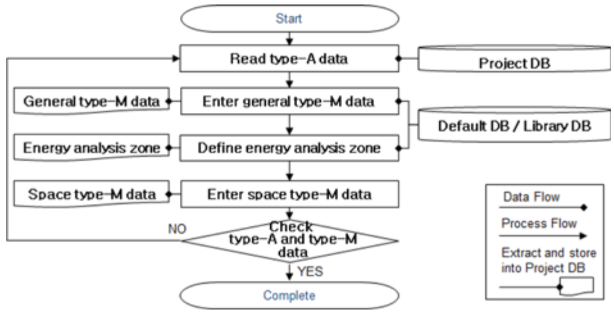

Fig. 4. Type-M Data Input Procedure

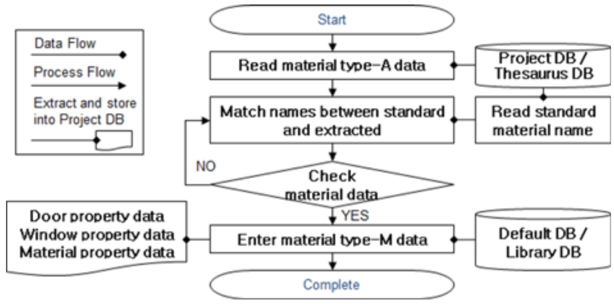

Fig. 5. Material-property Matching Procedure

type-A data input function, material names are standardized via the material-property matching function using a thesaurus DB. Since the default and library DB contain only standard material names, the used material must include the standard names. Because end-users have many possible names for a particular material (e.g., con'c, con, and concrete), the material name should be standardized to add property data (e.g., conductivity, density, and specific heat). To that end, the material names used for each element are matched with standard names in the thesaurus DB through the material-property matching function. In this regard, extracted material type-A data can include the standard name with the original name to match the materials with property data in the default and library DB. Finally, the original name of the used material use the final BELC results to determine the specifics for each material.

4.2.4 Calculation Function

For the DOE-2 based BELC process, an INP file is necessary for a building description. In this regard, the calculation function creates an INP file automatically using a conversion mapping table. Table 5 shows the data conversion mapping table from IFCXML file to INP file.

Type-A data and type-M data in the project DB can be converted into an INP file. After converting the file format from the required data (type-A and type-M) to an INP file, the function automatically implements DOE-2 based on BELC. If there are no errors (an error may occur, because the building model has wrong information from the modeling process of the design phase), then the BELC result is a SIM file. The function automatically converts the resulting data from the SIM file into graphical images.

Table 5. Data Entity - Functions Matching

Data Entity \ Key Functions	Type-A data input function	Type-M data input function	Material-Property matching function	Calculation function
DATA_INPUT	C	C R U	C R	R D
DATA_SCHUDLE		C R U		R D
DATA_DETAILEDSPACE		C R U		R D
DATA_MATERIAL	C	R U	C R	R D
DATA_SPACE	C R	C R U		R D
DATA_STORY	C R	R U		R D
DATA_WINDOW	C	C R U	C R	R D
DATA_ZONE	C	C R U D		R D
DATA_DETAILEDMATERIAL	C R	R U D	C R	R D
DATA_OVERHANG		C R U D		R D
DATA_GLASS	C R	R U D	C R U	R D
ANALYSIS_RESULT				C R U D
ANALYSIS_ATTACH				C R U D
ANALYSIS_REQUIRED				C R U D

