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Testing Emerging Technology for M&V of an Old Building

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Abstract: *This paper demonstrates a simulation-based M&V using emerging technology such as 3D scanning, Photo-2-3D, BIM, BIM2BEM, weather ISP for very old school building where almost no documents are available. Compared to the legacy practice, these emerging technologies reduce manual work of the simulation-based M&V and offer reliable data that can be direct simulation inputs or with which simulation modeler can make reasonable assumption on the simulation input. Although this project is still on-going and several critical steps of the M&V are left, taking advantages of emerging technology seem to be very promising thanks to their benefit and confidence offered to M&V experts.*

Keywords: *M &V, building energy simulation, ESCO, 3D scanning, BIM, model transformation*

1. INTRODUCTION

To reduce greenhouse gas emission of existing buildings, energy demand management needs to be done prior to expanding renewable or alternative energy supply. Green retrofit is a typical method of the energy demand management for existing building. When ESCO (Energy Service Company) carries out a green retrofit project, if the promised energy saving cannot be met, ESCO has to reimburse the retrofit expense. Thus scientific and systemic M&V (Measurement & Verification) of ECM (Energy Saving Measure) is very required to hedge the project risk and to increase ESCO's credential. As ESCO is not a brand-new business, a number of M&V method have been tried and M&V guidelines also have been published [xxx]. While legacy methods rather depend on M&V performer's experience and heuristics, this paper introduces an attempt using new instrumentation based on ICT (Information Communication Technology), which can raise productivity and efficiency of M&V.

2. MEASUREMENT & VERIFICATION (M&V) ANDREGULAR PRACTICE

2.1 M&V

M&V is a process of measuring the improved performance by installing ECMs in a facility, and then of verifying the improved performance in an objective and scientific manner. The improved performance means saved utilities of the facility such as electricity and gas. ECMs not only include efficient mechanical and electrical systems, but also include optimized controls and high performance envelope. Therefore selection of adequate and economicECMs among a variety of ECM options is a key factor for a successful green retrofit project.

Figure 1 illustrates a typical process of M&V for green retrofit. Depending on ECM type, M&V scope and method can be largely varied. While Method I and II is to measure direct power consumption by on/off of ECMsand to estimate energy savings by measuring all or parts of output and subsidiary energy attributes, respectively, Method III is the calibrated simulation where both passive and active ECMs are applied to whole facility andmore specifically, when little historical data are available.

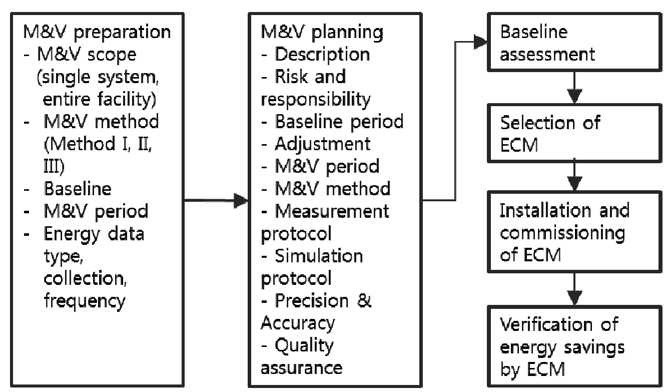

Fig. 1. Typical process of M&V for green retrofit

2.2 SIMULATION-BASED M&V

This paper focuses on Method III, simulation-based M&Vbecause its performance mostly depends on setting up a reasonable baseline. To do so, surveying available energy attributes and collecting energy data and then calibrating the simulation model upon available utility data is very essential. However almost all steps of the simulation-based M&V (Figure 2) from geometry modeling to model calibration highly depend on human manual practice, thus it is highly subjective and prone to rule-of-thumb.

This paper purposes to demonstrate potentials of emerging technology in reducing painful efforts of collecting energy data, constructing energy model, model calibration, and ECM selection and sizing. It is also demonstrated that using emerging technology offers more accurate and objective survey than manual works do.

