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DIFFICULTIES AND ISSUES IN SIMULATION OF A HIGH-RISE OFFICE BUILDING

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ABSTRACT

With the growing focus on low energy buildings, Building Energy Performance Simulation (BEPS) tools have been widely used. However, many issues remain unsolved in terms of transparency, reproducibility, objectivity and usability of such tools. In the paper, the authors report issues and difficulties that a simulationist encounter when applying EnergyPlus to a high-rise office building. The issues are as follows: (1) immature simulation environment (user's subjective judgment, assumptions and simplification of the reality), (2) lack of information on simulation inputs, (3) no certification of the simulation model and modelers, (4) uncertainty in inputs and human behaviors, and (5) ante mortem and postmortem use of the dynamic simulation tool. This paper describes how the aforementioned issues hinder efficient use of building simulation tools. The authors developed a dynamic energy simulation model for a high-rise office building (33 stories above ground and 6 underground levels, a total floor area of 91,898 m^2). In the paper, the aforementioned issues are elaborated in detail. Finally, the paper addresses 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 un-calibrated model.

INTRODUCTION

Over the last two decades, a lot of simulation tools (DOE-2, EnergyPlus, eQuest, ESP-r, IES-VE, TRNSYS, etc.) have been developed along with the improved computer processing ability. The accuracy and reliability of those are verified in many studies (IBPSA 1987-2011; BESTEST, IEA Annex 10, ANSI/ASHRAE 140-2007). The architect's old paradigm of decision-making, which was based on the experts' rules of thumb or simplified calculation methods, now shifted to a new paradigm, which heavily depends on the quantitative assessment using the BEPS tools. Recently, the efforts to utilize the BEPS tools during building life cycle are encouraged for green, smart and 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 operation phase.

In general, there is a difference in the simulation model made at design phase vs. at operation phase. The BEPS model of design phase cannot be validated in terms of simulation accuracy due to the absence of the comparison target. Thus, the domain experts or clients only have to investigate the validity of input variables ('not accuracy of output'). In other words, the problem caused by lack of the information and data in the design phase is usually eclipsed by the subjective assumption and judgment of a simulationist.

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 et al., 2010). The calibrated BEPS models are able to predict the annual energy use 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 et al., 2012). However, it is widely acknowledged that the information and input data required for a simulation model has not been managed well for most real-life buildings. Therefore, the inherent issues and problems of simulating existing buildings are not significantly different from those of simulating new buildings.

The authors were requested to deliver a simulation model of a real-high rise office building. The clients wanted to have a simulation model as accurate as possible to develop and analyze energy saving strategies of their building. The details of the building, located in Seoul, are 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 the issues that occured during the modeling process as well as how we coped with the issues.

PROJECT BACKGROUND

The subjective judgment of the building operator has significant influence on building performance even if the mechanical systems are automatically operated.

The operator proactively plans the operating strategies. He/she also often determines the control based on years of his/her extensive field experience such as setting outdoor damper opening ratio depending on indoor and outdoor environmental conditions, or occupant complaints (stuffy air or smell). This manual approach can't bring accurate diagnosis, rational management, 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 and decision making. EnergyPlus was selected as the BEPS tool by the client's strong request.

This project was conducted from 19th March 2012 to 18th May (had to be finished strictly within two months), and the work items were as follows: (1) developing a simulation model of the building, (2) comparing measured data to simulation prediction, (3) calibration of simulation model if needed, (4) developing energy saving strategies of the building. 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 (3 Ph.D. and 1 M.S.).

TARGET BUILDING

The target building is S building (Figure 1) located in Seoul, Korea. 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 several 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.

Figure 1 S building (Viracon, 2012)

The HVAC systems and plants are as follows: Constant Air Volume (CAV) for lobby, Variable Air Volume (VAV) for office, Fan Power Unit (FPU), and Fan Coil Unit (FCU) for extreme control zones to keep high level of comfort condition, 3 steam boilers, 1 centrifugal chillers for cooling, and 2 centrifugal chillers for the ice storage, 2 absorption chillers, 7 heat exchangers.