C = Create, R = Read, U = Upload, D = Delete

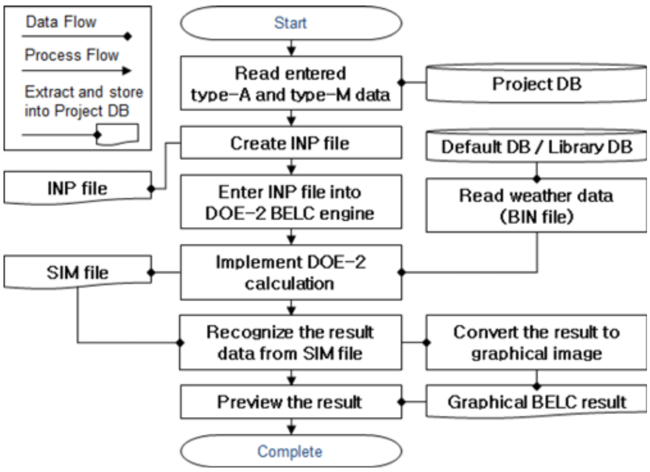

Fig. 6. Calculation Procedure

4.3 Required Data Relationship

The required data for the BELC process from the IFCXML file are stored or loaded into the project DB. The project DB is a key component in the proposed system. In the system, type-A and type-M data demonstrate relationships with each other as shown in Fig. 7. There are 14 data entities in the proposed system, shown as an Entity Relationship Diagram (ERD). In the ERD, the index data provide a foreign key to another data entity. The data entity of ANALYSIS_REQUIRED can be a major entity for the proposed system. From this entity, the DATA_INPUT entity is referred to as a data input index, and ANALYSIS_ATTACH is referred to as an analysis index. In addition, DATA_INPUT has three data relationships with type-M data: DATA_MATERIAL as the material type-M data, DATA_SPACE as the space type-M data, and its own data entity as the general type-M data.

Using the developed ERD, a BELC system using the IFCXML file is designed with four functions. For each function, pre-defined data are Created, Read, Updated, And Deleted (CRUD) automatically and systematically. In addition, since the data entities have relationships with each other, some data are referred to in order to manage data within the system. The type-A data input function are used to automatically extract type-A data from IFCXML. This extracted type-A data are updated by the second function as type-M data input. Material names, which are extracted from IFCXML, are standardized via thesaurus names by the material-property matching function. Finally, the entered data are gathered into the calculation function to create an INP file for BELC. The four functions are matched with the data entities as shown in Table 6.

4.4 Work Process Improvement

According to the workflow and ERD, the proposed system for BELC using IFCXML was developed with a User Interface (UI). The UI consists of three processes: project setup, data input, and calculations.

4.4.1 Project Setup Process

An IFCXML file is required to create a new project for BELC in the proposed system. After a user writes the title of a new project and summarizes abstracts on the system, the IFCXML file is uploaded into the proposed system. While the IFCXML file is being uploaded, type-A data are recognized by the specific extraction algorithm of the proposed system. Extracted type-A data are stored in the project DB, which exists in the proposed system.

4.4.2 Data Input Process

The type-M data input function consists of three data types: general, space, and material. Since the data input process is linked by the default and library DB, type-M data can be entered by a selected given menu. In addition, because such general, space, material, and element type-A data have already been extracted by the type-A data input function, additional required