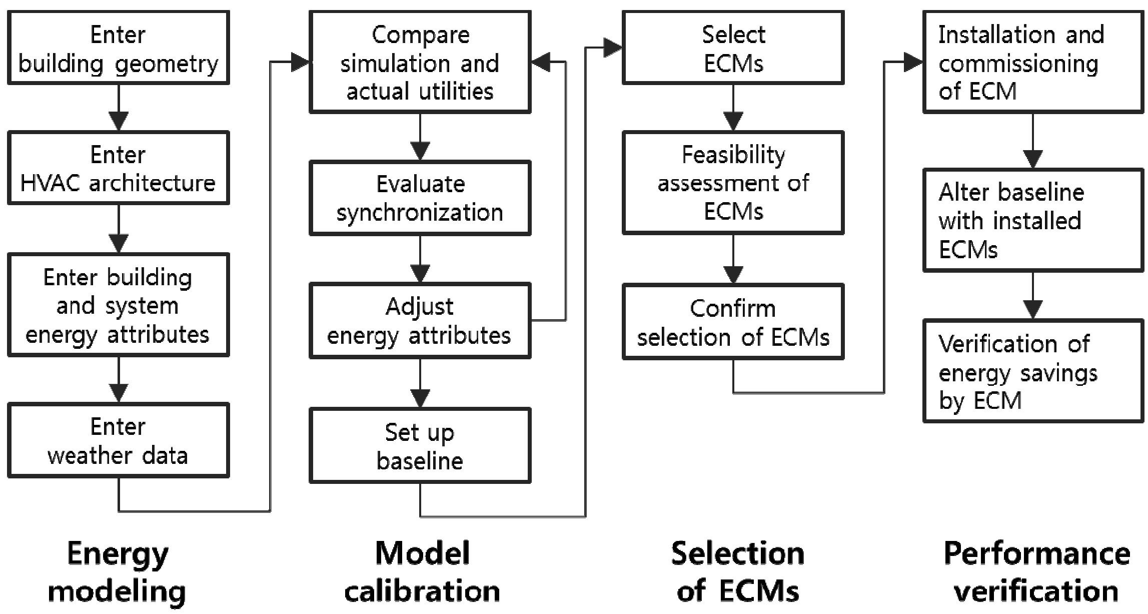

Fig. 2.Typical process of simulation based M&V and feasibility assessment

2.3 EMERGING TECHNOLOGY FOR M&V

Table 1 compares legacy practice of the simulation-based M&V with the emerging technology that can replace or expedite the legacy practice. Legacy practices of M&V tend to be done manually using rule-of-thumb or M&V expert's best knowledge, if there is no apparent data or information. Emerging technologies can compensate the weakness of the legacy practice, reduce M&V expert's work load, and provide reliable data for decision-making.

3D scanning is frequently employed for composing as-built drawings of new building. Existing buildings, however, requiring retrofit are typically more than 20 years old, thus it is very often the as-built drawing cannot precisely deliver the current building state. 3D scanning is very useful to capture the current state of a building as precise as a few millimeters of cracks and differential settlement.

Photo-to-3D can replace the 3D scanning if only surface geometry of a building is needed. Although it is based on photogrammetry requiring a quite large number of pictures, it is a lot cheaper than 3D scanning. However, it is often argued that reconstructed 3D point cloud data is frequently out of scale against actual object.

Scan-to-BIM helps building information modeling by means of matching a 3D scanned object to the building component in library with the most similar shape. Thus it expedites constructing BIM by replacing dull and repetitive modeling works. It is typically placed as a plug-in of BIM authoring tools.

BIM-to-BEM is a model transformation technology that not only converts BIM geometry to BEM geometry, but also implants energy simulation context to the resulting BEM such as default values of energy attributes, building operation schedules and thermal zoning. It is a type of knowledge based system whose knowledge DB represents experienced building energy modeling experts.

Weather ISP (Information Service Provider) and database offers a high resolution actual weather data. Although they charge for the data and unavailable regions are often observed, they are very convenient actual weather data source for the simulation-based M&V.

Meters and imager, a.k.a. ESCO (Energy Service Company) equipment, measuring flow rate, temperature, humidity, pressure, CO_2, CO, power, current, and voltage have been already used for M&V. Additionally meters measuring U-value and SHGC (Solar Heat Gain Coefficient), moisture meter, IAQ meter, infrared meter, and handy power plug meter expands the scope of collectable energy data. As they are not meant for long term measurement, entering resulting instantaneous values for simulation inputs is not recommended. However, this short term measurement apparently helps the simulation modeler make a reasonable assumption for simulation inputs.

