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BIM IFC information mapping to building energy analysis (BEA) model with manually extended material information

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A B S T R A C T

To reduce fossil fuel based energy consumption in buildings, different methods have been proposed. Interestingly, one of the most significant factors in building energy consumption has been reported in the area of improving building designs. However, building energy analysis (BEA) is typically conducted late in design, by energy analyst specialists. The ability to try out new ideas early in the design process in order to choose the best alternative is not ordinarily taken advantage of, due to the difficulty and expense of modeling the building and energy systems. Building information modeling (BIM) provides the user with an opportunity to explore different energy saving alternatives in the design process while avoiding the time-consuming process of re-entering all the building geometry, enclosure, and HVAC information necessary for a complete energy analysis.

While significant time savings are being made by not having to create the building geometry within the simulation interface in BIM energy modeling simulation, there is a good possibility of missing, misplaced, or deformed building elements during a BIM data exchange process. This research focuses on one of the major limitations – inaccuracies through simplifications in construction/material data – and aims to improve the accuracy of energy modeling process by developing an object based approach in materials in which the energy modeler may change and expand various properties in building materials. In testing the performance of the proposed approach, the results from the proposed energy modeling process in the case study are compared to those of existing energy modeling software which showed significant gains in accuracy.

1. Introduction

Buildings consume 40% of all energy in the USA, with electricity use representing the majority of this energy [11]. Depending upon the energy cost and climate where a building is located, existing and advanced construction technologies and building design strategies can significantly reduce energy consumption. According to a CERL report (2009), a design improvement including an envelope insulation and a material selection can result in a significant amount (30%–35%) of energy reduction beyond the ASHRAE 90.1 2007 standard for less than an additional 2% in construction cost [33].

When it comes to energy reduction, energy modeling/simulation can be very effective [34]. However, most building energy analyses (BEAs) have been conducted late in design, by energy analyst specialists. The ability to try out new ideas early in the design process in order to choose the best alternative is not ordinarily taken advantage of, due to the difficulty and expense of modeling a building and its energy systems. Today BIM provides the user with an opportunity to explore different energy saving alternatives in the early design while avoiding the time-consuming process of re-entering all the building geometries, enclosures, and HVAC information necessary for a complete energy analysis [27]. This approach would also help project teams make cost-effective retrofit decisions such as how much rigid insulation should be put on a roof during re-roofing. This research developed a new object based approach in materials properties using BIM technology that the user may change or expand while securing data operability between BIM based 3D design and energy performance management. Detailed tasks include (1) the establishing of automatic data parsing in IFC, and (2) the developing of an object based approach in BIM material properties. To test the feasibility of the proposed approach, the results of a case study from the

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proposed energy modeling process will be compared to those of existing energy modeling software such as GBS.

2. Current research review

The BIM open standard in Industry Foundation Class (IFC) is applied in this research. IFC files, as an open BIM standard, not only contain geometries of walls, columns, beams, doors, windows, and other building components, but also contain specific attributes for each object, such as material type, material property, and vendor, to name a few. IFC was applied to construction scheduling [19,21], cost analysis [12,30], quantity takeoff (QTO) calculations [20], bridge design [15], concrete reinforcement supply chain [1], building design review systems [22], and construction safety [31]. Significant research has been conducted in the area of IFC data extraction in the design and construction of facilities, but energy modeling in BIM has not been widely researched.

In the early days, energy modeling tools were complex, and required a great deal of time [10] gathering and accurately entering the myriad of building description data required for simulation. In the traditional energy modeling, all the required information was mostly input by the modeler and simplifications to the proposed geometric design were frequently made due to the fact that the input process was too complex and required a lot of information. For example, DOE-2.2 and EnergyPlus were developed for the predicting of energy consumption in the building sector to determine the energy consumption profile, but were very exhaustive and required labor intensive effort ([13] and [32]). Today BIM can be used as an intelligent 3D model that enables the designer to more efficiently plan, design and manage buildings. Rather than just the lines and arcs associated with traditional computer-assisted design (CAD) tools, BIM includes additional benefits of intelligent objects of a building structure such as exterior/interior walls, roofs, windows, doors, floors, an envelope shape, and its orientation. In addition, energy modeling requires supplementary data such as composite materials, and thermal properties (density, specific heat, conductivity, and thickness) of each material.

Based on the level of details stored in a BIM model, different BIM energy simulations are possible in the different design phases as follows:

Table 1 shows that there are three different phases in the design process. In the preliminary phase, there is very limited information stored in a BIM model such as total square footage. Using the information, the owner can see an approximate energy estimate. In the early design phase, however, there is more information available such as building shape, orientation, approximate HVAC type, occupancy information, and the number of users. During the detailed design phase, the user can have an accurate estimate using lighting control, light power density value and so on.

Cho et al. [9] developed a strategy to include sustainable fixtures in predicting energy generation using BIM technology. Chen and Gao [8] presented the result of a pilot study in optimizing building energy performance using a multi-objective generic algorithm using BIM energy simulation. Raheem et al. [35] analyzed annual energy consumption and CO_2 emissions in a single house using BIM. Kim et al. [19,21] developed an energy simulation process that runs in DOE 2.2 using BIM open standard (IFC). Reeves et al. [26] developed guidelines for using building energy modeling (BEM) using BIM. Jiang et al. [16] investigated a set of the key BIM server requirements for information exchange in energy efficient building retrofit projects. Kim et al. [19,21] developed a semantic material name matching system to find a standardized material name and its associated material property values. Also, several researchers [25] proposed a method using a genetic algorithm and pareto optimality to determine the desired design option for various double glazing systems. They developed an application for data exchange from a gbXML file to an IDF file in EnergyPlus. Attia [3] surveyed the selection criteria of building performance simulation tools between various stakeholders on a construction project where the result indicated a broad range of differences between designers and the simulation tools. Sullivan and Keane [28] proposed a graphical user interface to input the necessary information representing a HVAC system into a BIM-based building energy simulation in IFC. This demonstrated a possibility of information exchange between the BIM model and the BEA tools. Bazjanac [37] described the methodology and interoperability of IFC-based BIM and BEA tools where geometry and HVAC information is re-transported into EnergyPlus. It is noteworthy that Bazjanac [36] reported of building geometry which should be defined as a system of surfaces in energy simulations using "space boundaries" which are the critical part of building definitions in energy simulations. He reported that it would be important to consider the second level space boundaries since the entire area is defined as their surface in pairs provide unique and consistent rate of transmission or flow. Katranuschkov et al. [17] developed an energy enhanced BIM (eeBIM) framework where the authors intended to close the current gap between existing data and tools from a building operation and design to enable an efficient life cycle energy performance estimation and decision-making. Also, it is important to recognize the effort of ISES which is a European FP7 industry-driven project. The objective of the project was to develop the building blocks which integrate, complement and empower existing tools for design and operation management [14]. With the advent of BIM technology, Arayici et al. [2] described how the industry is experiencing difficulties reinventing the workflow, training staff and assigning responsibilities, and changing the way a building is modeled. A typical BIM data has to be combined with other kinds of construction related data to be efficiently applied in real tasks such as energy simulation [17]. They described the importance of developing a framework enabling the integration of multiple needed resources (climate, occupancy, material data, etc.) and the interoperability of a number of energy analysis, cost analysis, CAD, FM and monitoring tools.