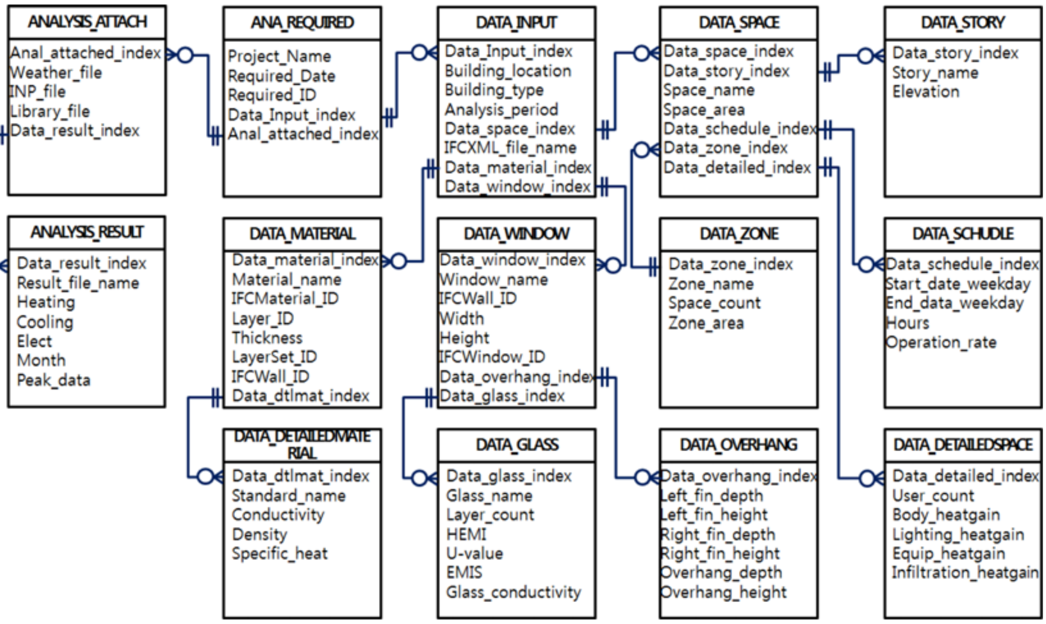

Fig. 7. Data Entity Relationship Diagram

Table 6. Data Conversion Mapping Table from IFC to INP

Building Element		INP Requirements	Extracted Data form IFC	Related Entity on IFC
Space		shape	sweptArea	IfcExtrudedAreaSolid
		height	depth	IfcExtrudedAreaSolid
		azimuth	refDirection	IfcGeometricRepresentationContext
		X	location	IfcAxis2Placement3D
		Y		
		Z		
Envelope	Wall/Roof	height	depth	IfcShapeRepresentation exp:pos=“1”
		width	coordinates	IfcShapeRepresentation exp:pos=“0”
		azimuth	refDirection	IfcGeometricRepresentationContext
		tilt	axis	IfcGeometricRepresentationContext
		X	location	IfcAxis2Placement3D
		Y		
		Z		
	Floor	shape	sweptArea	IfcExtrudedAreaSolid
		height	depth	IfcExtrudedAreaSolid
	Door & Window	height	overallHeight	IfcDoor/IfcWindow
		width	overallWidth	IfcDoor/IfcWindow
		X	location	IfcAxis2Placement3D
		Y		

type-M space data for BELC can be entered based on type-A space data. On the other hand, type-M material data are entered through the material-property matching function with type-A data elements in order to determine the applied element. Figs. 9 and 10 show the design of the type-M data input UI of the proposed system.

Type-M data that are entered must be checked before they are stored in the project DB. The required data can be exported as metadata through an Excel spreadsheet for use by other BELC or BEA tools. Using the exported spreadsheet, the user can enter the required data into the other tools without further data collection. After the user ensures that the required data are entered in the proposed system, the data are automatically stored in the project DB.

4.4.3 Calculation Process

Using the required data from the project DB, an INP file is automatically created by the proposed system. Thus, the proposed system can convert the entered data into a specific INP file format. For example, a value for the type-A element depth data is

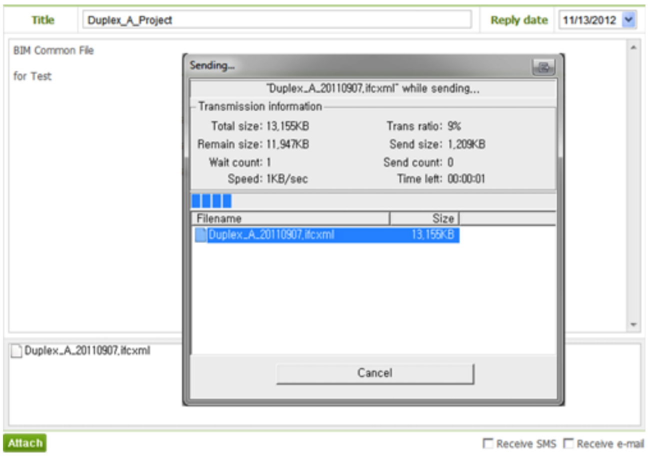

Fig. 8. System UI to Create a New Project

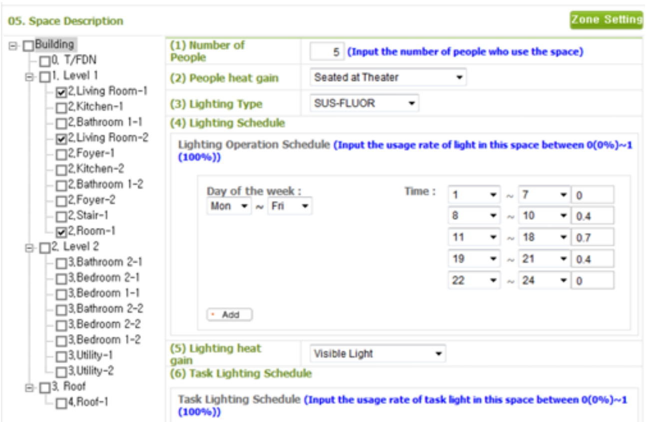

Fig. 9. System UI for Type-M Data Input

converted into the height of the subject element through a conversion algorithm using the calculation function. After creating the INP file in the proposed system, the INP file is entered into the DOE-2.2 engine to calculate the energy load

