DOI: 10.1007/s12541-016-0099-4 ISSN 2234-7593 (Print) / ISSN 2005-4602 (Online)

# A Study on Data Visualization of Embedded Sensors for Building Energy Monitoring using BIM

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KEYWORDS: Building energy management system, Building information modeling, Energy operation center, 3D web-browser, Building energy saving

*In recent years, building energy consumption has increased in response to climate change, resulting in a worldwide reduction of energy efficiency. A strong response is required, through both the enhancement of building energy efficiency and the reduction of power usage. These objectives could be achieved by pursuing "Blackout" prevention, through developing a control unit such as that of the urban energy grid system that was used in the Energy Operation Center (EOC) for smart cities. In this context, this paper presents an optimization operation technique for Building Energy Management Systems (BEMS), using control monitor-based Building Information Modeling (BIM) for the efficient operation of the EOC. BIM is one of the approaches that can be used for the visual representation, management, and exchange of information on all aspects of a building. The EOC should be able to efficiently represent the data from the building information, and the operator maintaining it should be able to promptly acquire the data for handling it. This suggests that the control of energy consumption by a Building Automation System (BAS) to maximize building energy efficiency will lead to improved total energy performance, reduced operating costs, and reduced environmental impact.*

Manuscript received: August 27, 2015 / Revised: December 15, 2015 / Accepted: January 21, 2016

## 1. Introduction

Energy efficiency has become a necessity worldwide. In 1995, the Kyoto Protocol insisted that we need to improve our energy efficiency and reduce our $CO_2$ footprint.[1] Building sector is one of the fastest growing energy consumption sectors. It is estimated that the amount of energy consumed in buildings in European Union (EU) is 40~45% of the total energy consumption, about two-thirds of which is comprised of consumption from dwellings. In the current decade, energy demand in the commercial and residential sectors is increasing by 1.2% and 1.0% annually, respectively.[2]

Building structures consume significant levels of electrical energy and are responsible for substantial greenhouse gas (GHG) emissions.[3] A framework for addressing energy management has been proposed by Carnieletto with assumed objectives of increased energy efficiency, decreased operation cost of energy utilization, decreased dependence on use of fossil fuel for energy needs, and consequently decreased GHG emissions.[4] Building Energy Management Systems (BEMSs) are now an established aspect of modern buildings for saving building energy.[5] BEMSs are widely used to gather data from a set of sensors installed in a building. BEMSs are only reactive systems, and prediction is not used. Therefore, it is necessary to propose and develop smarter systems that are fully focused on energy improvement. Although data can be gathered by these existing systems, information about energy use should be provided to the user for saving building energy.

Most domestic energy use is invisible to the building user. Most people have little knowledge of the amount of energy they are using for different purposes and of the amount they could reduce by changing their daily behavior or investing in efficiency measures. Hence, it is important to provide feedback to ensure energy use is more visible and more able to be understood and controlled. In this study, several discussions with providers of building software products revealed similar findings. Although this evidence is largely anecdotal, many of their customers report energy savings of 5~15%. A number of intervention studies have shown that effective energy feedback can influence energy saving behavior among building occupants.[6] In fact, if only 1% of US households achieve such energy saving, the amount of energy saved would be the same as removing 535,000 cars from the road or the equivalent of the energy produced by two 675MW coal-fired peak power plants.[7] To overcome these difficulties in the domestic industry, this paper presents a total energy management and operating system that has been set up in a test-bed.

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### 1.1 Related works

In recent years, various researchers have explored how to reduce building energy as well as the benefit that gained by post-construction management from harnessing BIM information and capabilities.[8] Guinard proposed a wireless sensor network (WSN) design tool to support building energy management. The approach takes advantage of the available BIM data to accurately describe the WSN deployment environment. The use of an accurate propagation model, coupled with an agent based optimization algorithm offers a scalable solution to design a large WSN.[9] Jeng proposed a three-dimensional (3D) smart space design framework in which space (e.g., space for furniture, walls, floors, etc.) was viewed as one-dimensional (1D) with the other two dimensions of technologies (for ubiquitous computing) and living factors (e.g., safety, health, and sustainability requirements).[10] Bhatt et al. proposed an ontology-based spatial-terminological inference approach to validate work-in-progress designs of smart environments. The approach checks the design for compliance with the spatial and functional constraints of environment entities based on available architecture data in a Industry Foundation Class (IFC) format.[11]

In addition, Irizarry suggested that BIM be used for monitoring the flow of materials, availability of resources, and visually mapping the respective supply chains.[12] Alahmad presented power consumption integrated with BIM to create a Real-time on-line electronic BIM model.[6]

In this study, a 3D shape model in BIM was applied to an energy monitoring system. Through energy monitoring systems applied with a 3D shape model, building energy consumption was confirmed intuitively by a facility manager in each room. The web -browser therefore needed to be made by a 3D shape model in BIM.

