Data availability and validity issues for dynamic simulation of a high-rise office building

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ABSTRACT
For better energy management of a high-rise office building, an accurate dynamic building simulation model is required for rational energy management. The dynamic simulation model can answer what-if questions as well as be used for real-time Building Energy Management System (BEMS). Dynamic modeling of an existing building as operated requires much more efforts, insights and understanding than dynamic modeling of that as designed. This paper reports, how the authors (simulationists) developed a dynamic energy simulation model for a large office building (33 stories above ground and 6 underground levels, a total floor area of 91,898 m^2). The simulation project, inclusive of modeling, calibration and validation, was finished within a tight time schedule (2 months) by four people (1 M.S. and 3 Ph.D. students). In the paper, the following issues are elaborated: (1) gathering building information (architectural, mechanical, electrical, schedules, etc.), (2) handling disagreement between construction documents and a reality, (3) dealing with absent (unknown) and uncertain inputs, and (4) tweaking the simulation model when the tool can't simulate as it is. Finally, the paper shows the comparison between the simulation prediction and measured energy use. The tool used in the study is EnergyPlus 6.0. This paper focuses on modeling process and issues, simulation results from the uncalibrated model.

KEYWORDS
real-life building, data availability and validity, energy simulation, EnergyPlus

INTRODUCTION

For the past 50 years, a variety of Building Energy Performance Simulation (BEPS) tools have been developed and the accuracy and reliability of BEPS tools are sufficiently verified (IBPSA, 1987-2011). The past paradigm of decision-making,

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which was based on the experts' rules of thumb or simplified calculation methods, moves to a new paradigm, which depends on the quantitative analysis using the BEPS tools. Recently, the efforts to utilize the BEPS model at whole building life cycle are encouraged for green, smart, high performance buildings. For example, Database for Analyzing Sustainable and High Performance Building (DASH, 2012), California Commercial End Use Survey (CEUS, 2012), and Building Performance Partnership (BPP, 2012) attempt to apply the BEPS model at the operation phase.

In general, there is a huge difference in the simulation model between design phase and operation phase. The BEPS model of design phase is impossible to validate the accuracy of the results due to the absence of the comparison target. Thus, the domain experts or clients investigate validity (not accuracy) of input variables. In other words, the problem caused by lack of the information and data in the design phase is usually offset by the subjective assumption and judgment made by simulationists.

On the other hand, the BEPS model of operation phase is usually compared to measured data. The model is usually calibrated, to be able to predict the measured energy use. The simulation model is often labeled as 'calibrated' if it falls within a specific error margin (e.g. 5%) (Maile T. et al, 2010). The calibrated BEPS models are able to predict the annual energy use of commercial buildings to within a 5% error from measured consumption (Waltz, 2000) or 5% mean bias error (MBE) and 15% coefficient of variation of the root mean squared error (CVRMSE) with monthly data (ASHRAE, 2002) (Samuelson H.W. et al, 2012).

The authors are requested to make a simulation model of a real-high rise office building. The purpose of the project is to apply the simulation model to energy saving strategies of the building. The building, located in Seoul, is as follows (33F, 91,898m^2, 47 air handling units, 122 fan coil units, 4 packaged air conditioners, 5 chillers, one ice storage system, 5 cooling towers, and 3 boilers). This paper describes modeling and simulation of the aforementioned building. The simulation model will be tested for potential use of the real-time building operation and control. In the paper, experiences and lessons learned throughout the project are reported.

PROJECT BACKGROUND

The subjective judgment of an operator has significant influence on the comprehensive decision of building operation even if the mechanical systems are automatically or optimally controlled. The operator proactively plans the operating strategies, but he also often controls manually depending on the indoor and outdoor environmental conditions, and the occupant patterns or requests. This manual approach cannot ensure he/she always does accurate diagnosis, managing, and decision-making. According to Zhu (2006), many existing energy auditing approaches may overlook intricate relationships between different factors that affect the energy consumption of a large facility. The operator usually responds to unpredicted situations with a small number of alternatives. Therefore, this project was initiated to check the possibility of applying simulation tools for real-time building operation, which will ensure rational building energy management. EnergyPlus is selected as the BEPS tool by the client's request in this project. .

This project was conducted is from 19th March 2012 until 18th May, and the goal is as follows: (1) developing a simulation model of the building, (2) comparing measured data to simulation prediction, (3) calibration of simulation model, (4) developing energy saving strategies. In this paper, only (1) and (2) are described, and (3) and (4) will be reported elsewhere. The team consisted of one professor and four graduate students.

TARGET BUILDING

The target building is the S building (Figure 1) located in Seoul. The S building, which was completed in December 2004, is owned by a telecommunication company. The building is 33 stories above ground and 6 underground levels with a total floor area of 91,898 m^2. The primary use of the building is office space, but the lower part of the building (from 4th floor underground to 4th floor above the ground) has the dining rooms, multipurpose halls, an auditorium, and sports facilities. The façade is composed of a glass curtain wall system, which is approximately 70% window-wall ratio. The glazing is low-e double pane.