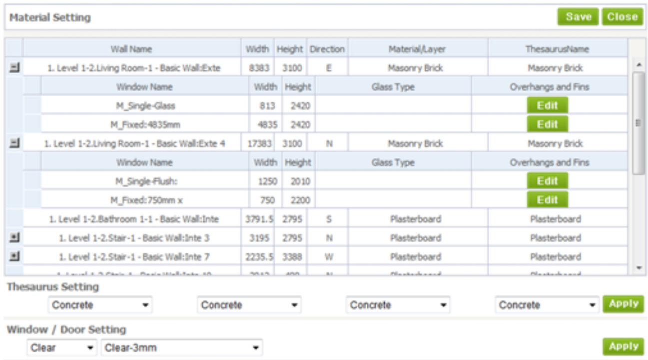

Fig. 10. System UI for Material-property Matching Type-A Data Element

with a weather file (BIN file) of the specific location. In this regard, the weather file is automatically determined by building location, which is entered by the type-M data input function.

5. Case Study

To validate the proposed system, a sample building model was applied to the proposed and current approaches. The most widely used current approaches include a manual BELC process using the eQUEST program with manual data input and the EnergyPLUS program with a BIM-based gbXML file format input by a BELC engineer. Both programs can calculate the building energy load based on the DOE-2 and EnergyPLUS-8.1 engines. The BELC process using current programs was developed as a BEA tool for use by a specific engineer that enters additional information, including BEA requirements, such as HVAC systems and any environmental requirements for a simulation. As such, BEA requirements are needed within the BELC process and require specialized knowledge; otherwise, the BELC process can't run on current programs. In contrast, BELC requirements are composed of architectural information and some operational