### 1.2 Research objective

In this study, the research objective was to develop an energy management platform using BIM. This platform was used to monitor building energy consumption in the test-bed. This platform can help the facility manager to control the building equipment. The test-bed in the application of the platform was set in an elementary school.

To meet this research objective, the study was carried out in two phases: (1) change phase from BIM to web- browser, and (2) application of web browser in the test-bed. The change phase involves reviews of the application of BIM in other research fields and methods for making the web-browser. The application phase involves obtaining results from the application of the test-bed.

## 2. Methodology of Building Energy Visualization

### 2.1 Construction of web browser using BIM

Although widely used, the CAD model only contains parameters for buildings, and is thus too superficial to satisfy the increasing demand for integrated information from owners, architects, engineers, and contractors. BIM, which is now commonly accepted, was first introduced by Dr. Eastman in one of his newsletters in the 1970s and later illustrated in his books and papers. After the first debut of BIM in 1987, it has become popularized for the exchange and interoperability of digital information, especially during the last decade. A BIM model

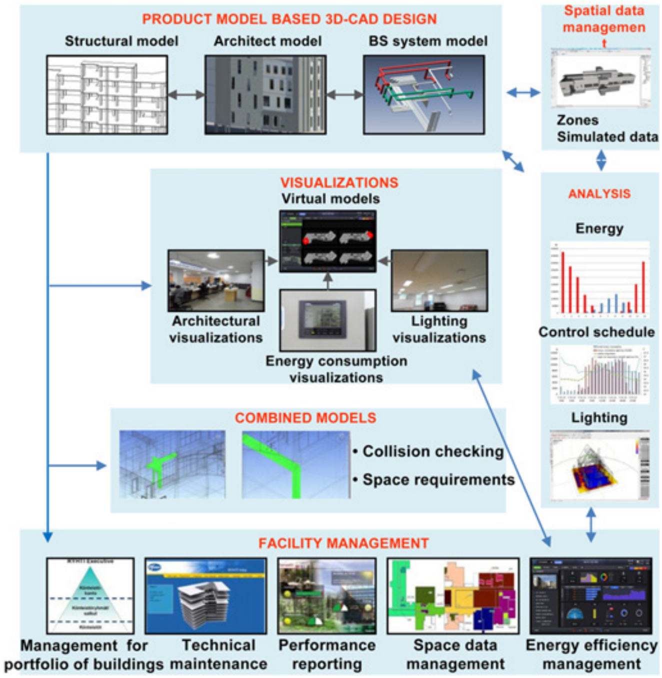


Fig. 1 Application of building

captures multi-disciplinary information rather than fragmented drawings to realize 3D visualization. Design and construction team members responsible for the various facets of the architecture, structure, mechanics, electronics, materials, schedules, cost, and energy determine their own BIM separately, and then combine them to build a single, systemic, comprehensive, seamless building model.[13]

Interoperability supports different capabilities, and addresses different problems in the exchanges of data. The most common and important form of data exchange is between the BIM platform and the set of tools that it can support. In these cases, specific portions of the platform's native data model (the data structure used by the platform internally) are translated. The translation is realized by defining the required model data on the platform (called a model view), placing it into the format required by the tool, and then adding other non-model information.[14]

Fig. 1 shows the set-up of BIM. In this study, BIM was used for the visualization of the measured environmental and energy consumption data. Through this visualization, facility managers were able to report on the energy consumption of buildings and control the equipment of buildings in EOC.[15]

Many studies were implemented for constructing a platform using BIM. Many advantages are involved with making decisions and sharing information among the facility managers in EOC by supplying a variety of information about energy consumption and the environment.[16-18]

Chiang et al. proposed a platform, real-time replay system (RTRS), to provide such a visualized and interactive environment through the Unity 3d game engine.[16] Fassi et al. developed a platform to visualize extremely larger and complex 3D models on the web and share information (textural, image video, etc.) linked to the model in a simple and immediate way using the web.[17] Hajibabai proposed that GIS environment be used to link spatial and scheduling information relevant


Fig. 2 Conversion of BIM data format

to GHG emissions from construction activities.[18]

These studies on 3D model using BIM have the potential to enhance the visualization of environmental data and could help facility managers better understand the status of energy consumption. There, in this paper, BIM was used as an effective method to visualize data linked to location information in a building.

