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Application of Building Information Modeling in Energy Management of Individual Departments Occupying University Facilities

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***Abstract*—**To assist individual departments within universities in their energy management tasks, this study explores the application of Building Information Modeling in establishing the 'BIM based Energy Management Support System' (BIM-EMSS). The BIM-EMSS consists of six components: (1) sensors installed for each occupant and each equipment, (2) electricity sub-meters (constantly logging lighting, HVAC, and socket electricity consumptions of each room), (3) BIM models of all rooms within individual departments' facilities, (4) data warehouse (for storing occupancy status and logged electricity consumption data), (5) building energy management system that provides energy managers with various energy management functions, and (6) energy simulation tool (such as eQuest) that generates real time 'standard energy consumptions' data against which 'actual energy consumptions' data are compared and energy efficiency evaluated. Through the building energy management system, the energy manager is able to (a) have 3D visualization (BIM model) of each room, in which the occupancy and equipment status detected by the sensors and the electricity consumptions data logged are displayed constantly; (b) perform real time energy consumption analysis to compare the actual and standard energy consumption profiles of a space; (c) obtain energy consumption anomaly detection warnings on certain rooms so that energy management corrective actions can be further taken (data mining technique is employed to analyze the relation between space occupancy pattern with current space equipment setting to indicate an anomaly, such as when appliances turn on without occupancy); and (d) perform historical energy consumption analysis to review monthly and annually energy consumption profiles and compare them against historical energy profiles. The BIM-EMSS was further implemented in a research lab in the Department of Architecture of NTUST in Taiwan and implementation results presented to illustrate how it can be used to assist individual departments within universities in their energy management tasks.

***Keywords*—**Sensor, electricity sub-meters, database, energy anomaly detection.

I. Introduction

A. Research Background

ENERGY management has become an important facility management issue for universities in Taiwan. Individual departments within universities are usually held responsible for managing the energy efficiency of their facilities. This becomes a challenging task when several departments occupy the same facility and that individual departments lack reasonable energy consumption benchmarks or indices. Although Taiwan Government has issued average EUI (energy usage intensity, Wh/m^2) indicators for universities as energy benchmarks, these indicators are unable to assist facility managers in further assessing the energy efficiencies of their facilities, spotting the over-consumed areas and identifying the directions of energy management [1]. As a result, the average EUI indicators are not as effective for 'energy management' purpose.

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B. Energy Management Issues in University Facilities

Different departments within a university in Taiwan often occupy different portions of the same facility (across several floors). They may have large variances in energy needs due to their contextual factors such as space dimension, occupancy level, available equipment. Within the same building (same 'existing environment' conditions), two departments with different 'occupancy' needs are likely to consume different amount of energy, and it will be unreasonable to say that the department consuming less energy is more energy efficient than the other. This study thus argues that it is critical to take into account the 'management' factors while assessing the energy efficiencies of individual departments within universities. For effective energy management, individual departments are in great need of a tool capable of first assessing their energy efficiencies from 'management' perspective to identify problem areas and improvement plans exhibiting immediate energy saving effects, before any other expensive energy saving measures such as building renovations are taken.

C. Building Information Modeling (BIM) Trend

U.S National Building Information Modeling Standards (NBIM-US) define BIM as "the act of creating an electronic model of a facility for the purpose of visualization, engineering analysis, conflict, analysis, code criteria checking, cost engineering, as-built product, budgeting and many other purposes…" [2]. Information contained in BIM can be shared by different stakeholder of building lifecycle from the design, construction, until operation phase. Standard of information shared by BIM has been developed [2]. Therefore, different building lifecycle stakeholders (e.g. architect, engineer, facilities manager, etc.) can work together on the same fabric, ensuring better coordination and information delivery [3].

The information and data stored in the BIM model can be useful for facilities' management purpose. BIM information and data can be retrieved and transferred directly to facilities' management (FM) systems which minimize the time required to input data manually into the FM systems. In addition, BIM's visualization and analysis capabilities can potentially enhance various FM functions [4]. This idea will solve the current issue of manually entering the data for various FM systems, such as computerized maintenance management system [5], energy management system [6], building automation system, etc.