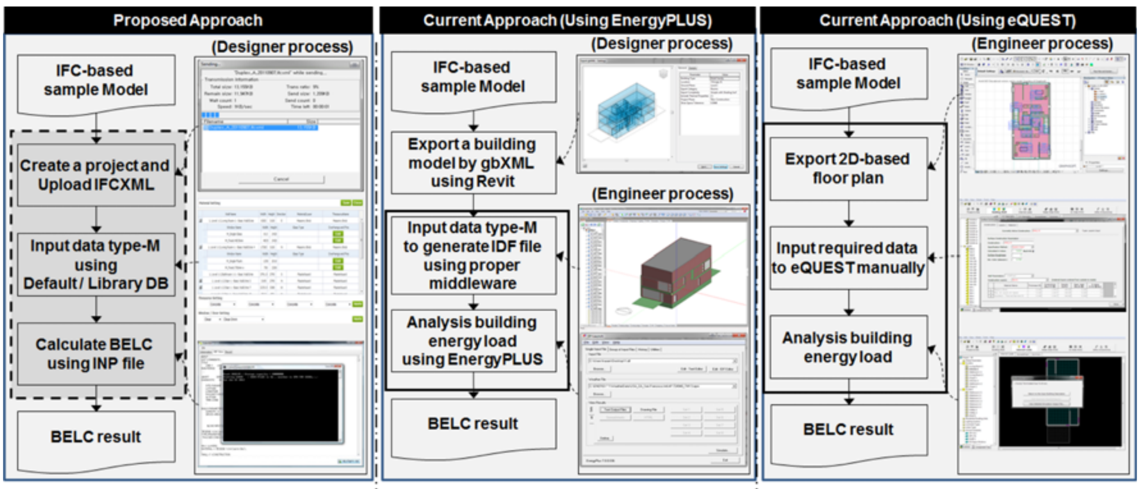

Fig. 11. Comparison of the Proposed and Current Approaches

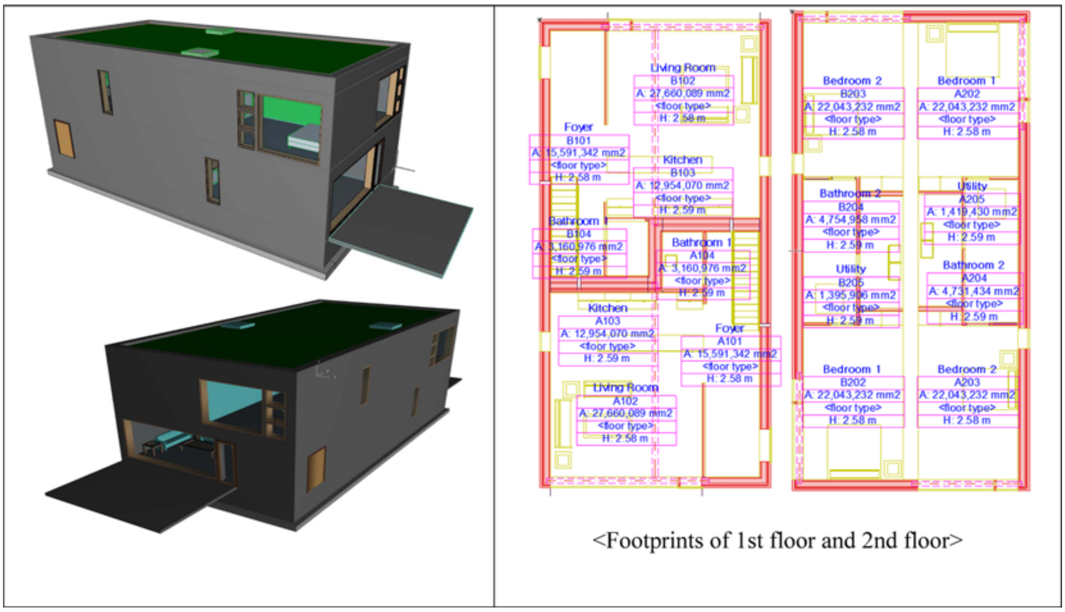

Fig. 12. Common BIM File Images

information including weather and schedules. This information can be handled by designers using default libraries. In this case study, two designers with seven years of work experience at an architecture and design firm in Korea and familiarity with the BIM-based design process ran the proposed approach using a sample building model. The final results from both approaches were the same, although the approaches were different. Fig. 11 provides a comparison of the proposed and current approaches.

In this case study, the proposed system was applied to a common BIM file from the BuildingSMART alliance (http://buildingsmartalliance.org/index.php/projects/commonbimfiles/) website, with a net area of 156.64 interior square meters of modeling by a designer in the design phase. The common BIM file was designed with a foundation, exterior and interior walls, two floors, eight spaces per floor, a roof, and several windows and doors. The eight different spaces reflect various usage types including a living room, foyer, bathroom, kitchen, and bedrooms. The boundaries of each of the spaces include interior or exterior walls in relation to each other. Exterior walls, which are necessary to analyze building energy consumption, were designed as brick on block.

While using the proposed system without a BELC engineer, an IFCXML file was first created with ArchiCAD 14 by the designers. The IFCXML file was then uploaded into the proposed system as basis data. At this time, the proposed system recognized type-A data from the IFCXML file. Since the IFC schema is not intended to store and carry all relevant data for the BELC process (Maile *et al.*, 2007), type-M data must be entered into the system by the designers. As such, a default library DB was applied for this process to easily and systemically input type-M data. In the default library DB, there are various sets of pre-defined data for BELC, such as schedules of each building type, location geography data, and the heat gain of each type. Since the designers applied the results of BELC as an alternative of the building design, including the representation and the conceptual materials in the early design phase, the required data during the design development phase of the BELC process by a designer is lower than in the BEA process by an engineer. In this regard, the other information types for input data of the alternative of the design component might be used as a default value when using a library. Thus, the procedure for type-M data input is available to the designer during the early design phase. In addition, the procedure for creating an INP file for the DOE-2.2 engine runs automatically and systematically without any additional user interaction.