To create a building model, the user must specify a plan profile for each building story, together with a series of parameters that are used to generate all of the BIM objects and properties required for the target simulations.[19] These parameters are stored in the Graphical User Interface (GUI), and the building shape model can be modified by editing one or more parameters and regenerating the model.

The GUI can also import building models from BIM / 3-D CAD tools using either the IFC or Open Green Building XML Schema (gbXML) format. Data from IFC BIM are simplified for use in energy simulation by the Geometry Simplification Tool (GST) energy.[20]

Fig. 2 shows the conversion of the BIM data format. To provide energy consumption information, the BIM of the test-bed was transferred to the web browser. The building shape model in BIM was converted to a file format to show in the web browser using the 'web published model' program, which is an add-on program in Revit. The filename extension in this format was wpm. This file was loaded in HTML and output at the web browser.

### 2.2 Data acquisition of building energy consumption

The BAS comprises electronic equipment that automatically performs specific facility functions. The commonly accepted definition of a BAS includes the comprehensive automatic control of one or more major building system functions required in a facility, such as the HVAC system, lighting, power, lifts, and security. In short, BAS is intended to integrate the traditionally separate functions of Temperature Control, Energy Management, Fire, and Security under one common operation. In addition, BAS includes a collection of sensors that determine the condition or status of parameters to be controlled, such as temperature, relative humidity, and pressure. Similarly, output devices impart electronic signals or physical actions to control the devices. Examples include electric relays or dampers, and valve actuators.[21] In this study, through BACnet, BAS enables users, to wirelessly access the energy consumption, on an anywhere and anytime basis.

BACnet data is expressed in Extensible Markup Language (XML) using data elements. The XML is a popular technology in data processing and communications, due to its ability to model a wide range of data and its ability to be transformed and extended. XML can be used for exchanging files between systems, integrating buildings with energy utilities, and expanding enterprise integration with richer web services.[22]

Fig. 3 shows the BAS Gateway system used to integrate each facility in the test-bed. Each facility was controlled and monitored separately before application of this system.[23] Through this system, the measured data was transferred and saved in the server in EOC.

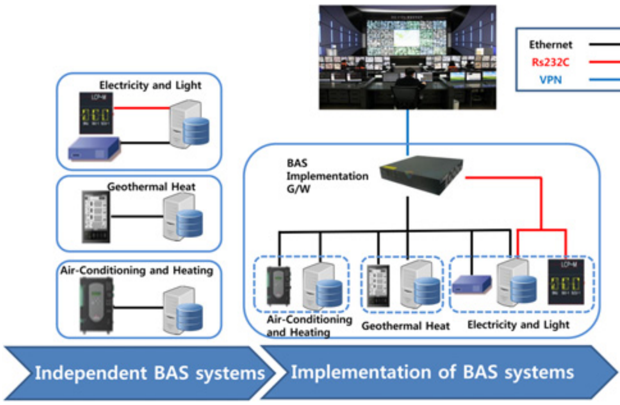


Fig. 3 BAS gateway system concept in test-bed

### 2.3 Visualization strategy

Novel graphical and direct-manipulation approaches to query formulation and information visualization are now possible. While research prototypes have typically dealt with only one of the many data types (such as 1-, 2-, and 3-D data temporal and multi-dimensional data trees and network data), successful commercial products will need to accommodate several data types. These products will need to provide smooth integration with existing software and support the full task list: overview, zoom, filter, details-on-demand, relate, history, and extract.[24] However processing data using the above method is too difficult because of the massive size of the data. Through data visualization, the pattern and feature of data could be determined.[25]

In this paper, building energy information was supplied to the facility manager using a multiple viewpoints approach. A system of multiple viewpoints consists of a number of viewpoints that represent the knowledge elements of actors' interests on the artifacts (products), a set of transition mappings for pairs of viewpoints in the system, and a merge function that defines how to construct a final result set based on these viewpoints.[26] The information, such as energy consumption by use, the hour, and for each space, was provided in the monitoring system, for the effective management of building energy consumption.