3. Problem statement on current BIM based energy modeling approach

Energy modeling using BIM opens a potential to simplify the whole process by seamlessly leveraging the required information stored in an architectural or mechanical model. McGraw Hill Construction [24] reported that energy performance simulation is very common nowadays—73% use these tools in BIM. However, there are a few limitations/problems reported in BIM based energy simulations such as difficulty in BIM data exchange [19,21], lack of HVAC equipment data, and uncertainty in building zoning [29]. While a significant time saving can be achieved during the BIM based data exchange, there is a major

Table 1
Information available in different design phases in BIM energy modeling.

Different design phases	Preliminary design	Early design	Design and detailed design
Information available (LoD)	Total square footage, building shape, orientation and so on.	HVAC, occupancy schedule, outside air flow per person, outside air flow per floor area, outside air change per hour value, number of users, and so on.	Detailed types of HVAC, walls, roof construction, lighting efficiency, lighting control, equipment power density value, light power density value, equipment efficiency, daylighting control, occupancy sensor, glazing, window to wall ratio, and so on.
Accuracy of energy modeling	Low	Medium	High

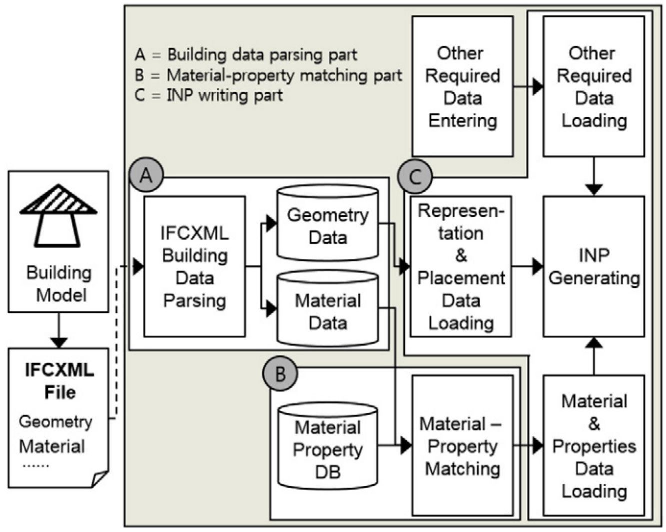

Fig. 1. Overview of proposed system.

problem of simplification resulting in missing, misplaced, or deformed building elements in BIM data exchange. Especially, this research recognized a research need in the area of construction and material data, for which current BIM based modeling tools provide users with a very limited option of choosing different building components particularly in walls, floors, roofs, etc. in the modeling process. Compared to most energy simulation software (EnergyPlus or eQUEST) which has a variety of materials to choose in the simulation process, BIM based tools offer just a few choices in their programs. GSA [29] reports of limitations and recommends a few guidelines such as "improved transfer of curtain wall data and curved surfaces". With composite layers such as bricks and plywood in a single wall, most BIM energy modeling software currently does not give the user all the option to customize the wall as a composite wall. Instead, he/she should simplify the wall and choose the material as either bricks or plywood in the modeling process. These assumptions may be inaccurate and not coordinated with the proposed design.

4. Proposed methodology

This research intends to establish a BEA system using an object based approach in material properties while utilizing BIM technology with the goal of increasing the accuracy of the energy modeling result.

In a BIM based energy simulation process, the input data mainly consists of the building geometry, material properties, internal loads, HVAC systems and components, weather data, operating strategy and schedules, and simulation specific parameters [23]. A BIM in IFC contains sufficient information for the analysis of the envelope performance in energy modeling. It also contains information on how spaces touch the fabric elements such as walls and slabs.

Fig. 1 shows the overall procedure of the proposed BIM based energy modeling approach with three sections:

- In part A of filtering, the building data in IFC is divided into geometry and material data. The building geometry is needed for the simulation of the building's thermal performance. Traditionally, the geometry is imported using 2D-DXF/DWG files as a footprint for the creation of the energy model. As more and more 3D building geometry models are becoming available, major BIM software shows its capability for generating IFC file of the building geometry automatically. This research utilizes the importing of the building geometry in specifying the location, space types/sizes and thermal zones of a building.
- In part B of mapping, a material's name is matched to a set of predefined materials properties where thermal properties of conductivity, density, specific heat and resistance are stored. In case the material is not found in the existing database, then a new set of materials properties will be added and stored in the library accordingly.
- In part C of extending, all the information is gathered to produce an INP file which is loaded into the DOE 2.2 energy simulation engine. While the geometric information (floors, walls, roofs, openings and spaces) has been extracted from the BIM, additional information is required to be defined including: the duration of the simulation, heating ventilation and air conditioning (HVAC) system, site location in coordinates, material types, report type, utility rates, and layer constructions. Since the additional information is not collected from a BIM model, the user needs to add information into the proposed system during the simulation process. DOE 2.2 generates a comprehensive energy report in the format of simulation (SIM) file which allows the user to read explicit details of the simulation ranging from peak building loads to monthly plant energy utilization.