ISSUE #1. IMMATURE SIMULATION ENVIRONMENT

One of the difficulties is to collect relevant information for simulation inputs. Although EnergyPlus provides a choice for defaults or several input options, it still requires expertise, in-depth understanding, and experience of a simulationist. Literatures (e.g. ASHRAE) suggest some reference values. However, in most cases, they are not a single deterministic value but a range with minimum and maximum. Therefore a simulationist has to pick one value in the range using his arbitrary subjective judgment. For example, the respective 'fraction radiant' values of internal heat (people, lights, and equipment) have to be decided with discretion of a simulationist. Although these values are highly influential to simulation results, they are not obtainable from drawings and specifications.

Contrary to architectural information, mechanical information is far from enough. Although a simulationist can persistently ask relevant mechanical/electrical/system information to other building stakeholders, it is wrong expectation to receive the well-structured and well-organized information. To make a perfect simulation model, the simulationist has to request all information to each domain. When he/she gets, he/she verifies, validates, and converts information to simulation model. Be noted that the design process in the AEC (Architecture, Engineering, and Construction) industry is very time-and-cost-limited. The simulationist cannot blindly wait until the information is available.

Therefore, the subjective judgment of a simulationist often becomes a substitute for the lack of information. Although the dynamic simulation tools have the capability to represent the behavior of building, extensive information has to be ready. The simulation process is significantly intensive to make the model, debug the errors, and report the results. Thus, the perfect simulation model is not feasible, and the dynamic simulation model may be difficult to be achieved with the original purpose under the current AEC context. In other words, making a simulation model may become rather out of touch with reality.

In this project, the client's main requirement to the team is as follows: (1) developing the most detailed simulation model of the building as much as possible, (2) the model should be very accurate (less than 5% error) and (3) the project must be completed within two months. Since the target building has the BEMS system (1,692 measurement points), the simulation results were easily compared to the recorded measured data. Thus, the client requested that the simulation model should be close to the target building as much as possible. The client wanted to exclude modeling assumptions and simplification of the reality as much as possible. Also, the accuracy of the simulation model should be less than 5% error (difference in energy use between simulated and measured data).

However, the authors encountered the following problems. First, the client was very interested in energy simulation but was not aware if what specific kinds of Information And Data (IAD) are required and how the IAD are to be 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 internal privacy protocol of the telecommunication company. In other words, the security and privacy protocol is more significant to the company than energy savings, which is, the authors believe, the most common case. Not the entire set but a subset of drawings was provided intermittently, which delayed a seamless development of the simulation model. Temporal modeling process by the team was not significantly respected and such data weren't sufficiently provided.

Secondly, 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 to provide accurate comfort control. The aforementioned occurrences were not represented in old drawings/documents and the authors had to resort to the operators' oral description. Such changes and modifications to the building have not been documented, hindering the team from full acquisition of necessary IAD. In other words, as long as a simulationist is not fully aware of the entire building maintenance history, the simulationist cannot help realizing the model based on the up-to-date IAD, and it takes extreme effort and time to represent the simulation model as close to the real building as possible.

Thirdly, IAD didn't coincide 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 fan's electricity use from January 1 to January 5 2012. Figure 2(a) and (b) are mutually contradictory since fan electricity use doesn't reflect fan airflow rate. In such cases as above, the authors had to make a reasonable assumption based on the building usage schedule, dialogues with building operators, cross-comparison between the measured data, etc.

For the project period, the authors regularly reported the aforementioned issues to the clients at weekly meetings, and explained assumptions and simplifications made by the authors. 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.