### 2.4 Importance of motivating behavior in saving energy consumption

Reducing energy consumption by motivating energy efficient behavior has considerable potential. In one study, an investigation of energy use in a public housing continues to provide unexpected findings regarding the importance of occupant behavior in actual energy consumption.[27] Another study reported 4~20% short-term energy saving behavior changes from building occupants when appropriate marketing approaches were aggressively employed.[28]

Researchers have recently begun exploring how sharing energy use information with building residents can increase energy efficiency. One study demonstrated that giving building occupants information that enables them to compare their electricity use to others can result in a more reliable improvement in electricity utilization than simply providing individuals with raw values of average daily power draw.[29] Petersen et al. investigated how providing near real-time energy use information to dormitory occupants affects their power consumption.

Table 1 Building status of test-bed

| Entity | Contents |
|---|---|
| Address | 29, Noel 1, Sejong City |
| Propose of building | Educational facility |
| Completion year | February 2012 |
| Gross area [$m^2$] | 10,682 |
| Annual operation time | 2,184 (for 2012) |

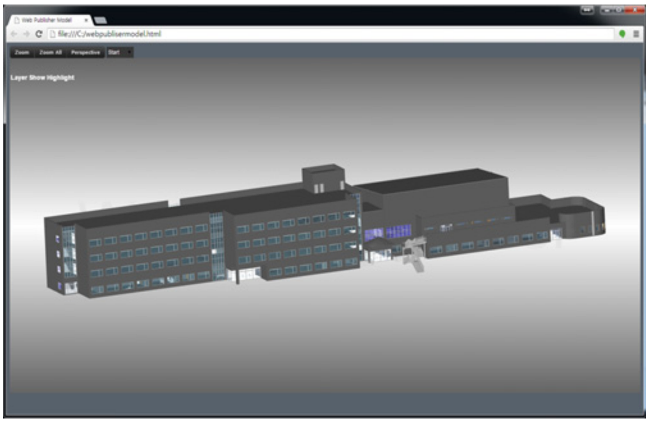

Fig. 4 Web-browser on shape model of test-bed

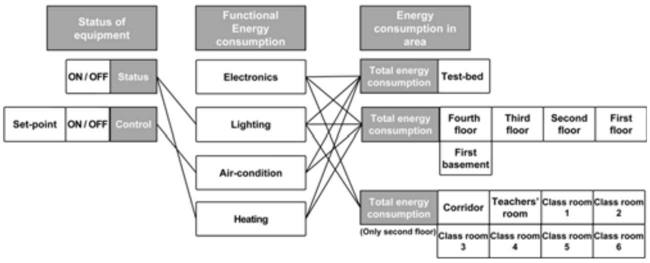


Fig. 5 Collected data on test-bed[23]

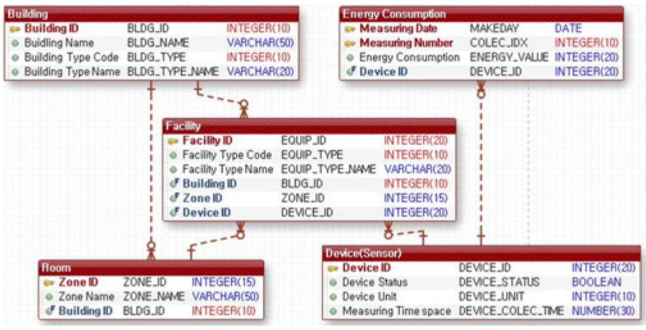


Fig. 6 ERD of the database on 3D web-browser

Overall, the introduction of feedback, education and incentives resulted in a 32% reduction in electricity use. The results of this research provide evidence that it is possible to create resource feedback systems that, when combined with education and incentives, motivate and empower college students to reduce resource use in dormitories.[30]

As mentioned earlier, the motivating energy saving behavior is a very important aspect of reducing energy consumption. To reduce energy consumption, the notification of the user's energy consumption was required. In this current paper, the test-bed was managed by the facility manager in EOC because BAS was used in the test-bed. Therefore, the information about energy consumption, such as electronics, lighting, air-conditioning and heating, in the test-bed was supplied to the facility manager through this platform.