In comparison, for BELC using both the eQUEST and EnergyPLUS programs by a BELC engineer, the IFCXML file cannot be imported. Thus, the whole building description, including geometry and material information must be entered manually into the eQUEST program. Additionally, in order to use the EnergyPLUS program, a gbXML file must be exported from the BIM-based authoring tool to generate an IDF file (i.e., the input data file for EnergyPLUS) using proper middleware. In this regard, the middleware requires some additional information to generate the IDF file, such as HVAC system and environmental requirements for a simulation. Moreover, in order to use the EnergyPLUS program for a BELC process, since the EnergyPLUS program is BEA software, a designer must learn the data input procedure using the UI of EnergyPLUS without an engineer, even to calculate the building energy load, which is not a result of building energy analysis. On the other hand, to enter space data using eQUEST, the polygons of every space are defined by the parameters with accurate location data. After defining the polygons of the spaces and footprints, material information must be defined using the eQUEST program UI. Construction data are created as a composite material set including the layer and material data. In this regard, the property data of each material

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REPORT- LS-D Building Monthly Loads Summary WEATHER FILE- TMY SEOUL KR

MONTH	COOLING ENERGY (MBTU)	TIME OF MAX DY	TIME OF MAX HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM COOLING LOAD (KBTU/HR)	HEATING ENERGY (MBTU)	TIME OF MAX DY	TIME OF MAX HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM HEATING LOAD (KBTU/HR)	ELEC-TRICAL ENERGY (KWH)	MAXIMUM ELEC LOAD (KW)
	- - - COOLING - - -						- - - HEATING - - -						- - - ELEC - - -	
JAN	121.65895	4	17	41.F	37.F	652.622	-50.753	29	6	9.F	6.F	-207.396	0.	0.000
FEB	112.29136	14	17	45.F	36.F	666.452	-38.090	12	5	25.F	23.F	-157.897	0.	0.000
MAR	153.25652	22	17	64.F	50.F	738.867	-21.848	5	6	27.F	24.F	-129.364	0.	0.000
APR	150.98735	28	17	73.F	58.F	771.451	-9.935	3	6	37.F	35.F	-94.861	0.	0.000
MAY	183.82172	12	17	75.F	64.F	799.573	-3.736	7	6	50.F	46.F	-59.822	0.	0.000
JUN	200.58994	14	17	86.F	71.F	830.183	-0.438	3	6	55.F	53.F	-19.530	0.	0.000
JUL	199.74464	20	17	88.F	79.F	826.801	-0.009	7	6	66.F	64.F	-1.665	0.	0.000
AUG	223.30878	11	17	88.F	80.F	842.891	-0.037	25	6	59.F	55.F	-4.029	0.	0.000
SEP	184.41380	15	17	81.F	69.F	815.096	-0.383	11	6	61.F	56.F	-16.917	0.	0.000
OCT	166.66086	5	17	73.F	61.F	789.368	-6.964	30	6	39.F	38.F	-81.949	0.	0.000
NOV	134.11433	6	17	61.F	51.F	724.627	-23.066	27	6	25.F	21.F	-152.156	0.	0.000
DEC	118.77327	1	17	52.F	45.F	659.953	-42.221	4	6	14.F	10.F	-177.716	0.	0.000
TOTAL	1949.622						-197.479						0.	
MAX						842.891						-207.396		0.000

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REPORT- LS-A Space Peak Loads Summary WEATHER FILE- TMY SEOUL KR