4.1. Part A: IFC building data parsing

The proposed system extracts information from the BIM model by parsing the material, location and quantities for all individual elements using IFC format, then the data is stored in the proposed system. As shown in Fig. 2, the building data parsing starts with a BIM created in 3D/CAD BIM software. Then, the necessary data (geometry and materials) is extracted in IFC from the BIM. Finally, the retrieved geometry and material information is stored within the proposed system. In the figure, an example of a BIM model is shown with a gypsum board wall

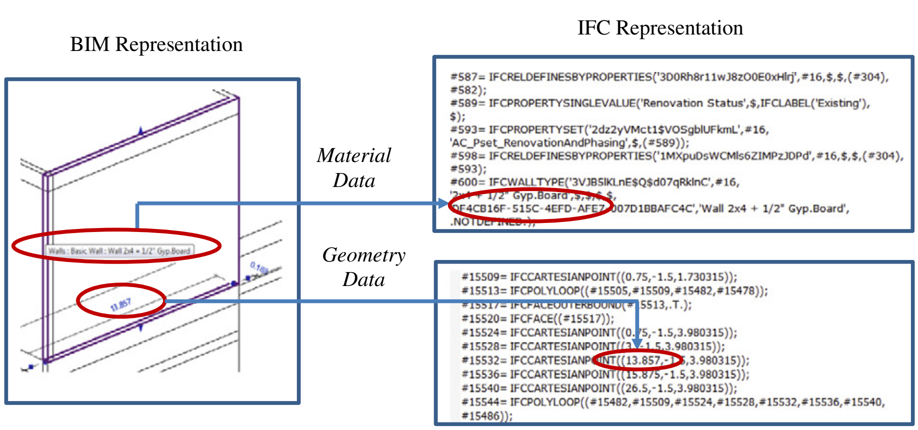

Fig. 2. BIM—IFC data exchange process.

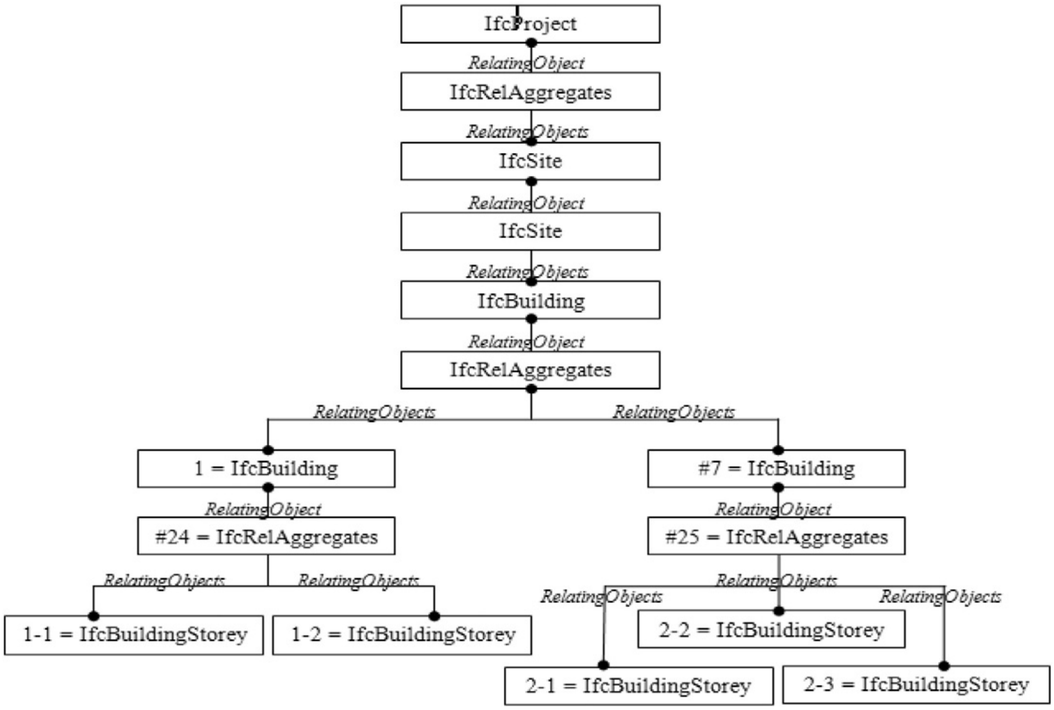

Fig. 3. Graphical illustration of IfcSpatialStructureElement [5].

of the geometric information (length: 4.33 m) and material type ($2 \times 4 + 1/2$ gyp board). Overall, the BIM included over 60,000 objects in building components.

IFC encompasses a vast amount of information in an attempt to address all information related to a building over its lifecycle. buildingSMART designed IFC as an entity-relationship model that is

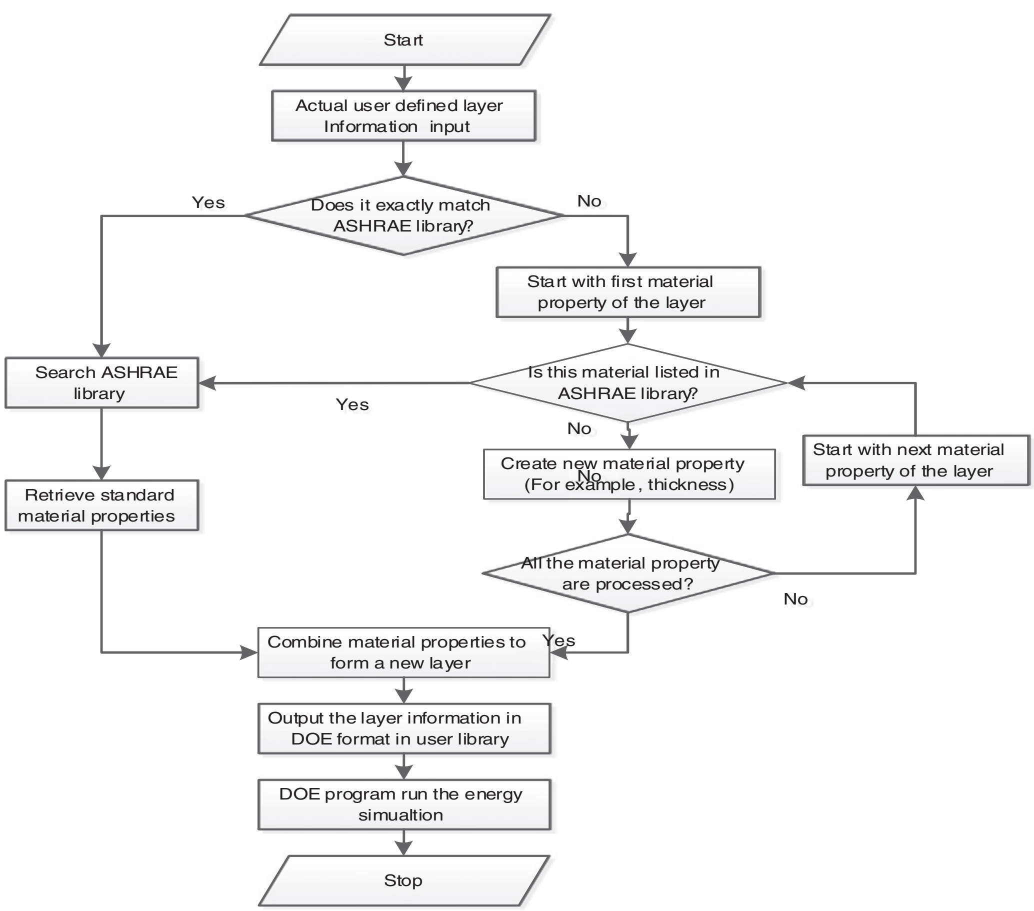

Fig. 4. Materials matching process in the proposed system.