D.Research Objectives

While university facilities are in operation, the energy managers of individual departments need an effective tool to detect ‘abnormal energy consumptions’ or ‘anomalies’ of problem spaces in a real time fashion, so that immediate actions can be taken to terminate abnormal conditions to save energy. To detect energy consumption anomalies during a typical day, the energy management tool needs to be able to constantly assess and compare the ‘actual energy consumption’ of a space at a certain time (hour) against its ‘historical energy consumption data’ or its ‘reasonable energy consumption’ assessed based on the statuses of occupancy, HVAC equipment, lighting fixtures, and office equipment.

To assist individual departments in their complex energy management tasks, this study explores and adopts various plausible techniques such as BIM, sensors, electricity meters, IT and cloud technologies to establish an BIM-based Energy Management Support System (BIM-EMSS) for energy managers of individual departments.

There are two major research objectives of this study:

1) To present the conceptual framework and functions of the proposed BIM based Energy Management Support System (BIM EMSS).
2) To illustrate the BIM-EMSS mockup interfaces to demonstrate how the system works in a realistic research lab (RB906) in the Department of Architecture, National Taiwan University of Science and Technology.

II. BIM Based Energy Management Support System: Conceptual Framework

To assist energy managers in university facilities in dealing with energy management issues mentioned above, this study explores and adopts the following seven plausible techniques to propose the BIM based Energy Management Support System (BIM-EMSS), whose conceptual framework is shown in Fig. 1.

A. Environmental Sensors

This research proposes that the following two types of sensors be installed in a facility of a department to capture the occupancy status and indoor/outdoor temperature of various rooms or space within the facility (① in Fig. 1):

1) Occupancy sensors: installed on each workstation for each occupant within each space to indicate the presence or absence status of each occupant at any given time;
2) Temperature sensors: an indoor temperature sensor is installed in each room or space; and an outside air temperature sensor is installed on the outside of the fenestration of the room or space.

Status data from the occupancy and temperature sensors of all rooms are constantly transmitted back and stored in the ‘Data warehouse’ component (④ in Fig. 1) of the BIM-EMSS [7]-[9].

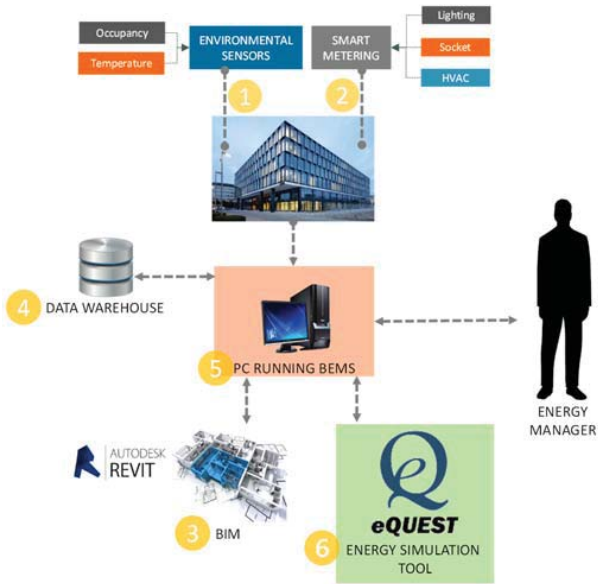

Fig. 1 The conceptual framework of the BIM-EMSS

B. Smart Metering

It is proposed that the following three types of smart meters be installed in each room in a facility of a department to record the ‘actual electricity consumptions’ of various equipment (② in Fig. 1):

1) Lighting sub-meter: installed for each room to record hourly ‘actual electricity consumptions’ of all the lighting fixtures at the ceiling;
2) HVAC sub-meter: installed for each room to record hourly ‘actual electricity consumptions’ of all the HVAC units;
3) Socket sub-meter: installed for each room to record hourly ‘actual electricity consumptions’ of all the appliances connected to all the sockets within the room;

Hourly ‘actual electricity consumption’ data from three sources of all rooms are constantly transmitted back to the ‘BEMS’ component (⑤ in Fig. 1) of the BIM-EMSS [10].