SPACE NAME	MULTIPLIER SPACE	MULTIPLIER FLOOR	COOLING LOAD (KBTU/HR)	TIME OF PEAK	DRY-BULB	WET-BULB	HEATING LOAD (KBTU/HR)	TIME OF PEAK	DRY-BULB	WET-BULB
2.Living Room-1	1.	1.	50.917	AUG 17 5 PM	86.F	72.F	-14.974	JAN 29 6 AM	9.F	6.F
2.Kitchen-1	1.	1.	34.605	AUG 17 5 PM	86.F	72.F	-8.122	JAN 29 6 AM	9.F	6.F
2.Bathroom 1-1	1.	1.	8.290	AUG 17 5 PM	86.F	72.F	-8.075	JAN 29 3 AM	9.F	6.F
2.Living Room-2	1.	1.	48.559	AUG 17 5 PM	86.F	72.F	-13.844	JAN 29 6 AM	9.F	6.F
2.Foyer-1	1.	1.	52.027	AUG 11 5 PM	88.F	80.F	-23.325	JAN 14 6 AM	9.F	7.F
2.Kitchen-2	1.	1.	31.822	FEB 16 5 PM	37.F	29.F	0.000		0.F	0.F
2.Bathroom 1-2	1.	1.	8.384	AUG 17 5 PM	86.F	72.F	-1.669	JAN 29 3 AM	9.F	6.F
2.Foyer-2	1.	1.	31.528	AUG 11 5 PM	88.F	80.F	-14.908	JAN 14 6 AM	9.F	7.F
3.Bathroom 2-1	1.	1.	25.942	AUG 11 5 PM	88.F	80.F	-29.100	JAN 14 7 AM	9.F	7.F
3.Bedroom 2-1	1.	1.	65.418	AUG 17 5 PM	86.F	72.F	-22.998	JAN 29 6 AM	9.F	6.F
3.Bedroom 1-1	1.	1.	38.397	AUG 11 5 PM	88.F	80.F	-11.837	JAN 14 6 AM	9.F	7.F
3.Bathroom 2-2	1.	1.	11.734	AUG 11 5 PM	88.F	80.F	-8.509	JAN 14 6 AM	9.F	7.F
3.Bedroom 2-2	1.	1.	35.943	AUG 11 5 PM	88.F	80.F	-12.785	JAN 14 6 AM	9.F	7.F
3.Bedroom 1-2	1.	1.	55.211	AUG 17 5 PM	86.F	72.F	-4.125	JAN 29 6 AM	9.F	6.F
3.Utility-1	1.	1.	3.842	AUG 17 5 PM	86.F	72.F	-1.181	JAN 29 3 AM	9.F	6.F
3.Utility-2	1.	1.	3.903	AUG 17 5 PM	86.F	72.F	-1.196	JAN 29 3 AM	9.F	6.F
4.Roof-1	1.	1.	339.048	JUL 21 5 PM	82.F	76.F	-36.145	JAN 29 6 AM	9.F	6.F
SUM			845.571				-212.790			
BUILDING PEAK			842.891	AUG 11 5 PM	88.F	80.F	-207.396	JAN 29 6 AM	9.F	6.F

Fig. 13. BELC Result From Proposed System

can be entered using the eQUEST default library for conductivity, density, and specific heat data. Subsequently, the strategy information for the spaces must be defined manually for occupancy, ventilation, heat gain, and schedules. Finally, the results from DOE-2.2 based on BELC is shown in Fig. 13 and is the same result as the BELC process using eQUEST 3.64. In addition, the BELC result of EnergyPLUS provided the same results as the BELC process. The exact same BELC results were output from both the current and proposed approaches using the sample building model.

6. Discussions

During the early design phase, the efficiency of the design process to improve building energy performance is increased when a designer can self-check BELC results without the tedious and repetitive involvement of an engineer in the BELC process. Moreover, the use of an IFC/IFCXML file format as a standard BIM-based building model in the proposed system can ensure the commonality and flexibility of IFC-based BIM data. In the proposed system, during the early design phase, the designer can consider the results of BELC to design the building information including representation and location, by using the default library DB. Afterwards, detailed materials are determined by the designers, and they can be assured of a detailed BELC result using specific data for the BELC process. These can be input data for use in the building energy analysis by a BEA engineer.

To adopt the proposed system, the BIM-based building model must include the required data for the BELC process, such as spaces, zones, materials, and occupant strategies. For this reason, this level of detail of the building model has to be defined in order to use the proposed system. Since the building model, which is generated during the design process, is not optimized for the BELC process, there are some limitations: 1) the scope of the BELC result depends on the level of detail of the building model, 2) the speed of data processing may increase with the size of the building model, and 3) there are limits in the conversion of the 1st and 2nd space boundaries for a free-form building model including a curved wall. To address these limitations, the scope of the BELC by each level of detail of a building model is defined to determine the accuracy of the BELC process. In addition, the data extraction module should be upgraded to extract the specific BIM data to reduce the file size and to improve the capacity of the free-form designed building model.

Since the required data for the BELC process can't be fully automated and generated, a designer has to review and manually input some types of required data. Focusing on the material property data which is material type-M data, after the material names are extracted from an IFCXML-based building model by the material-property matching function, the related property data are mapped to the name through a semantic material name matching algorithm (Kim *et al.*, 2013). After that, a designer can check for any errors or missing matched material data. In addition, if the designer needs to generate some alternatives to improve the building energy performance, the designer can manually change the results of the matched material data. In this regard, the material property data are inputted from the default and library DB without any involvement of a BELC engineer. Moreover, focusing on the operation strategy, including occupant schedules, the set up depends on the building type. In this regard, operation strategies are managed by the default and library DB in the proposed system. Subsequently, after the designer checks the inputted data or if it is necessary to adjust the operation strategy data, the designer can change the values per the specific project environment. Therefore, the efficiency of the review and items that require manual input can be improved upon by using the proposed system that includes a robust library DB. As such, the accuracy of the proposed system depends on the capacity of the library DB. This paper presents the library DB as a sample to validate a case study, which is a common BIM file provided by the BuildingSMART international alliance.