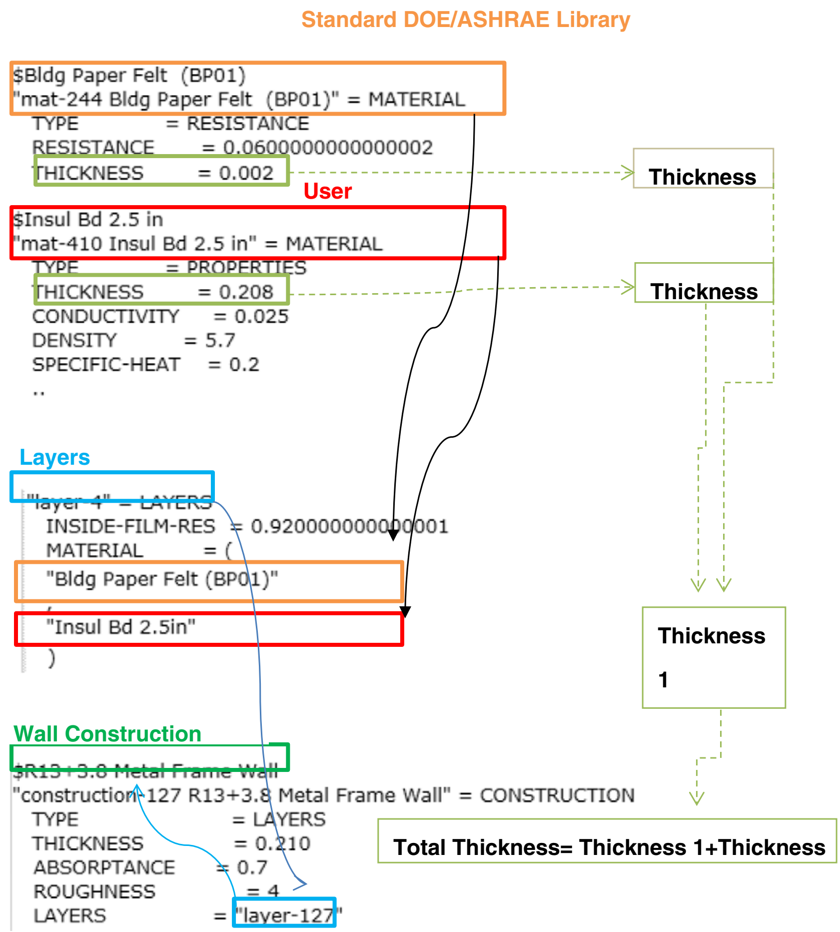

Fig. 5. Customizing the materials properties in BIM based energy modeling.

organized into an object-based inheritance hierarchy. While the IFC model is immense and constantly growing with each new release, an energy simulation in this research only requires certain sections of IFC. In constructing an energy simulation, one section we are particularly interested in consists of the geometric and spatial information about the structure. For the extraction of geometric, spatial and relationship information we examined the sub-entities in the *IfcRoot* tree. *IfcRoot* is the most abstract root class and all entities that are subtypes of *IfcRoot* can be

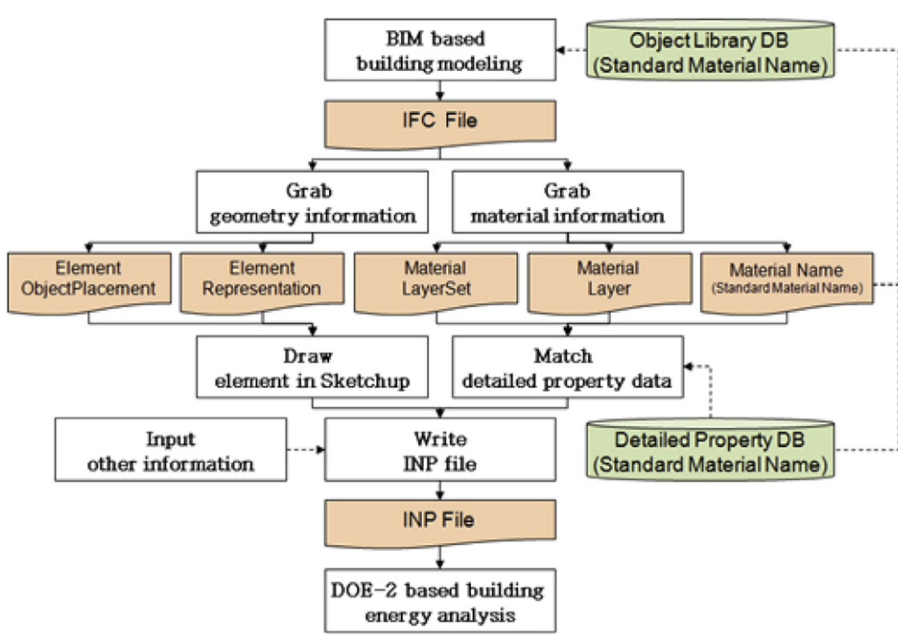

Fig. 6. Creating an INP file in object based materials properties system using BIM.