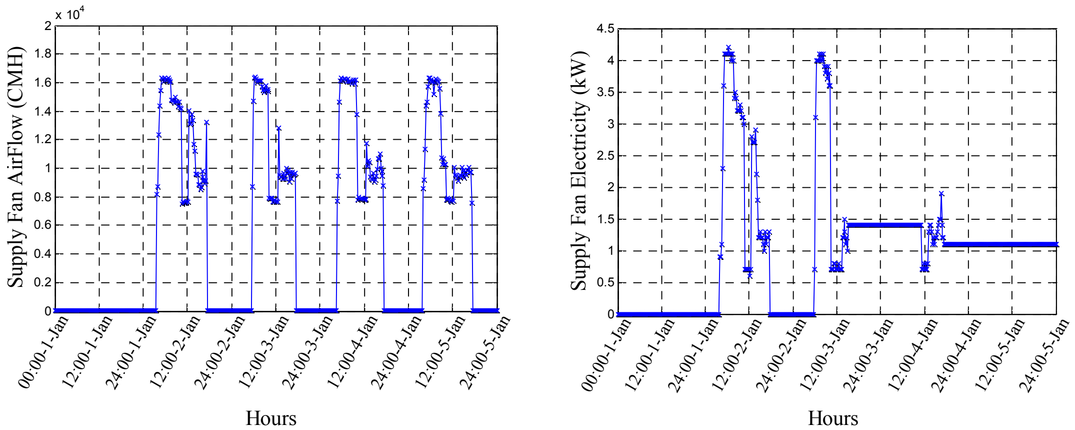
ISSUE #2. SUBJECTIVE ASSUMPTION AND JUDGMENT

The modeling process can be subdivided into three steps: (1) geometry modeling, (2) systems modeling, and (3) others. In each process, simulationists should use their own subjective assumption and judgment based on their knowledge and experience. Simulationists have to pay careful attention to how to make reasonable assumptions and judgment in terms of objectivity, reproducibility, repeatability, and reliability of simulation results.

Geometry modeling

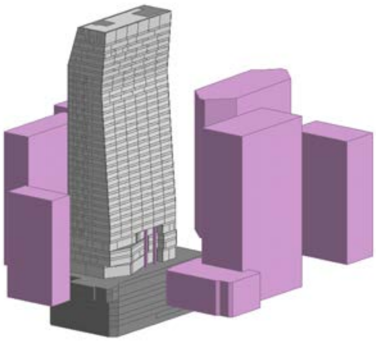
The thermal zoning is essential for energy modeling. The level of details with regard to thermal zoning is very significant in modeling process. Usually, simulationists simplify the geometry of the blueprints for sake of time and efforts. If the building geometry becomes complex and the number of internal spaces increases, the computation time to solve for the heat flow between the spaces exponentially increases.

However, there is no clear-cut guideline for thermal

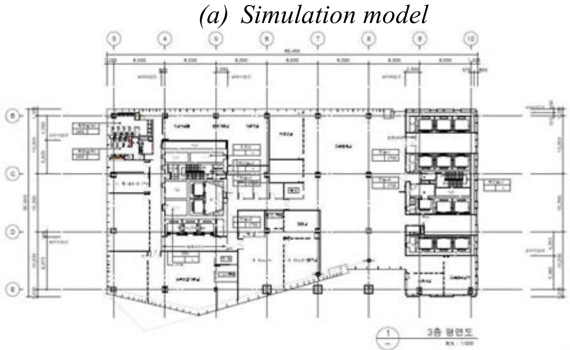


(a) fan airflow rate *(b) fan electricity use*

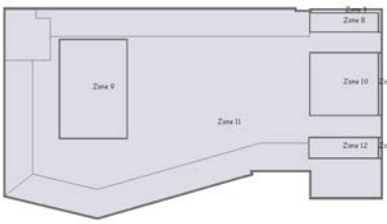
Figure2 Measured data of supply fan air flow rate and fan electricity use zoning. The subjective judgment of a simulationist is widely adopted. In this regard, the reproducibility and repeatability of simulation results are extremely influenced. In this project, the authors tried to make the most detailed simulation model as much as possible. However it was difficult to do due to the number of zones and computing time. Figure 3 (c) shows the most simplified zoning plan with which the client had to agree to. Although the zoning plan was simplified, the total number of zones ended up with 785.