BEMS (Building Energy Management Systems) and transmitters are used for long term measurement. While BEMS manages whole facility, transmitters are installed in systems and equipment requiring monitoring. BEMS by itself can be an ECM because it has controllability over managing systems.

Proprietary sizing tool is known as offering more optimized measure for sizing plumbing and control equipment such as pipe, duct, valves, and dampers, and also for sizing renewable energy systems whose boundary exceeds the existing sizing method. Some simulation tools also offer sizing option based on internal load calculations.

TABLE 1: Regular practice vs. emerging technology forthsimulation-based M&V

M&V process	Regular practice	Emerging technology
Geometry modeling	Manual energy modeling referring to as-built drawing Manual energy modeling using actually measured values if no existing drawings	3D scanning Photo-to-3D
Energy modeling		Scan-to-BIM BIM-to-BEM
Collecting energy data	Identifying type and capacity of HVAC and plants via documents, facility manager survey, physical visit Short term measurement using instruments (temperature, flow rate, pressure, power, current, voltage). If not possible, reasonable assumption and approximation based on hand book data Occupant survey Assumed low performance value for insulation, air tightness, if no documentation LPD, EPD, occupant density and their schedule per generally referred value Standard weather data Monthly utility bills	Weather database, weather ISP U-value meter, SHGC meter, moisture meter, IAQ meter, infrared meter, powerplugmeter, daylight sensor, occupant sensor Long term monitored data by BEMS Long term measurement using transmitter
Calibrating energy model	Manual adjustment upon modeler’s rule of thumb	Parameter identification using optimization algorithm Stochastic parameter identification
ECM selection	Based on energy savings perceived over installed ECMs	Evaluation by energy simulation
ECM sizing	Rule of thumb, per unit floor area, ESCO’s in-house metrics, universal sizing table	Proprietary sizing tool and simulationfor each ECM

3. TESTING THE EMERGING TECHNOLOGY

Due to the site limitation, only several technologies presented in Table 1 have been applied in an old building of Seoul Tech. The applied technology is to acquire energy attributes of the test building, which should be inputs of the simulation baseline. Alsothe result acquired by the technology has been compared with those by legacy practice of M&V.

3.1TEST BED

The test bed (Fig.3)is a two-story building having class rooms, labs, offices and service areas. It was initially constructed around 50 years ago and numerous retrofits have been done, but there is no written record of retrofit details. Only several floor plans and MEP drawings are available. Although it uses campus steam for heating, no submetering is available. Only monthly electrical consumption is available. Campus plant provides steam for heating via perimeter convectors and package air conditioners provide cooling. All exterior walls, roof, floors are made of bare concrete without insulation. Windows are the most recently replaced, but with clear single pane. Roof is covered by black urethane coat and topped with gravels.

3.2 BUILDING GEOMETRY SURVEYING: MANUAL MODELING VS. 3D SCANNING VS. PHOTO-TO-3D

To capture the building geometry, ee first tried the Photo-to-3D. About a hundred of panorama pictures are taken around the test building, and then they are posted to the ReCap 360 for stitch-up. Unfortunately only three sides of all the six sides of the building are reconstructed to 3D (Figure 3), because the distance between the building and camera is not uniform, thus the Recap 360 does not seem to recognize the overlapped scenes.

The we tried 3D scanning. About thirty scenes are captured for exterior and forty scenes are captured for interior. Then these Point Cloud images are imported in the FARO Scene and then exported to the ReCap for noise removal and resolution adjustment. Finally the registered Point Cloud images are exported to the Revit to building a BIM of the test building.

As shown in the Figure 3, 3D scanned geometry model is almost the same as actual building in terms of orientation, dimension, scale, and ratio. The Photo-to-3D geometry model is, however, distorted and off-the-scale, thus it is not possible to be used as watermark baseline for further digital modeling. As presented in Table 2, when the 3D scanned values are compared with the values found in existing drawings, it is found that quite many energy attributes have been modified, which are not properly documented.