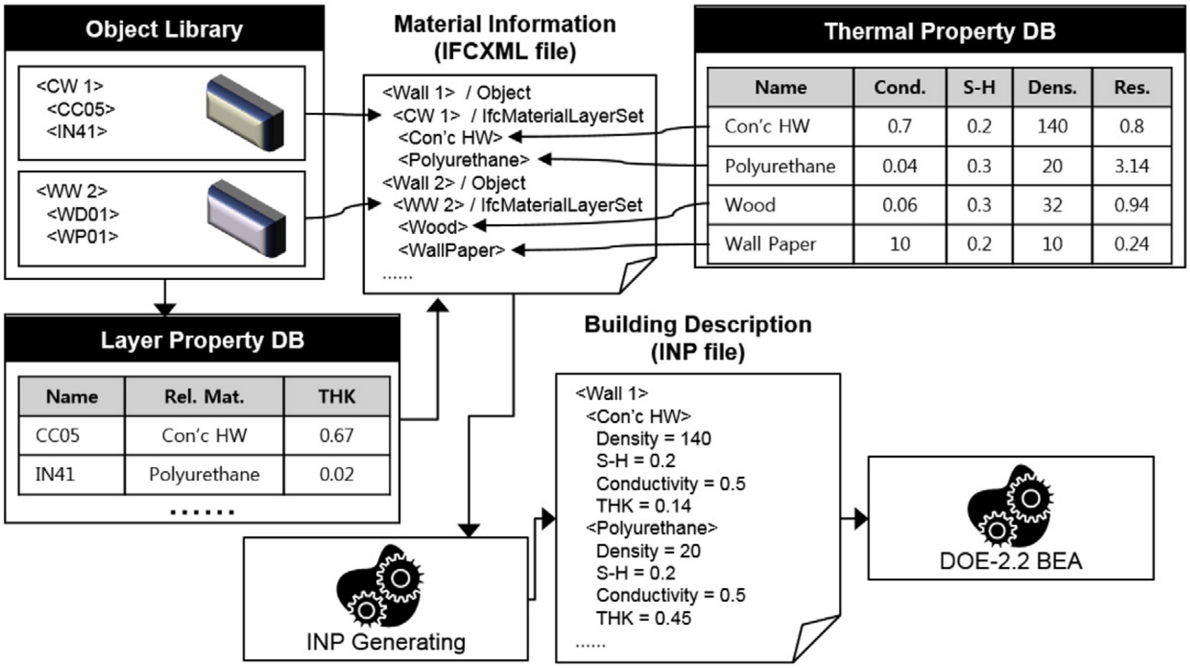

Fig. 7. Material–property matching process.

used independently, whereas others are not meant to be used as independent entities [5]. Information about building elements can be found deep within the subtypes of *IfcRoot*. To be more specific, to find geometric and spatial information about a slab, one could trace through the following path: *IfcRoot* → *IfcObject* → *IfcObjectDefinition* → *IfcProduct* → *IfcElement* → *IfcBuildingElement* → *IfcSlab*.

Consequently, each new subtype adds information in the form of relationships and attributes. Graphically illustrated in Fig. 3, where the original graphical illustration of IfcSpatialStructureElement was developed by building SMART in 2007.

4.2. Part B: Building materials properties matching using object libraries

Material property matching is one of the most crucial parts in the proposed approach. In the current BIM based approach, there is a potential for a modeler to make assumptions about thermal properties since not many material options are available. These assumptions are often inaccurate and not coordinated with the proposed design. As shown in Fig. 4, the material data extracted from a BIM model in IFC are first matched to a material's name in BEA engines such as DOE-2 or EnergyPlus which stores a set of thermal properties (e.g. density, specific heat, conductivity, and thickness). Unlike most BIM based energy modeling software, DOE-2.2 comes with dozens of different layers of composite layers stored. In addition, if one chooses a building material not pre-defined in BIM based software, the proposed approach allows him/her to gather the necessary information (density, U-value, etc.).

Fig. 4 shows that the proposed system recognizes each component as an object and can collect necessary information (materials or thickness to create a new layer type in the DOE program user library. At the beginning of Fig. 4 the system retrieves the information from each layer. If the type of a layer is identical with the material type in the ASHRAE library, the system will use the property information stored in the standard material library. However, if the type of a layer is not the same as the default types in the library, the system will create a new property based on its new material type or thickness. The system continues repeating this process until all the material properties of the layer are processed. Then all the material information is combined to construct the layer in the user library. The proposed system utilizes

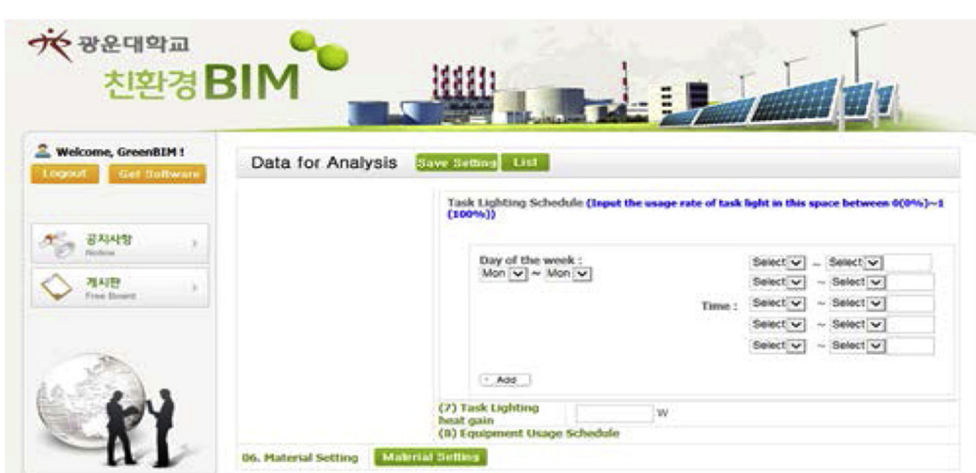

Fig. 8. Proposed energy modeling system.

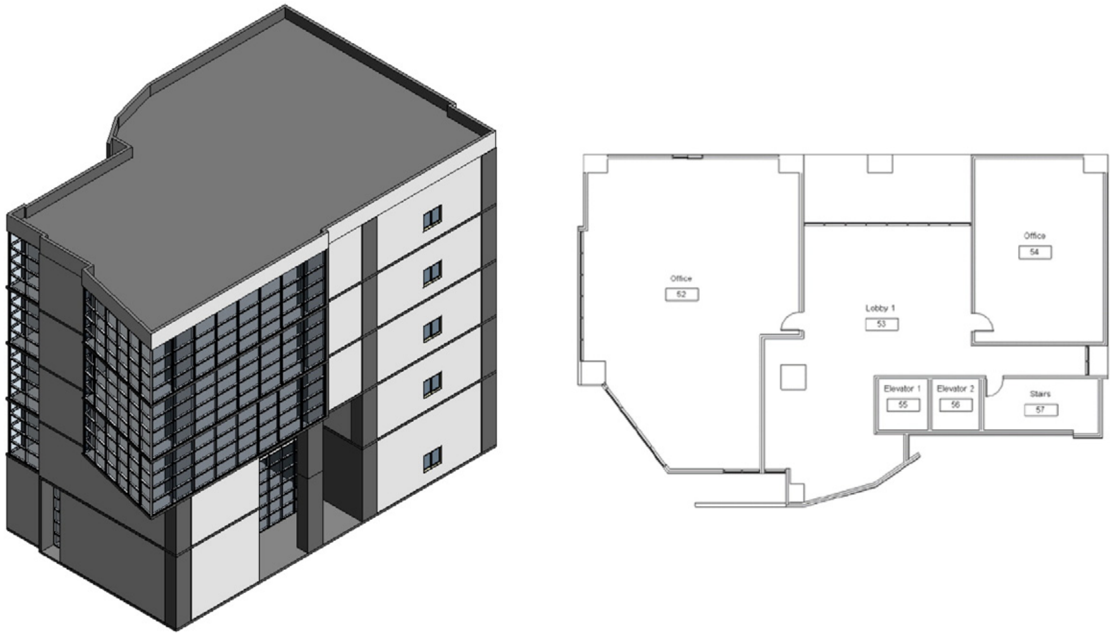

Fig. 9. Proposed office building and its floor plan in BIM model.

the user library to recognize the layer type and run the energy simulation.