(a) Simulation model



(b) Floor plan (3F)



(c) Thermal Zones (3F)

Figure 3 Geometry modeling, floor plan and thermal zones

System modeling

The subjective judgment of a simulationist is also involved in system modeling stage. EnergyPlus provides various simulation inputs related to simulation parameters, climates, schedules, zones, HVAC, and controls, etc. In particular, EnergyPlus has capabilities to represent various HVAC systems and simulate sophisticated controls (e.g. equipment load distribution, temperature manager, dynamic operation of blinds, etc.).

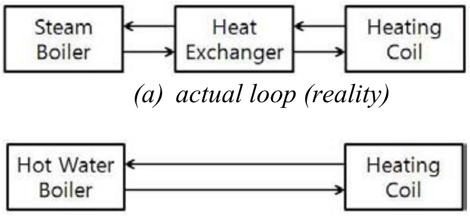
Although this is a feature of dynamic simulation tools, it can be an obvious obstacle for transparent modeling. The Input Output Reference of EnergyPlus is over 2,000 pages except the Engineering Reference, which describes the dynamic theories and principles. It is difficult to have in-depth perfect understanding of all objects and control options. With this in mind, a simulationist usually repeats his/her familiar objects that he/she once used before. Even though he/she is well aware that an object better fit to given system configuration/controls may exist, it is not easy to dig deep into the thick reference manuals. Please be noted that that the simulation task usually must be quickly finished so that it can be used for design feedback and performance evaluation. Accordingly, the simulation model of a building may vary since a simulationist has to resort to his/her familiar objects.

The simulation results are influenced by complex relationship among many different objects. For example, a variable of pump operation asks for an input of overall loop flow, which also has to be determined with relationship between internal loads, HVAC operation schedules, operation schemes of plant and condenser, and availability managers of each loop. Even though these aforementioned variables interplay, it is not easy to define how the building will be constructed/configured/operated by designers/operators. A simulationist is usually annoyed with lack of the details of building/system operation and controls. This situation makes the subjective assumptions and judgment of a simulationist indispensable.

The simulation model and an actual building are rarely identical to each other, and the simulation model is made to approximate the reality as close as possible. However most simulationists have different understanding about objects, loops and relationships between objects, loops, or objects and loops. Even though the dynamic simulation tool provides a lot of modeling components, a simulationist cannot develop a simulation model identical to a real building due to the limitation of topology rules.

Most BEPS models do not capture significant impact of HVAC faults on actual energy performance, and it makes as much as 22% discrepancy between simulation prediction and measured energy use (Basarkar et al., 2011). One of the problems in diagnosing building/HVAC systems using the simulation is that as mentioned above, it is difficult to get exact IAD of the actual system/schedule (e.g. the operation schedule, partial load efficiency, COP, etc.). In the target building (Figure 3), the operation schedule of AHUs has been continuously changed by operators. Two absorption chillers had been operated intermittently (about a day per 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 (privacy issue). 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 had been provided, the real building couldn't 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 loop. Due to lack of library for the steam-to-hot water heat exchanger in EnergyPlus (Maile et al., 2010b), the authors simplified it as shown in Figure 4. In other words, the steam boilers were modeled as hot water boilers based on the assumption that both have the same efficiency.



(a) actual loop (reality)

(b) as modeled

Figure 4 simplification made by simulationists

There are three plant loops (6F-34F, B6F-5F, 24 hours IT rooms) for the cold to be distributed throughout the building. 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 was modeled as stand-alone (each chiller connects to each loop).