The HVAC systems are as follows: (1) air-side systems: Constant Air Volume (CAV) for lobby, Variable Air Volume (VAV) for office, FPU (fan power unit), and FCU (fan coil unit) control zones to maintain the comfort condition, (2) water-side system: the 3 steam boilers, 1 centrifugal chillers for cooling, and 2 centrifugal chillers for the ice storage supply the heat and cold to the heat exchangers.

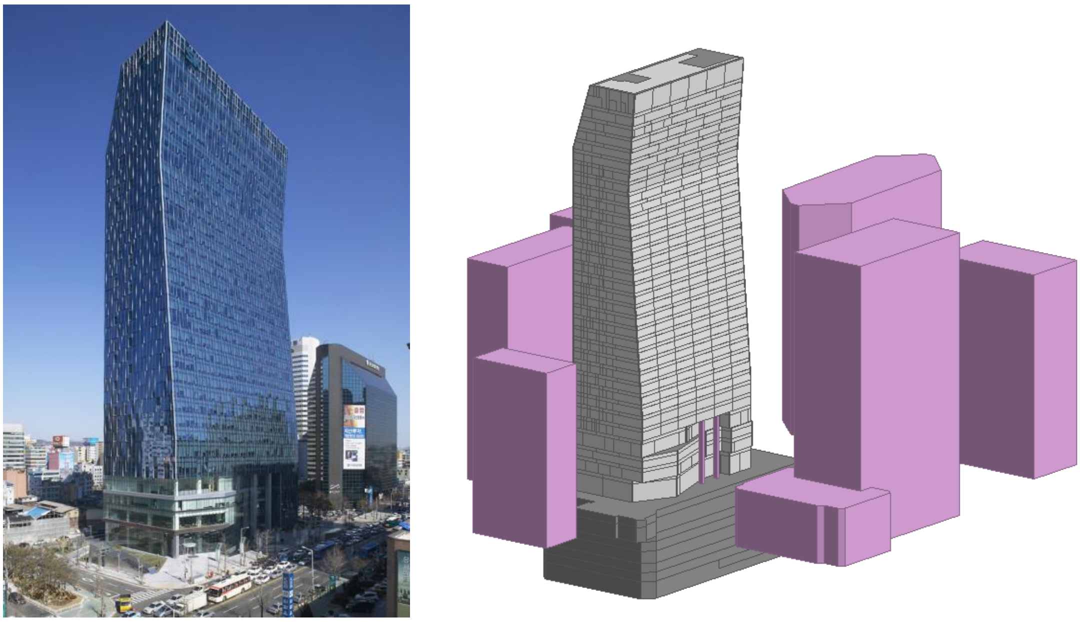


***Figure 1**. The S building (left)(viracon, 2012), simulation model (right)*

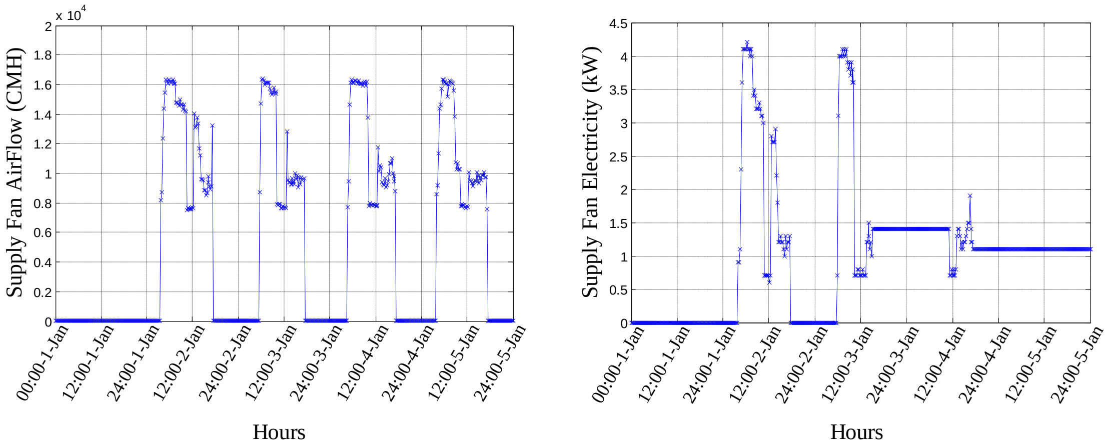
DATA GATHERING

In this project, the client's core required to the team the following: (1) developing the most detailed BEPS model as much as possible, (2) the model should be very accurate (less than 5% error) and (3) the project must be strictly completed in two months. Since the target building has the BEMS system (1,692 measurement points), the simulation results are easily compared to the recorded measured data. Thus, the client requests that simulation model should be close to the target building as much as possible. The client wants to exclude modeling assumptions by simulationists and simplification of the reality as much as possible. Also, the accuracy of the simulation model should be less than 5% error (difference between simulated and with measured data).