Fig. 5 shows the detailed process of creating a new property set based on a new material type and thickness. The type of material that is not stored in the standard library will be collected separately along with different thickness and is used to create a new wall type "R13 + 3.8 metal frame wall" where the total thickness is the sum of 0.002 (bldg paper felt) and 0.208 (insul Bd 2.5 in) and create a new layer set of "layer-127".

4.3. Part C: INP writing

Through combining the processed information from parts A & B, an INP (data input) file is generated.

Fig. 6 shows the process where the INP file is created for DOE-2.2 BEA for mapping 3D geometry to BEA input. Information stored in IFC will be grouped into different sets of elements such as ObjectPlacement, representation, LayerSet, material layer and its name in the IFC schema. Then the information is proceeded to match property data in the user defined library to create the INP file.

INP files consist of following categories such as loads, meters, pumps, circulation loops, plant equipment, air systems, zones, economics and reports. The loads category requires much of the basic information about the subject building model. Also, required is a set of additional information (desired run period – maximum of one calendar year, building occupancy type – e.g. office, warehouse, parking garage, building location, proposed HVAC system—the proposed system uses hardcoded systems from the DOE-2 library, and applicable utility rates) that is not collected from a BIM model. Thus, the required information is entered to the proposed system. The data combined in the process is utilized to create an energy input file. Once the INP file is created, it becomes possible to run an energy simulation using DOE-2.2 engine which generates results such as building energy performance, energy cost summary, space peak summaries and so on.

The final output of using the information stored in material information in IFC is used to create an energy input file for the DOE-2 energy simulation engine. Fig. 7 shows an example of how the information collected from multiple layers of wall materials of concrete HW-polyurethane and wood-wall papers are used to create an input file, INP.

So, the proposed research provides an automatic mapping of building materials to a set of object libraries. A computer program was developed in a computer language, Ruby for the application. The program extracts the geometry and material data from a BIM and finds a match according to the names of the materials stored in a materials property library. After the matching, the computer program sends all the collected information to DOE 2.2 energy simulation engine to generate a comprehensive energy report. The object library is embedded in the SketchUp software and collected to the BIM software through the software support of the SketchUp plug-ins.

5. Case study

The proposed approach was to provide more materials properties so that the accuracy of BIM based energy modeling can be increased. The proposed system used the Ruby console to load the developed scripts for energy simulations. The Ruby script extracts the geometry and material data from a BIM and finds a match according to the names of the materials stored in a materials properties list.

Table 2
Zoning of the office building.

	Office		Lobby	Elevator		Stairs	Storage		Hallway	Toilet		Mechanical Room
	Office 1	Office 2		Elevator 1	Elevator 2		Storage 1	Storage 2		Toilet 1	Toilet 2	
1st floor	X	X	X	X	X	X				X	X	
2nd floor	X	X	X	X	X	X	X	X	X	X	X	
3rd floor	X			X	X	X						X
4th floor	X			X	X	X	X	X		X	X	X
5th floor	X			X	X	X	X	X		X	X	X

Table 3
Layers list of the BIM model.

Building components	Actual layers used in the proposed approach		Layers found in GBS	
	Layers	Area/ U-value (BTU/ft^2–h–°F)	Layers	Area/ U-value (BTU/ft^2–h–s°F)
Roof type	Blt-up roof 7/8 in Bldg paper felt (BP01) 2 MinBd 3.5 in R-13.5 Wood Sft 1.5 in	4387 sf /0.021	R20 over roof deck Blt-up roof 3/8 in (BR01) Bldg paper felt (BP01) 2 MinBd 2 in R-10.4 (IN24) Wood Sft ¾ in (WD01)	4387 sf /0.044
Wall type	Face brick 5 in Bldg paper felt (BP01) Insul Bd 2.5 in MinWool batt R15 GypBd 1.5 in	36,010 sf /0.768	R13 ± 3.8 metal frame wall Face brick 4 in (BK05) Bldg paper felt (BP01) Insul Bd 1 in (HF-B5) MinWool batt R13 w/Mtl Frame 16 in oc GypBd 5/8 in (GP02)	36,010 sf /0.102
Floor type	Conc HW 140 lb 5.5 in carpet with fibrous pad (CP01)	20,768 sf /0.512	Interior 4 in slab floor Conc HW 140 lb 4 in (CC03)	20,768 sf /0.725
Energy use intensity kBtu/ft^2/year	83.1		88.9	
Total energy use MBtu/year	1665		1781	

To evaluate the proposed approach, a prototype of an object based approach in material properties was developed as shown in Fig. 8 which shows a user interface. After logging into the system, the user needs to add to the system some additional information such as desired run period—maximum of one calendar year, building occupancy type, building location, proposed HVAC system, and applicable utility rates.

To measure the performance of the proposed system, a case study was conducted with an office building with a net area of 20,768 ft^2. The BIM file in Fig. 9 was designed with a foundation, exterior and interior walls, five floors, the roof, and many windows and doors (Table 2).

The first step in the process is to create a BIM which contains geometry and material data. The completed BIM is then exported in the XML variant of the open industry standard IFC. The specific computer authoring program used in this case study was ArchiCAD 14 which has a capability to produce files IFC files in SPF data exchange format. Once the BIM is completed, all the necessary information was gathered

Table 4
Object list of material properties.