C. Building Information Modeling

The ‘space type’ concept was adopted by this study for energy management purpose [1]. This research proposes that a BIM model be built, with certain software such as REVIT, for all individual ‘spaces’ in the facility the department occupies. The BIM model built should include the ‘geometric’ and ‘information’ elements of various components such as the external walls and windows, interior partitions and panels, finished floor and slabs, ceiling tiles, workstations and furniture (desks and chairs), light fixtures, HVAC units, and various appliances (personal computers, screens, laptops, printers, scanners, refrigerator, etc.) as well as environmental sensors and smart meters (③ in Fig. 1) [11], [12].

The roles the BIM model plays in the BIM-EMSS are:

1) Visualization: to indicate the ‘occupancy status’ of each workstation (presence or absence) and ‘equipment status’ of each light fixture or HVAC unit (on or off) within each room in a 3D geometric view.
2) Data retrieval: to allow data extraction from various components within each room (such as external wall sizes and materials, window sizes and materials, number of light fixtures and wattages of lamps, number and tonnages of HVAC units, etc.) and automated energy analyses or simulations (no need for data input).

D. Data Warehouse

A centralized data warehouse is devised to store the data recorded from the environmental sensors, hourly actual electricity consumptions logged from three types of smart meters, information of the BIM model established for the facility the department occupies during building operational phase, as well as the hourly energy consumption data estimated by the energy simulation tool. Historical data stored can be accessed and retrieved anytime by the BEMS component to perform necessary data analyses for energy management purpose (④ in Fig. 1) [13].

E. Building Energy Management System (BEMS)

It is proposed that a personal computer running ‘Building Energy Management System’, such as those developed by Johnson Control or Honeywell, be established to provide energy management functions (to be described in Section III) for energy managers (⑤ in Fig. 1). The BEMS component is considered as the core of the BIM-EMSS. It takes queries and input data from various sources, such as energy managers, environmental sensors, smart meters, BIM model and energy simulation tool (e-Quest). Then, the BEMS will offer various energy management functions, such as performing energy analyses, generating various kinds of charts, as well as further identifying abnormal energy consumptions rooms or problem areas, and suggesting smart energy saving actions [14], [15].

F. Energy Simulation Tool

The ‘standard energy consumption’ was another concept adopted by this study for energy management purpose [1]. This study proposes that energy simulation tool (such as eQuest) is used to estimate, for each ‘space’, ‘hourly standard energy consumptions’ in a particular day during operational phase (⑥ in Fig. 1), against which ‘hourly actual energy consumptions’ of that space are compared for energy management purpose.

Various input data are required to be fed into the ‘energy simulation tool’ to estimate various types of ‘hourly standard energy consumptions of a space:

1) Existing climate: climate conditions around the site, which are recorded by the temperature sensor outside a space or room and can be retrieved automatically from the ‘data warehouse’.
2) Building infrastructure: building envelope characteristics of the building, and HVAC system schemes installed in the occupied spaces, which can be retrieved automatically from the BIM model stored in the ‘data warehouse’.
3) Occupancy status and schedules: hourly presence or absence statuses of occupants in a space in a particular day are recorded constantly and stored in the ‘data warehouse’.
4) Equipment status: hourly on or off statuses of equipment (HVAC, lighting, appliance) in a space in a particular day are constantly recorded and stored in the ‘data warehouse’.
5) Indoor temperature: hourly indoor air temperatures in a space in a particular day are recorded constantly and stored in the ‘data warehouse’.

Various types of standard energy consumption estimates (‘standard EUIs’) for the spaces are predicted (HVAC, lighting, appliances).

III. Energy Management Functions

Given the conceptual framework and six components of the BIM-EMMS, it intends to provide the following three types of energy management functions to the energy managers.

A. Visualization of Space Statuses

To show the 'current status' of a certain space at a particular time in a day during operational phase, the BIM-EMMS provide 3D visualization of space (from BIM) that displays current statuses of occupancy and equipment. Several visualization techniques, such as overlaying object in 3D model with color or symbol to show the status of each space (occupied, on/off), are adopted. Having this visualized model, energy managers are expected to have better perceptions of space statuses and can take more appropriate corrective actions (e.g. which lamps should be turned off, or how much appliances should be turned off).