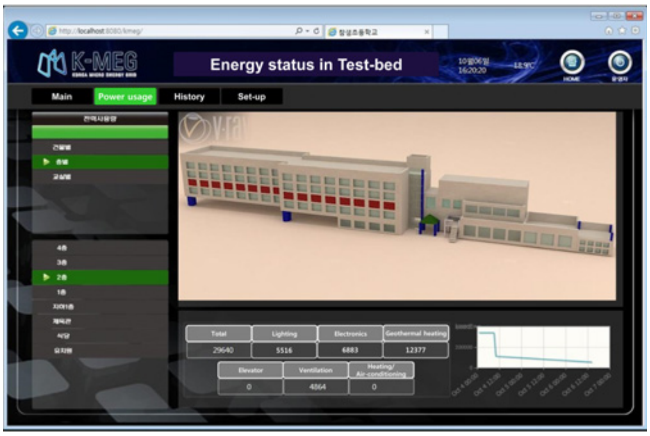


Fig. 7 3D web-browser of test-bed

## 3. Case Study

### 3.1 Data acquisition of building energy consumption

For the test-bed, an elementary school was selected in Sejong. The building has five –floors with a total floor area of 10,682$m^2$. It consists largely of classrooms, some office rooms and a gymnasium. The test-bed receives hot water and chilled air from the plant in the underground machine room for its HVAC system.

The BIM of the test-bed was constructed by Revit. As mentioned above, this BIM data was transferred to the web -browser. Fig. 4 shows the test-bed shape model in the web -browser.

The test-bed has an HVAC system, Geothermal Heat, Electricity, and Lighting for energy management; however, it can be operated through the BAS by an operator who has no knowledge of the methods of building management for energy efficiency. Furthermore, other buildings also have the same arrangement. Therefore, for energy savings from BEMS, various sensors and digital meters that gather data every 5 minutes were easily installed, and the data was linked to the BAS Gateway to integrate the control information. The information of various items of equipment, such as Geothermal Heat, Electricity, and Lighting, was stored on the integration management platform of the EOC, for the Energy Operation Service (EOS), which provides energy information to the end users.

Fig. 5 shows the collected data on the test-bed. The energy consumption of the entire building and each floor was measured. The energy consumption by Lighting and HVAC system was also collected. Especially, the energy consumption data on the second floor was collected from each room separately.[31]

Table 2 Usage of power (monthly)

| Month | 2012 (MWh) | 2013 (MWh) |
|---|---|---|
| Jan. | - | 89.624 |
| Feb. | 9.12 | 90.532 |
| Mar. | 138.80 | 88.746 |
| Apr. | 82.30 | 78.344 |
| May | 57.82 | 68.656 |
| June | 50.22 | 76.654 |
| July | 61.29 | 81.65 |
| Aug. | 64.89 | 78.96 |
| Sep. | 59.33 | 81.99 |
| Oct. | 71.56 | - |
| Nov. | 72.29 | - |
| Dec. | 80.24 | - |
| Sum | 746.86 | 735.165 |

The collected data which should be visualized was support to facility manager. Through this information, they can make decision how operate building's facility. Afterwards, the conceptual design is carried out, and the conceptual scheme is derived. Fig. 6 illustrates the Entity-Relationship Diagram (ERD), which is a database structure of a 3D web browser for visualizing building energy consumption. In this ERD, each table has the individuals` IDs. Through relations with each parameter in the tables, the energy consumption was visualized according to use, time, and each space.

For reference, BIM refers to the technology needed to generate and maintain the information that is produced during the entire life cycle of a building from design to maintenance, and is applied in various fields, such as energy management, building management and repairment.[32] Fig. 7 shows a 3D web browser that gives the energy consumption of a facility according to time and space. The status of energy consumption can easily be checked at any point in the building. When clicking on the left button, the space in which the energy information needs to be known is marked in a red color.

Through the BIM platform, energy consumption data are visualized at the GUI in the EOC, so that the building status, energy consumption data in the building, and building spatial information, can be effectively confirmed. Revit Architecture by Autodesk was used in this study. Autodesk Revit has a .NET framework application-programming interface (API), which makes it possible to use any of the .NET compliant programming languages (C#, VB.NET, etc.) to develop a plug-in. It is useful for designing a building model that can be easily applied for a GUI in the EOC.