Layer name	Layer properties		Thermal properties			
	Related material	Thickness Ft (m)	Conductivity Btu/h–ft^2–F (W/m–K)	Density lb/ft^3 (kg/m^3)	Specific heat Btu/lb–F (kJ/kg–K)	Resistance h–ft^2–F/Btu (K–m^2/W)
Conc HW 140 lb 8 in (CC05)	Conc HW 140 lb	0.6667 (0.2032)	0.7576 (1.310)	140.0 (2243)	0.2 (837)	0.88 (0.155)
Cmt mortar 1 in (CM01)	Cmt mortar	0.0833 (0.0254)	0.4167 (0.721)	116 (1858)	0.2 (837)	0.02 (0.035)
Cmt plaster 1 in (CM03)	Cmt plaster	0.0833 (0.254)	0.4167 (0.721)	116 (1858)	0.2 (837)	0.20 (0.035)
Com brick 8 in (HF-C9)	Com brick	0.6667 (0.2032)	0.42 (0.727)	120 (1922)	0.2 (837)	1.59 (0.280)
Plywd 1 in (PW01)	Plywd	0.0209 (0.0064)	0.0667 (0.115)	34 (45)	0.29 (1213)	0.31 (0.055)
Polyurethane 1/2 in (IN41)	Polyurethane	0.0417 (0.0127)	0.0133 (0.023)	1.5 (24)	0.38 (1590)	3.14 (0.553)
CMU HW 8 in hollow (CB11)	CMU HW	0.6667 (0.2032)	0.606 (1.048)	69 (1105)	0.2 (837)	1.10 (0.194)
AcousTile 1/2 in (AC02)	AcousTile	0.0417 (0.0127)	0.033 (0.057)	18 (228)	0.32 (1339)	1.26 (0.222)
Face brick 4 in (HF-A2)	Face brick	0.3333 (0.1016)	0.77 (1.331)	130 (2083)	0.22 (921)	0.44 (0.078)
CMU HW 8 in hollow (CB11)	CMU HW	0.6667 (0.2032)	0.606 (1.048)	69 (1105)	0.2 (837)	1.10 (0.194)
GypBd 3/4 in (GP03)	GypBd	0.0625 (0.0191)	0.0926 (0.16)	50 (801)	0.2 (837)	0.67 (0.118)
CMU LW 6 in hollow (CB46)	CMU LW	0.5 (0.1524)	0.2777 (0.48)	55 (881)	0.2 (837)	1.8 (0.317)
PartBd Md dens 3/4 in (PB02)	PartBd Md dens	0.0625 (0.0191)	0.7833 (1.355)	75 (1202)	0.31 (1297)	0.08 (0.014)
Blt-up toof 3/8 in (BR01)	Blt-up roof	0.0313 (0.0095)	0.0939 (0.162)	70 (1121)	0.35 (1464)	0.33 (0.026)
Insul Bd 3 in (IN24)	Insul Bd	0.2500 (0.0762)	0.0240 (0.042)	15.0 (240)	0.17 (711)	10.42 (1.836)
Wood Sft 3/4 in (WD01)	Wood Sft	0.0625 (0.0191)	0.0667 (0.115)	32.0 (513)	0.33 (1381)	0.94 (0.166)
Insul Bd 1 in (HF-B2)	Insul Bd	0.083 (0.0254)	0.025 (0.043)	2 (32)	0.2 (837)	3.32 (0.585)
Steel siding (AS01)	Steel siding	0.005 (0.0015)	26 (44.97)	480 (7690)	0.1 (418)	0.0019 (0.000033)
Conc HW 140 lb 2 in (HF-C12)	Conc HW 140 lb	0.1667 (0.0508)	1.000 (1.73)	140 (2243)	0.2 (837)	0.17 (0.029)
Insul Bd 2 in (HF-B3)	Insul Bd	0.167 (0.0508)	0.025 (0.043)	2 (32)	0.2 (837)	6.68 (1.177)
Stone 1/2 in (HF-E2)	Stone	0.0417 (0.0127)	0.83 (1.435)	55 (881)	0.4 (1674)	0.05 (0.009)
Felt 3/8 in (CC07)	Felt	0.0313 (0.0095)	0.11 (0.162)	70.0 (1121)	0.35 (1464)	0.33 (0.026)
Conc HW 140 lb 4 in (CC03)	Conc HW 140 lb	0.3333 (0.1016)	0.7576 (1.310)	140.0 (2243)	0.2 (837)	0.44 (0.078)
Conc HW 140 lb 12 in (CC07)	Conc HW 140 lb	1.0000 (0.3048)	0.7576 (1.310)	140.0 (2243)	0.2 (837)	1.32 (0.233)
Conc LW 80 lb 8 in (CC26)	Conc LW 80 lb	0.6667 (0.2032)	0.2083 (0.360)	80 (1282)	0.2 (837)	3.2 (0.564)
Conc LW 40 lb 4 in (HF-C14)	Conc LW 40 lb	0.3333 (0.1016)	0.1 (0.173)	40 (641)	0.2 (837)	3.33 (0.587)
Urea Formald 5.5 in R23 (IN52)	*Urea Formald R23*	0.4580 (0.1396)	0.0200 (0.035)	0.7 (11)	0.3 (1255)	22.90 (4.036)
Conc HW 140 lb 10 in (CC06)	*Conc HW 140 lb*	0.8333 (0.2540)	0.7576 (1.310)	140.0 (2243)	0.2 (837)	1.10 (0.194)
MinWool fill 3.5 in R11 (IN11)	MinWool fill R11	0.2917 (0.0889)	0.0270 (0.046)	0.60 (10)	0.2 (837)	10.80 (1.903)
AcousTile (HF-E5)	AcousTile	0.0625 (0.0191)	0.035 (0.061)	30 (480)	0.2 (2142)	1.79 (0.313)

Layer conductivity = material conductivity.
Layer density = material density.
Layer specific heat = material specific heat.
Layer resistance = (material resistance per unit thickness (1 in)) × (layer thickness).

Table 5-1
Sample DOE 2-2 simulation output: monthly fuel requirement summary (electricity consumption).

Electric consumption (MBtu)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space cool	11.46	12.28	13.57	15.82	22.3	31.3	38.3	44	40	31.1	18.3	10.2	288.4
Heat reject.	0.03	0.03	0.07	0.07	0.2	0.55	0.68	0.8	0.8	0.44	0.14	0.03	3.82
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space heat	1.57	1.16	1.23	0.89	0.55	0.27	0.1	0.1	0.1	0.41	1.02	1.84	9.14
HP supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot water	0	0	0	0	0	0	0	0	0	0	0	0	0
Vent. fans	6.99	6.79	7.67	7.91	8.9	9.68	10.6	11	10	9.62	7.71	6.85	104.7
Pumps & aux.	7.4	6.82	7.43	8.25	10.7	13.6	16	17	16	14.1	9.65	6.41	133.1
Ext. usage	1.98	1.77	1.98	1.91	1.98	1.91	1.98	2	1.9	1.98	1.91	1.94	23.22
Misc. equip.	41.3	37.41	42.28	40.51	42.1	40.8	41.3	43	39	42.1	39.7	40.7	490.1
Task lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area lights	27.76	25.13	28.44	27.25	28.3	27.4	27.8	29	26	28.3	26.7	27.4	329.5
Total	98.41	91.35	102.7	102.6	115	125	137	147	134	128	105	95.3	1382

from the BIM and loaded into the DOD 2.2 energy simulation engine. The final result was presented in the format of simulation (SIM) file in DOE-2.2 for a comprehensive breakdown of entire energy simulations, which contains detailed information in hundreds of pages. To validate the results of the case study, the results were compared with a different building energy system program, GBS which is a popular commercial product for running energy simulations of BIM and runs in gbXML files.