B. Real Time Energy Consumption Analysis

The BIM-EMSS allows energy managers to perform 'real time consumption analyses' on a certain space at a particular time in a day during operational phase. At any given time in a day when energy managers intend to perform energy analyses on a particular space, BIM-EMSS will produce in real time two profiles of energy consumption data to be compared visually:

1) Hourly 'actual energy consumptions' profile: hourly 'actual electricity consumption' data of a space are recorded constantly by the smart meters and stored in the data warehouse. Hourly 'actual electricity consumption' data prior to a time specified by energy manager are retrieved from the 'data warehouse' component of the BIM-EMSS and plotted.
2) Hourly 'standard energy consumptions' profile: hourly 'standard electricity consumption' data of a space are simulated and calculated by the software eQuest with input data such as the hourly climatic data, building infrastructure information of the space, hourly occupancy status and equipment status data, as well as the hourly indoor air temperature data recorded. Hourly 'standard electricity consumption' data prior to a time specified by energy manager are simulated and calculated by the 'energy simulation tool' of the BIM-EMSS and plotted.

Energy managers can examine the two energy consumption profiles and identify problem areas graphically. Energy mangers are to be warned for those hours that 'actual energy consumptions' are higher than the simulated 'standard energy consumptions' [16]-[20].

C. Automatic Anomaly Detection

The BIM-EMSS is designed to offer 'automatic anomaly detection' function to assist energy managers in identifying abnormal energy consumption situations in a particular space automatically at a particular time in a day during operational phase. During daily operation, there are differences between how occupants use equipment in a space and how energy manager expect them to (according to the ‘rules’ they have already predetermined per space). For example, occupants tend to leave the lighting equipment at 100% power level regardless of their occupancy level, while the energy manager want the lighting appliances to be decreased according to low occupancy condition. In this context, anomaly is detected when the actual operation setting is different with energy manager expectation.

To automatically detect 'energy consumption anomaly' in a space, the following three profiles at a particular time are plotted and compared:

1) Hourly actual energy consumption profile
2) Hourly occupancy status profile (hourly percentages of occupant 'presence')
3) Hourly equipment status profile (hourly percentages of equipment 'on')

'Energy consumption anomaly' will be detected when the 'occupancy status profile' is low, while the 'equipment status profile' is high (actual energy consumption' profile is expected to be high as well). The anomaly of consumption will be detected using time delay principle (15 minutes), means only odd condition that last for 15 minutes will be assumed as anomaly by the system. This will prevent false alarm (such as occupants only leaving the space temporarily) but also prevent further waste of consumption (since it's done hourly) [21]-[23].

D. Historical Energy Consumption Analysis

The previous three energy management functions are to be of use during daily operation. Energy managers are also equipped with 'historical energy consumption analyses' to compare recent energy consumptions against historical energy consumption data periodically (monthly or annually):

1) Monthly energy consumption analysis: Energy managers can specify the 'target month' to be analyzed and compared. The BIM-EMSS will first sum up the 'daily actual energy consumption' data (stored in the data warehouse) in the recent 'target month'. Then, the historical data of daily energy consumption within the same month in the previous years are averaged as the historical daily energy consumptions of the month. Two sets of daily energy consumption profiles are plotted and compared.
2) Annual energy consumption analysis: Similar to monthly energy consumption analysis. Two sets of monthly energy consumption profiles (recent year and historical years) are plotted and compared.

IV. BIM-EMSS Functions and Interface Mock Up: Demonstrations and Illustrations

A. The Subject

The subject is a space (RB906) in the Department of Architecture in the Research Building on NTUST campus. The Research Building is a nine-floor building (floor area of 1,100m^2 each), built of conventional reinforced concrete with tiles covered on the facade, and column-beam framing structural system. The Department of Architecture occupies the 7th, 8th and 9th floor of the Research Building.

The dimensions of the RB906 are 8.2 m x 9.9 m = 81.2 m^2. The layout of RB 906 is shown in Fig. 2. RB 906 is occupied by two different laboratory groups, with a total of eleven occupants (all are graduate students). The occupancy info can be seen on Table I, available equipment can be seen on Table II.