### 3.2 Energy analysis report of test-bed

To confirm the energy saving effect of the energy monitoring system, a baseline of power usage in the test-bed was established. For this, an audit of the energy performance of the test-bed was executed by a specialized organization.

As explained in the previous section, the monitored data gathered through the BAS is able to typically show all of the energy information every 5 minutes by a GUI. Energy efficiency is not intended to make use of integrated management by a few people to save wages, but for data analysis. The power usage of the test-bed is shown in Table 2.

Table 2 shows the usage of power from February 2012 to September

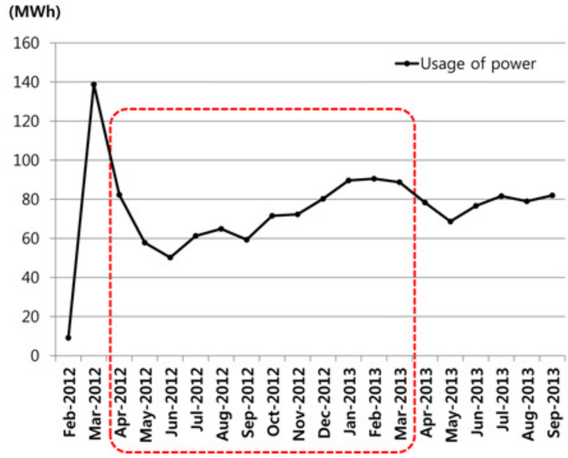


Fig. 8 Change of power usage (monthly)

Table 3 Functional power usage of test-bed [kWh]

| | Power usage [kWh/year] | Percentage [%] |
|---|---|---|
| Lighting | 193,839 | 22.31 |
| Electronics | 241,277 | 27.77 |
| Geothermal heating | 433,726 | 49.92 |
| Total | 868,842 | 100 |

Annual usage of power: 868,842 [kWh/year]

2013. As shown in Fig. 8, the usage of power in March 2012 was very high, because of a test run of building equipment. Usage of power from April 2012 was similar to that of most other educational facilities. Usage of power from April 2012 to March 2013 was designated as the annual baseline of power usage. Additionally, the baseline of monthly power usage was the usage of power from January to July 2013 because an energy saving method was applied to be tested after January 2014 and measured data was collected up to July 2014.

Table 3 shows the functional power usage of the test-bed, which is gathered by a digital meter in the EOC from April 2012 to March 2013. Table 3 shows that the power usage of the geothermal heat system accounted for 50% of the total power usage. The geothermal heat system was used to supply Heating, Air-conditioning, and hot-water. This percentage is very high considering that the power usage of Heating and Air-conditioning in general educational facilities is about 20~30%.

### 3.3 Result of energy saving on test-bed

The baseline of power usage in the test-bed was estimated as shown above. Employing the basic information is useful for calculation of the annual usage. Energy saving was calculated on the application of energy saving methods. In the test-bed, three energy saving methods were applied. The first method was an improvement of the geothermal heat system, the second was the control of Lighting and Air-Conditioning, and the third was a photovoltaics system. Table 4 shows that the total energy saving was 97.208(kWh) over the last year and the energy saving rate was 17%.

As shown in Fig. 9, energy usage in winter and summer (January, February, July, August) is more than that in spring (from March to

Table 4 Energy saving usage of the test-bed

| Month | 2013(MWh) | 2014(MWh) |
|---|---|---|
| Jan. | 89.624 | 79.113 |
| Feb. | 90.532 | 79.509 |
| Mar. | 88.746 | 88.961 |
| Apr. | 78.344 | 50.753 |
| May | 68.656 | 50.600 |
| June | 76.654 | 62.017 |
| July | 81.659 | 66.057 |
| Sum | 574.216 | 477.009 |
| Energy saving | 97.208 | |
| Energy saving rate | 17% | |

It is difference between Table 4 and 5, because of non-reflection of power usage in winter.