The HVAC was divided into two types: one with equipment for conditioning air and the other equipment for the airside functions. Air systems were used for different functions such as fans, dampers, etc. that send cooled air and ventilation into the various parts of building spaces. In this research, variable air temperature system was chosen as the air system. This type of system is used for the heat gains and losses. Primary systems used for chillers, boilers, etc. provide hot water, and electricity to the main distribution systems.

Table 2 shows the layer list built for the case study with three different components such as a roof, walls, and the floors. The materials described in Table 2 are unique and not found in the standard library set. Therefore, the proposed system made the new sets of additional material properties for accurate energy modeling, according to the material information extracted from the BIM model.

Table 3 shows the layers and the thermal properties of the building components (a roof, walls, and a floor) by a layer stored in the user library. As shown in Table 2, a comparison was made between two different approaches; one is from layers available in BIM software such as GBS and the other from actual layers using thermal properties information by a layer (thickness, conductivity, density, specific heat and resistance) from Table 3. Table 3 is now divided into the top columns of "layer properties" and "thermal properties". Layer properties store information on a building consists of "related material (pure material)" and "thickness". The other top column is titled thermal properties and contains information on energy performance. Those two types of properties in the object library are maintained according to the layers in each building component. For example, the layer's "Resistance" is obtained by applying the resistance of the related material per unit thickness to the thickness in the layer. With the simplified materials chosen in GBS, the energy estimate was calculated to be 225.2 kBtu. However, the actual energy estimate was calculated at 210.8 kBtu with correct materials shown on the right side of Table 3. The overall difference was 6.9% in total energy use. In this research, three building components were included: roofs, walls, and a floor. The difference would increase more when other factors are included in the process such as HVAC equipment selection or the different sizes of doors or windows.

This research utilized the DOE-2.2 energy calculation engine to generate a comprehensive set of energy simulations. The final energy simulation reports are in simulation (SIM) file format. This report allows the user to read explicit simulation details ranging from peak building loads to monthly plant energy utilization. The prototype built in the research was specifically designed for making the automatic model the same as the manual model built in eQUEST. The proposed object based material properties (Table 4) approach shows in Tables 5-1 and 5-2 where the total electricity consumption of the given building is estimated to be 1382 MBtu and the total gas consumption is 282.9 MBtu (Fig. 10).

6. Conclusion

The current systems focus on a manual process to enter data into the system where a possible error can occur. Also, a limitation with BIM based commercial software for energy modeling has been identified. Therefore, the research proposed a new approach to develop a BIM based BEA system using an object based approach in material properties which consists of three parts of building data parsing, material–property matching, and INP writing. The system retrieves information stored in IFC containing the types of geometry and material data, then adds

Table 5-2
Sample DOE 2-2 simulation output: monthly fuel requirement summary (gas consumption).

Gas consumption (MBtu)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space cool	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat reject.	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
Space heat	38.75	28.45	30.64	21.64	13.9	6.54	2.56	1.3	2.5	9.76	25.1	45.7	226.8
HP supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot water	4.94	4.53	5.13	4.86	4.9	4.59	4.51	4.6	4.2	4.6	4.49	4.76	56.11
Vent. fans	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps & aux.	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext. usage	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc. equip.	0	0	0	0	0	0	0	0	0	0	0	0	0
Task lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Area lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	43.69	32.98	35.76	26.5	18.8	11.1	7.08	5.9	6.7	14.4	29.5	50.4	282.9

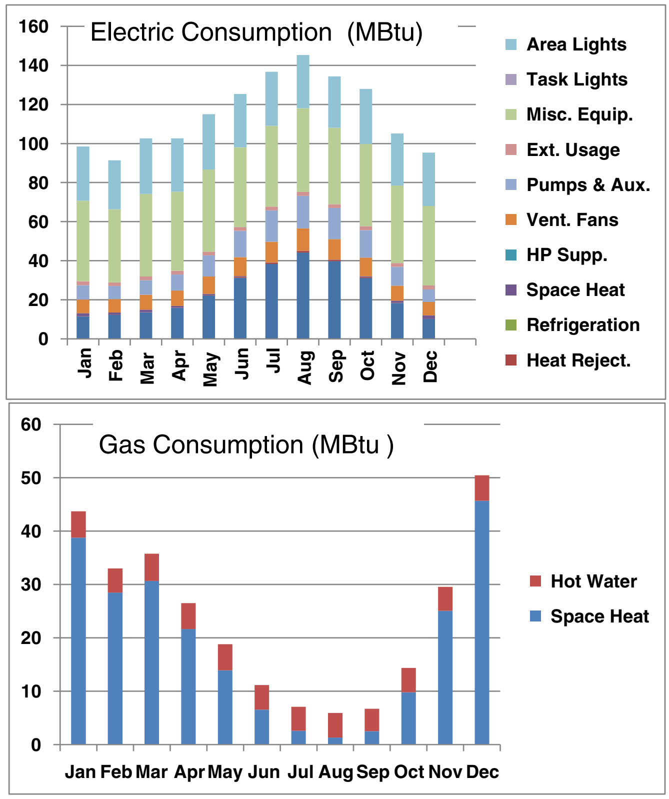

Fig. 10. Comparisons of electricity and gas consumptions.

the standard material's name to the material property database. Finally, the system creates the energy input file from the previous process. In order to validate the proposed approach, a case study has been presented where the current BIM approach with simplified materials and the proposed system with actual materials were compared. Due to the different materials available in both approaches, there was a difference of 6.9% in total energy use. In this research, three building components were included: roofs, walls, and a floor. The difference would increase more if other factors were included in the process such as HVAC equipment selection or the different sizes of doors or windows. Thus, the result shows that the simplification in BIM energy modeling process could lead to an inaccurate final estimate.

In the proposed approach, the geometry and material information needed to build an energy input file was automatically collected from a BIM file and parsed for energy simulation. It is found that the efficiency of the energy modeling process was improved by eliminating the manual data entering process. Also, the accuracy was increased by matching the material types to correct material properties values stored and maintained at the material property database. It became easy to add or modify the property values through the object based materials approach. This improved capability would allow designers to compare the performance of new building assemblies instead of relying on existing libraries or struggling to enter data manually.

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