Fig. 3. 3D scanning vs. Photo-to-3D

TABLE 2:Geometry acquired by 3D scanning and existing drawings

Energy attributes	Existing drawings	3D scanning
Orientation	Not specified	Azimuth 22.5° for the longest axis
Floor area	1354 m^2	Xxx
Floor height/ceiling height	No information	3300 mm / 2650 mm
Wall thickness	350 mm	350 mm
Roof thickness	Not specified	Xxx
Window size/location	1725 mm wide, but no height	Xxx
Room layout	Some alterations are missing	As-is state

3.3 BUILDING ENERGY MODELING: MANUAL MODELING VS. BIM2BEM

We firstly built a baseline model manually referring to existing drawings. As the test bed is not geometrically complex, only two days are enough to build the baseline. However, we had to visit the test bed from time to time to measure the values missing in the drawing. Also we had to estimate the dimension that is not visible.

Once the registered 3D scanned images are exported to Revit, we built a BIM. Since the 3D scanned images only represent dummy geometry, building information modeling should give semantics to the captured object. For instance, there is no way to tell a vertically squared object whether it is a wall or partition. When modeler specifies wall attributes, it is then recognized as a wall. Once the BIM is complete, it is converted to a gbXML in Revit and then converted again to a DOE2 Building Energy Model (BEM) in the Autodesk Green Building Studio. From 3D scanning to building a BIM takes about a week while the model transforming process (BIM to BEM) takes only a few minutes. In terms of the geometry accuracy, the 3D scan based BEM represents the test building very realistically.

The difference between manual energy modeling and BIM2BEM include thermal zoning, orientation, opening allocation, and geometrical protrusion and protrusion. The most significant difference would be thermal zoning, as shown as Figure 4. In manual energy modeling, zones are firstly defined and attributes of envelope objects are specified next. In BIM2BEM, envelope objects are firstly recognized and zones are then recognized if a zone is sufficiently enclosed by envelope objects.

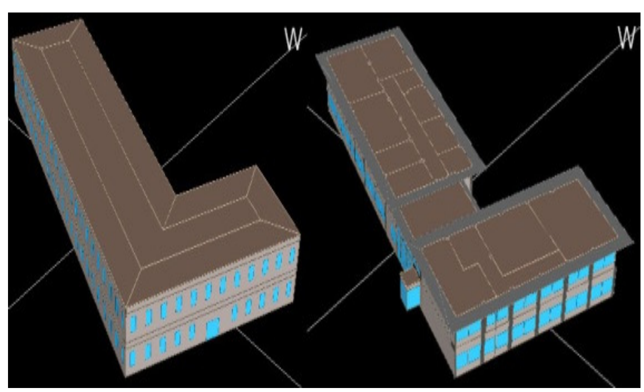

Fig. 4. Manual energy modeling (left) vs. BIM2BEM (right)

3.4 BUILDING ENERGY DATA SURVEYING: ASSUMPTION VS. ACTUAL MEASUREMENT

For collecting internal heat gain, we visited every room and surveyed average number of people, instance power consumption and capacity of luminaire and electrical devices. Also U value of exterior wall, roof, and glazing are measured using Testo 435 U-value meter. COP of air conditioners are also calculated. Unfortunately U-value of

Slab-On-Grade, air change rate, capacity of steam radiator could not be measured. Table 3 compares the energy attributes assumed referring to standards and catalog and the energy attributes actually measured. Most values are off the standard; in particularly LPD, EPD, U value of exterior walls and roof are largely outbound.

TABLE 3:Assumed and measured energy attributes

Energy attributes	Assumption	Actual measurement
Occupancy density	0.05 – 0.36 person/m^2 (ASHRAE 2009)	0.05 – 0.4 person/m^2
LPD (Lighting Power Density)	12-20-30 W/m^2 (ASHRAE 2009)	8.6 - 19 W/m^2
EPD (Electrical Power Density)	10.8-16.1-21.5 W/m^2 (ASHRAE 2009)	3.51- 4.1 W/m^2
U value of exterior wall	4.57 W/Km^2 (350 mm of bare concrete with 1.6W/mK)	3.14 W/Km^2
U value of roof	16 W/Km^2 (100 mm of bare concrete with 1.6W/mK)	3.14 W/Km^2
U value of glazing	3.40 W/Km^2 (6 mm of single clear glazing)	3.95 W/Km^2
SHGC of glazing	0.81 (6 mm of single clear glazing)	0.87
COP of air conditioner	3.2 (rated)	3