The observations and recordings of occupancy status, equipment status, and hourly actual energy consumptions were conducted during the week of May 11th – May 17th in 2015 (Monday through Sunday), starting at 09:00 daily until all occupants left the space. The interface mockup of the BIM-EMSS is devised, and RB906 used as a demonstration case to show the energy management functions described.

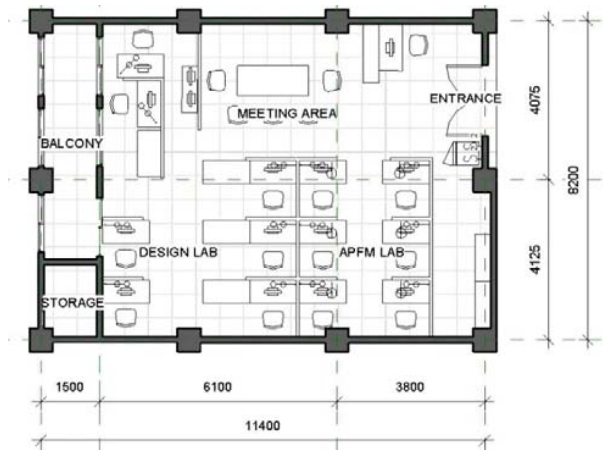

Fig. 2 RB906 Layout Plan

TABLE I
RB 906 Occupant Information

Laboratory Groups	Occupants	Activities	Schedule
APFM Lab.	5 people	Computer processing task Making model Meeting	Monday to Friday 9 AM - 5 PM
Urban Design Lab.	6 people		

TABLE II
RB 906 Equipment Information

Appliances	Type	Amount
HVAC	Split AC system	2
Lighting	T8 lamps	41
Office Appliances	Personal appliances:	
	Personal computer	7
	Laptop	4
	Public appliances:	
	Refrigerators	1
	Computer	3
	Printer	2

B. Visualization of RB906 Statuses

To spot irregular equipment use in a space, energy managers may want to 'inspect' visually and remotely the occupancy status and equipment status of the space in a day during operational phase from a centralized FM office. The 'visualization' function can be of use in this regard.

The BIM model is built for all the spaces in the Department of Architecture, the statuses of occupants, lighting, appliances, and HVAC units are linked between the sensors and the BIM model components, and visualization techniques are used to indicate the statuses. Fig. 3 shows the visualization of the on/off occupancy and equipment statuses in RB906 at 11:00 am of May 11th 2015 (represented in different color schemes: grey indicates 'off-status' and colors indicate 'on-status') in the BIM model: seven out of the eleven students are 'present' (in green); all twelve light fixtures are 'on' (in yellow); fourteen out of the seventeen appliances are 'on' (in red); and one of the two HVAC units is 'on' (in blue).

C. Real Time Consumption Analysis

Energy managers may want to know the actual energy consumption profile in a day during operational phase to see whether the energy consumption of a particular space is reasonable, and the 'real time energy consumption analysis' function can be performed to find out the answer.

Fig. 4 shows output results of the 'real time energy consumption analysis' at 16:00 of May 11th, 2015 for RB906. The blue-line profile indicates the 'hourly actual electricity consumptions' before 16:00 (data recorded and stored earlier, and retrieved from the data warehouse); and the grey-line profile indicates the 'hourly standard electricity consumptions' before 16:00 (data generated automatically by the eQuest simulation software based on hourly climatic data, occupant status, equipment status, and building infrastructure information of RB906).

The comparison of both the 'actual energy consumption profile' and the 'standard energy consumption profile' shows that:

1) 'Hourly actual energy consumptions' are higher than the 'hourly standard energy consumptions' between 9:00 and 13:00, indicating that the actual energy consumption could be abnormal. However, no action can be taken at this moment to fix this outdated 'abnormal situation'. If this 'abnormal situation' can be identified in time and energy saving actions taken, it is estimated roughly that 5~10% energy saving can be achieved.
2) 'Hourly actual energy consumptions' are lower than the 'hourly standard energy consumptions' between 13:00 and 16:00, indicating that the actual energy consumption is reasonable.

D. Automatic Anomaly Detection

Energy managers may want to check at a particular time of a day during operational phase whether the energy consumption of a particular space is considered as 'anomaly' based on the actual use and status in the space, and the 'automatic anomaly detection' function can assist energy managers in identifying possible anomalies automatically.