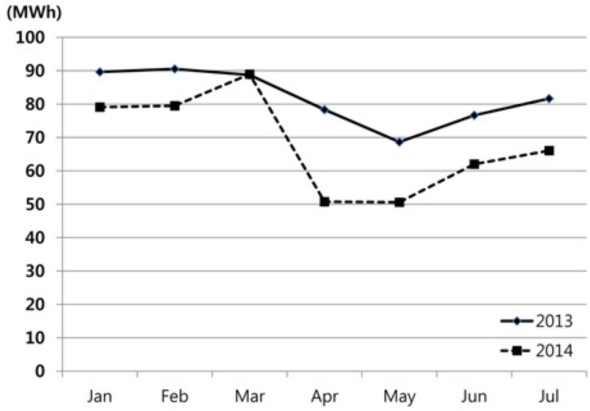


Fig. 9 Differences of power usage between 2013 and 2014

Table 5 Result of itemized energy saving

| Energy saving application | Improvement of geothermal heat system | Control of Lighting and HVAC system | Photovoltaics system | Sum |
|---|---|---|---|---|
| Baseline usage of energy (kWh) | 410,739 | 99,616 | 923,214 | 923,241 |
| Energy saving (kWh) | 26,353 | 46,874 | 38,520 | 111,747 |
| Itemized Saving rate (%) | 6.41 | 47.05 | 4.17 | 12.10 |
| Total saving rate (%) | 2.85 | 5.08 | 4.17 | 12.10 |

May). In terms of energy saving, energy consumption in January and February decreased by 11.95% due to the improvement of the geothermal heat system. Energy consumption from April was reduced by controlling the Lighting and Air-conditioning.

Table 5 shows the energy saving effect of each energy saving method. The improvement of the geothermal heat system resulted in a 2.85% energy saving effect in total energy consumption. The energy saving in the control of Lighting and HVAC system was 5.08%. The total energy saving effect was 12.1%. The energy saving effect shown in the 3D web -browser was included to control the Lighting and the HVAC system. Because many energy saving methods were applied to the test-bed, the precise effect of the 3D web -browser was not verified.

## 4. Conclusions

This paper presents BIM-based energy management for enhancing building energy efficiency. To achieve energy efficiency, buildings for energy efficiency action included devices and technologies including occupancy sensors, motion sensors, digital meters, BIM, BAS, BEMS, and a building energy integrated operation platform. This equipment needs to be able to store the data richness, in order to achieve energy savings through automation systems. A manager who has little expert knowledge can be employed, in order to reduce the cost of building management, because buildings only operate in one place, the EOC. Additionally, BIM easily provides advanced information to enable monitoring of more building equipment. BIM takes advantage of the available data visually from the building equipment. Thus, in the future, a city that includes intelligent buildings, the so-called “smart city”, will be easily managed and controlled because of the visualized building information, and it will very conveniently provide all the data throughout BAS in the EOC, of which only a few managers are needed to manage all the buildings, making it possible to reduce costs and energy consumption.

In this paper, a case study was presented to illustrate how the integration management platform can be used in practice. The goal was to enhance the energy efficiency of buildings, by managing the EOC. The EOC provides an energy operation service for operators, and stores various data from the equipment of the test-bed. Automation technologies are installed (i.e., BAS, BIM, occupancy sensors, digital meters, etc.) in the buildings to gather relevant data. BIM-based energy information visualization enables improved guidelines for operators in the EOC. In other words, EOC enables operators to utilize a number of functions including monitoring, analysis, searching for management information, integrated control system management, and external system support. It is expected that by using the BIM-based energy efficiency technologies, 12.1% energy savings will be achieved in the test-bed and will be applied to all buildings in Sejong City. If 10% energy savings can be achieved in 500,000 homes, 40 million dollars can be saved per year. All the steps explained above for enhancing the energy efficiency process were utilized through the case study.

In conclusion, this paper presented an optimization operation technique for BEMS, using a control monitor-based BIM for the efficient operation of a building energy integrated center. Because of the environmental data is linked to the location in a building, facility managers could make a decision to operate the facility within a short time frame. This could suggest the improvement of the total energy performance, the reduction of operating costs, and the reduction of the environmental impact associated with energy consumption. This would be controlled by BAS to maximize the building energy efficiency, pursuing “Blackout” prevention by developing a control unit of an urban energy grid system using the building energy integrated operation center for smart cities.

## ACKNOWLEDGEMENT

This work is financially supported by the Energy Efficiency & Resources Core Technology Program of the he Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (No.20152000000130), the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. NRF-2014R1A2A1A11054299), and the Korea Minister of the Ministry of Land, Infrastructure and Transport (MOLIT) as「U-City Master and Doctor Course Grant Program」.

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