3.5 WEATHER DATA: WEATHER ISP VS. NATIONAL WEATHER DB

Realistic weather data is the most critical model input for verifying energy performance of existing building. Acquiring and processing the actual weather data for a simulation input, however, takes expertise and time. In that case, the weather ISP can be an alternative. Weather data provided by Autodesk, actual weather of Year 2014 and standard EPW (Energy Plus Weather) have been compared for the test site. The nearestAutodesk weather station is 4 km far from the site and it is not for a specific year. Only temperature and relative humidity of the year 2014 weather are from the site weather station, but all other weather variables including solar radiation come from the Seoul city weather station. Figure 5 illustrates temperature profiles in case of the lowest and highest dry air temperature in 2014. It is observed that when actual temperature offset the norm, ISP temperature rather tends to match the actual than EPW does. Therefore when actual weather is not available, using the ISP weather data can be an alternative.

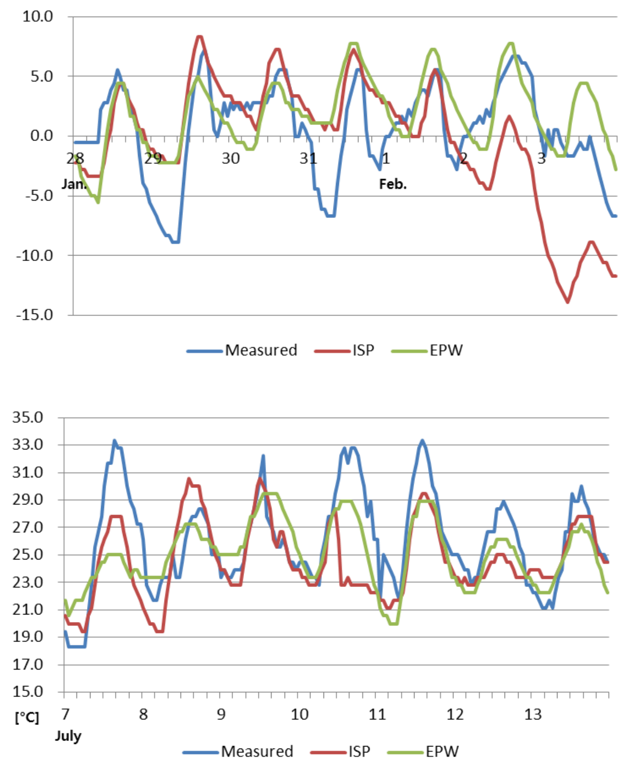

Fig. 5.Temperature between weather ISP, Year 2014, and EPW (Top: from Jan. 28th to Feb. 3rd, Bottom: from Jul. 7th to 13th)

3.6 OTHER

Critical energy attributes such as air change rate, U value of Slab-On-Grade, steam flow rate and inlet/outlet temperature of radiator, as of now, are still being collected. Since this paper only deals with the energy modeling step of the simulation-based M&V, the rest steps including model calibration, ECM selection and sizing, and performance verification of the selected ECM will be progressively done.

4. DISCUSSION AND CONCLUSIONS

This paper demonstrates a simulation-based M&V for very old school building where almost no documents are available. Compared to the legacy practice, emerging technologies reduce manual work of the simulation-based M&V and offer reliable data that can be direct simulation inputs or with which simulation modeler can make reasonable assumption on the simulation input. Although this project is still on-going and several critical steps of the M&V are left, taking advantages of emerging technology seem to be very promising thanks to their benefit and confidence offered to M&V experts.

To make these technologies more viable to M&V, however, we need to overcome i) cost and ii) QA (Quality Assurance) issues. Quality and accuracy of 3D scanning is much better than that of Photo-to-3D, but 3D scanning costs, as for now, at least ten times more expensive than Photo-to-3D.Services such as Scan-to-BIM, BIM-to-BEM and weather ISP cost at least several hundred dollars. U-value, SHGC, IAQ meters cost at least several thousand dollars. As instrument price is getting cheaper and software license becomes subscription-based, however, these technologies are expected to be affordable sooner or later.

Indeed QA issues for Scan-to-BIM and BIM-to-BEM seem to be more urgent. These two technologies are at their early stage of the development. Thus more real cases need to be tested and require more users' feedback. In particular, shape recognition of the Scan-to-BIM needs to be expanded to wider building component library and setting-up energy context of the BIM-to-BEM needs to be more flexible for localization and customization.

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