Fig. 5 shows output results of the 'automatic anomaly detection' functions at 13:00 of May 11th 2015 for RB906. The 'automatic anomaly detections' were conducted for HVAC, lighting, and socket (appliance) respectively. For each type of equipment, hourly actual energy consumptions profile, hourly occupancy status (in percentages), and hourly equipment status (in percentages) are plotted and illustrated in a 'tabbed window' in the central window. In addition, a list of 'anomalies' detected in three types of equipment are enumerated and summarized in 'Anomaly List' Window on the right.

Fig. 5 shows that no ongoing 'anomaly' was observed at 13:00. However, one socket/appliance related anomaly was detected at 12:00, when less than 10% of the occupants are 'present' (in green line), whereas 60% of the 'appliances' was 'on' (in brown line), resulting in the 'appliance energy consumption' increasing to almost 500 Wh.

The 'Anomaly List' Window in Fig. 5 also reveals that two lighting-related anomalies were detected at 10:00 and 12:00 due to low occupancy level with high lighting on-percentages; and HVAC-related anomalies were detected at 9:00 and 12:00 also due to low occupancy level with high HVAC on-percentages.

If further warning was issued or energy saving actions were taken immediately after each anomaly was detected during the week of May 11th through May 17th, energy consumption of RB906 would be expected to be reduced. It is estimated by this study that 5.8% energy saving could be achieved for HVAC in RB906; 13.8% energy saving for lighting; and for office appliances, condition such as occupants left the space without turning off their appliances could be avoided.

V. Conclusion

To assist individual departments within universities in their energy management tasks, this study explores the application of Building Information Modeling in establishing the ‘BIM based Energy Management Support System’ (BIM-EMSS). The BIM-EMSS consists of six components: (1) environmental and temperature sensors, (2) electricity sub-meters for lighting, HVAC, and socket in each room, (3) BIM models of all rooms within individual departments’ facilities, (4) data warehouse (for storing occupancy status and logged electricity consumption data), (5) building energy management system that offers energy managers with various energy management functions, and (6) energy simulation tool (such as eQuest) that generates real time 'standard energy consumptions' data against which 'actual energy consumptions' data are compared.

Through the building energy management system, the energy manager is able to (a) have 3D visualization of space statuses in BIM model; (b) perform real time energy consumption analysis to compare the actual and standard energy consumption profiles of a space; (c) to perform automatic anomaly detection on a certain space at a particular time in a day during operational phase; and (d) to perform historical energy consumption analysis to review monthly and annually energy consumption profiles and compare them against historical energy profiles.