However, the authors encountered the following Information And Data (IAD) problems. First, in this project, the client was very interested in energy simulation, but was not aware if what specific kinds of IAD are required and how the IAD are utilized in BEPS. Thus, although the project was already undertaken, there was neither well-prepared nor documented IAD. Although even the architectural and mechanical drawings and specifications are essential for BEPS modeling, the entire set of drawings were not provided to the team due to the security and privacy protocol of the company. In other words, the security and privacy protocol is more significant to the company that energy savings, which will be, the authors believe, the most common case. Not the entire set of but a subset of drawing are provided intermittently, which delayed a seamless development of the simulation model. Temporal modeling process by the team was not significantly considered and such data weren't sufficiently provided.

Second, the provided IAD were not up to date. During the site visit, the authors recognized that the use and configuration of many rooms and floors were changed. In addition, special FCUs were added to VIP rooms after construction, which is to provide accurate comfort control. The aforementioned occurrences were not represented in the drawings/documents and the authors had to resort to the operators' oral description. Such changes and modifications to the building have not been documented, limiting the team to full acquisition of necessary IAD. In other words, as long as the simulationist is not fully aware of the entire building maintenance history, the simulationist cannot help realizing up to date IAD, and it takes extreme effort and time to represent the simulation model close to the real building as much as possible.

Third, IAD was not coincided with one another. In the target building, BEMS was installed and the energy-relevant data were monitored. Figure 2 shows the measured supply fan airflow and electricity from January 1 to January 5 2012. Figure 2(a) and (b) are mutually contradictory since the energy use doesn't reflect fan airflow rate. In such cases as above, the authors had to make a reasonable assumption based on the building use schedule, dialogue with building operators, cross-comparison between the measured data, etc.



(a) fan airflow rate *(b) fan energy use*

***Figure 2**. Measured data of supply fan air flow rate and fan energy use*

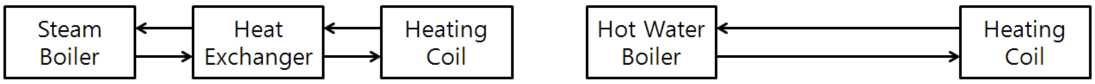
The last issue is quantification of simulation inputs. The authors made several site visits to quantify the uncertain inputs (e.g. indoor setpoint temperature, operation schedule of plants, rates of outdoor air to AHUs, etc.). However, after interviews with the operators, the authors realized that it is difficult to quantify the unknown parameters with the following reasons: even though the advanced automatic control is installed (e.g. enthalpy control, night-purge), the final decision-making is usually determined by the operators in the light of the indoor/outdoor condition, occupant's complaints, their subjective judgment, heuristics, and experience. Unfortunately, such subjective control history has not been documented. Even though the authors gathered the accurate information about the geometry and materials, what matters more would be the simulation inputs relevant to building operation and schedule.

The clients and simulationists recognize significant uncertainty of the simulation model due to the aforementioned reasons. For the project period, the authors regularly reported the abovementioned issues to the clients at weekly meetings, and explained the assumptions and simplifications made by the team in order to overcome the IAD problem. Without well-prepared or documented IAD, 'the most sophisticated/detailed model' can't be 'the most accurate model'. Thus, with the client's consent, the goals of project (development of the most detailed and accurate BEPS model with the error less than 5%) were compromised.

SYSTEM MODELING

Most BEPS models do not capture the significant impact of HVAC faults on actual energy performance, and it makes as much as 22% of energy use discrepancy between simulation model and measured data (Basarkar M. et al., 2011). The more serious problem is that as mentioned above, it is impossible to get the exact IAD of the actual system (e.g. the operation schedule, partial load efficiency, COP, etc.). In the target building, the operation schedule of AHU has been continuously changed by operators. Although there were two absorption chillers, they had been operated very intermittently (about once a month). Several FCUs were additionally installed for a few VIP spaces. In this study, they were excluded from the system modeling due to lack of information. In addition, since the performance curves of systems (chillers, fans, boilers, etc.) were not clearly provided by manufactures, generic performance curves in the data set of EnergyPlus were used instead.

However, even if the perfect IAD were prepared, the real building cannot be exactly simulated due to limitations of BEPS tools. For example, the target building has the condensing boilers and heat exchangers for transferring the steam heat to hot water. Due to lack of library for the steam-to-hot water heat exchanger in EnergyPlus (Maile T., et al., 2010b), the authors simplified it as shown in Figure 3. In other words, the steam boilers were modeled as the hot water boilers with the efficiencies of both (steam, hot water) identical.