The required data within the BELC process include the input of specific data values by a BELC engineer, such as information regarding people or equipment heat gain, and infiltration. Since a designer does not have sufficient specialized knowledge and expertise to conduct a BELC process, the designer can make a human-mistake during manual data input, and this can present a barrier to inputting the required data. The designer can thus be focused on BELC data that include the representation and placement of building elements and spaces and material data. During the early design phase, the operation strategy data (e.g., heat gain or infiltration) can be applied as generic default values for later decision-making in terms of building elements and BELC spaces. Generic default values can be adopted from ASHRAE standards or other international standards. In addition, since the operation strategy is not only design-specific, but also building type-specific, it is necessary to perform human activity-based space use analysis (Kim *et al*., 2013).

Finally, this study generated an INP file to calculate the building energy load using the DOE-2.2 engine to present the proposed methodology. In this regard, the building description format can be changed when adapted to other BELC engines. To that end, the proposed system can be modified to generate other required formats. Thus the proposed system can be extended and applied to the early design phase in other engineering process domains that require BIM-based building information in a building life cycle. Improving the efficiency of the data input procedure in the BELC process furthers the whole design process, and a building model can now also provide related information through an automated extraction algorithm. To that end, a data extraction algorithm must be developed per each objective of an engineering analysis. Using the automated extraction and transfer approach in the engineering process, repetitive and tedious manual data input processes can be improved to provide improved accuracy and a reliable computerized data input process. In general, an engineer has to enter the design information on his or her own into an engineering analysis program. However, the design information should be provided from the designer of the building, since the data do not require engineering knowledge or expertise. Identification of the potentially responsible parties for the data can improve clarity. Moreover, the proposed system provides a self-check for the BELC process by focusing on the design information without a BELC engineer, thus allowing for a fast track to determine an optimized building-design alternative.

7. Conclusions

To ensure project effectiveness and efficiency, the use of a BIM-based BELC process has increased along with the use of the IFCXML file format by architects, engineers, and the construction industry (AEC). The BELC process, however, creates several potential challenges due to the need to manually obtain BELC results, the need to have BELC engineers input specific information, and often unclear data authority and responsibility in the process.

To address and solve these problems, this paper proposed an automatic and systematic BIM-based BELC system for designers. To that end, data requirements for BELC were categorized by the following data input methods: general, space, material, and element. In addition, data types were defined as automatic (type-A) and manual (type-M). The proposed system consisted of four key functions: type-A data input, type-M data input, material-property matching, and calculation functions. Type-A data were automatically extracted using an IFC schema and used as a basis for type-M data input to ensure that the user can easily and accurately input the required type-M data. To validate the proposed system, a common BIM file, which is supported by BuildingSMART, was applied to both the proposed approach and the current approaches including the eQUEST program using an INP file and the EnergyPLUS program using a gbXML file. The BELC results from both approaches were exactly the same, which is desired since the subject building models were the same. However, the data input procedures were improved by automatically importing BIM data and systemically using a library DB.

This proposed system will enable architects and engineers involved in a building project to input their respective data separately, but concurrently. Consequently, the proposed system can contribute to increasing the efficiency of the data collection process. In addition, since the BIM-based building information can be re-used in a whole building life-cycle, the value of the BIM-based building model is increased by eliminating the unnecessary recreation of required data and by reducing the possibilities for inefficient human-mistakes. This creates the opportunity to increase the economics, accuracy, and productivity of the design process.

Future research should pursue further validation of the building model, including for free forms and curved walls. In addition, the proposed system should be further developed to support building energy certification and the HVAC system design process. Lastly, in terms of managing the quality of the BIM-based energy model, the methodology for updating the actual thermal properties of construction materials in an existing building should be developed with considerations about constructability by contractors. Lastly, collaborations with various stakeholders over and beyond the whole life-cycle should be further investigated.

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