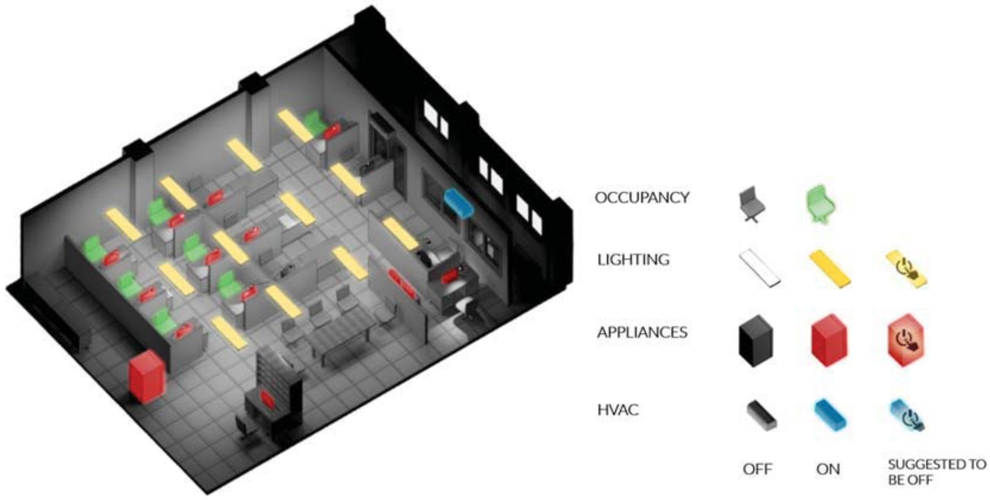

Fig. 3 Visualization of the RB906 in the BIM model

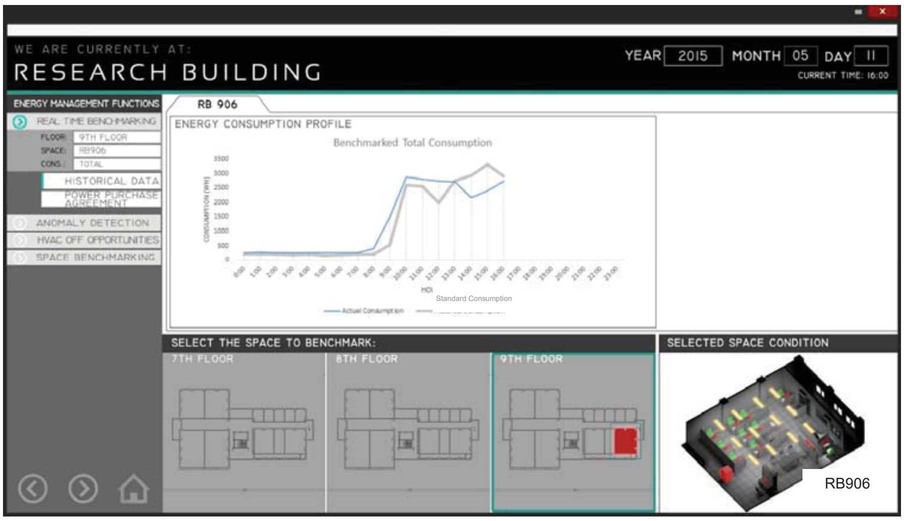

Fig. 4 Real time energy consumption analysis for RB906: comparing actual and standard energy consumptions

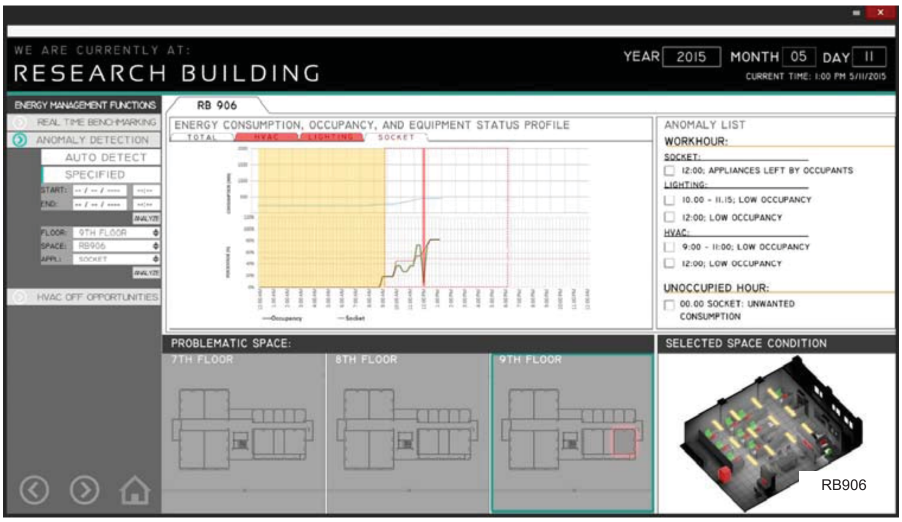

Fig. 5 Results of automatic anomaly detection for RB906

The BIM-EMSS was further implemented in a research lab in the Department of Architecture of NTUST in Taiwan and implementation results presented to illustrate how it can be used to assist individual departments within universities in their energy management tasks.

It should be noted that this study focused more on proposing a conceptual framework for the BIM-EMSS as a BIM-based energy management tool as well as devising real time energy management functions energy managers need the most in daily operation. Many technical issues of realizing the BIM-EMSS, such as how to indicate the on-off status of a sensor in the BIM model, how to retrieve data from the data warehouse and BIM model to feed into the simulation software, remain to be researched, resolved and implemented. These are important research tasks to be further conducted in the future.

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