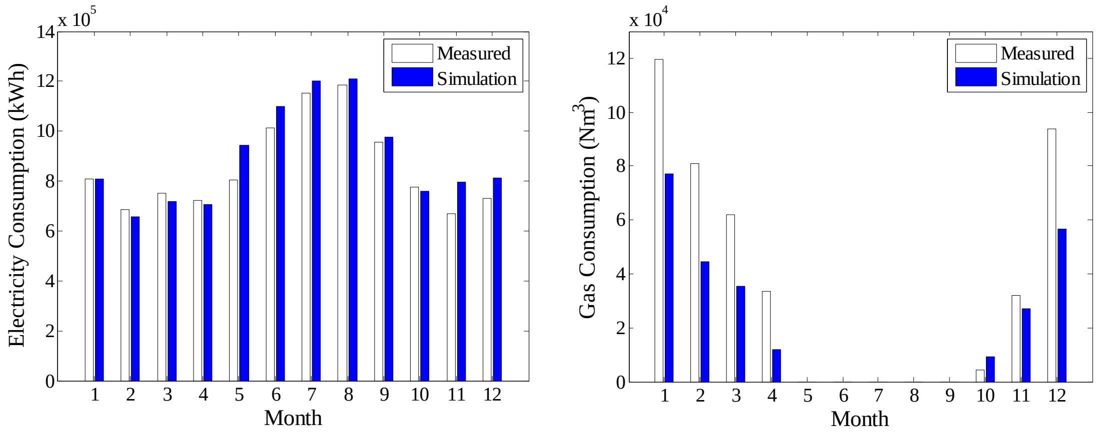
(a) actual loop (reality) *(b) as modeled*

***Figure 3**. The simplification by simulationists*

There are three plant loops (6F-34F, B6F-5F, 24 hours IT rooms) for the cold to be distributed throughout the buildings. The three loops are connected to the ice storage system for which three chillers provide the cold. Such interconnection between loops and chillers cannot be modeled according to EnergyPlus topology rules. Hence, each loop is modeled as standalone (each chiller connects to each loop).

RESULTS

Figure 4 and Table 1 compare measured 2010 monthly data to simulation results. The simulated electricity consumption (Figure 4 (a)) has a similar pattern with actual measured data, and the MBE and CVRMSE are 4.0% and 7.6% respectively. In contrast to the electricity, the MBE and CVRMSE of gas consumption (Figure 4 (b)) are -38.4% and 46.5%, which shows significant difference. The reason for the difference might be: (1) wrong input for the boiler efficiency, (2) not accounting for operator's manual control, (3) infiltration not considered, (4) underestimated heating setpoint temperature.



(a) electricity consumption *(b) gas consumption*

***Figure 4**. The comparison of measured data and simulation results*

***Table 1.** The comparison of simulation result and measured data*

Energy	*Simulation*	*Measured*	*MBE*	*CVRMSE*
Electricity (kWh)	10,667,711	10,257,547	4.0	7.6
Gas (Nm^3)	262,383	426,132	-38.4	46.5

It was recognized that there are huge uncertainties in determining inputs. In addition, modeling of the high-rise complex building requires extensive simplification of the reality and numerous assumptions have to be involved. To reduce such gap between the measurement and simulation prediction, a calibration technique must be introduced. The calibration can be done in three approaches: (1) trial and error, (2) solving for an optimization problem to find unknown parameters which minimizes the difference between the measurement and prediction (Yoon et al., 2011), (3) Bayesian calibration which accounts for stochastic nature of uncertain parameters. The calibration work for the simulation model developed in this project will be reported elsewhere.

LESSONS LEARNED AND CONCLUSIONS

The purpose of this paper is to share the experiences and lessons learned. In particular, this paper describes the difficulties, importance and influence of IAD. Most of existing buildings currently do not manage the accumulated IAD in a suitable form for processing a BEPS. It was recognized that the big difference exists between the reality (building as operated) and documents ((building as designed), and there is 'IADs as operated' for BEPS.

The accuracy and reliability of BEPS tools' prediction is very dependent on the IAD. The BEPS tools are just a 'tool' for convenient calculation, and the simulation results are strongly influenced by the IAD which are gathered and determined by simulationists. With this in mind, collecting and analyzing IAD is one of the most important steps in the simulation process. Some IADs are entered to BEPS without modification, but the others are assumed and modified. This 'assumption and modification' step is one of the most time consuming and labor-intensive parts in the simulation process. As a method to cancel out the incorrect prediction of the tool caused by the aforementioned issues and pacify uncertainty of the model, the calibration technique should be applied (Raftery et al., 2011). For increasing applicability of the dynamic simulation tools to real buildings, a systematic data gathering protocol and IAD structure needs further investigation.

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