Others

The remaining issue is how to determine internal loads, indoor setpoint temperatures (heating/cooling), operation schedule of plants, outdoor airflow rates to AHUs, weather, etc. In particular, these inputs are extremely uncertain and not easily quantified. With this regard, the authors had to make several site visits. However, after several interviews with the building operating team, the authors realized the following: even though advanced automatic controls were installed (e.g. enthalpy control, night-purge), the final decision of building operation was made solely by the manager of the operation team based on indoor/outdoor condition, complaints (e.g., stuffy air, smelling), the team's discretional judgment, heuristics, and experience. Unfortunately, such subjective control/operation history has not been documented. For accurate modeling, building operation and schedule are as important as modeling of geometry and materials.

Fortunately, the client provided the authors with the ESCO report of the target building where rough schedule information of the mechanical systems was provided. However, the report had the internal load information (lights, occupants, equipment) floor by floor, while EnergyPlus requires zone by zone. Therefore the load was normalized by each zone area, and the zone type was also taken into account for applying the schedule in DesignBuilder database.

The authors converted the weather data collected from the Seoul weather observation station to .epw format. The distance between the target building and the weather station is 1.6km far from each other. However, it should be noted that the weather station data can't represent local weather of the building where is located in the area full of high-rise office buildings.

ISSUE #3. UNCERTAINTY

An actual building is always under time-varying environmental conditions. In every moment, external and internal conditions keep changing, and the behavior of occupants is highly stochastic. Thus, when analyzing energy use of buildings, a single value of inputs, so called deterministic approach, is quite undesirable. Nevertheless, the deterministic approach is widely accepted such as a single value of internal load density, schedule, and activity level, etc. due to lack of information.

As an alternative, many uncertainty research using a probabilistic approach has been conducted (de Wit & Augenbroe, 2001; Macdonald, 2002; Hopfe, 2009). The aforementioned deterministic approach, taken by most engineers, is that each input is given as a single value, and a definitive result is derived. Whereas, the probabilistic approach present stochastic results based on the stochastic range of inputs. This approach is considered more objective, more rational, and more reliable for building performance assessment and decision-making than the deterministic approach.

However, the time required for uncertainty analysis hinders its extensive application. Most simulationists suffer from tight deadline as architectural designers. Under this context, one single simulation run is regarded as 'acceptable practice'. For simulating existing buildings, simulation tasks are repeated until simulation prediction converges to the measured energy use by trial and error method.

Meanwhile, one of the Monte Carlo methods, Latin Hypercube Sampling (LHS) method, has been effectively used with a relatively small sample. (Wyss & Jorgensen, 1998). The minimum number of simulation runs for LHS method is $4k/3$ (k: the number of inputs) (McKay et al., 1979). However, if a single simulation run would take more than an hour, the entire time for a series of Monte Carlo simulation would be a burden for a simulationist as well as architectural design team. In this regard, uncertainty analysis is not widely used for architectural design and simulation practice.

In this project, the authors could not conduct uncertainty analysis due to computation time. The authors had to finish within given two months period (1) modeling of geometry, systems and plant, (2) error check of input files, (3) analysis of simulation outputs. The authors as well as clients didn't want to wait for over 30 hours, the time required for one-year hourly simulation. During the project period, monthly simulation was run to save the time using four desktop computers (Intel(R) Core(TM) i5 CPU 2.67GHz, RAM 4GB, Window 7 64bit) at the same time. Table 1 shows the time required for monthly simulation. Uncertainty analysis was obviously out of the authors' considerations.

Table 1 Computation time for monthly simulation

MONTH	COMPUTING TIME
January	5 hours 48 minutes
February	5 hours 14 minutes
March	4 hours 56 minutes
April	2 hours 58 minutes
May	1 hour 28 minutes
June	36 minutes
July	40 minutes
August	40 minutes
September	30 minutes
October	1 hour 43 minutes
November	3 hours 25 minutes
December	4 hours 52 minutes

Uncertainty analysis also requires stochastic information of inputs (e.g. type of probability distribution, mean, standard deviation, etc.). As mentioned in Issue #1 that even a definitive value of inputs is not easy to obtain, it is obviously more difficult to estimate stochastic information of each input. The majority of previous researches on uncertainty analysis are based on literature, or rough estimation or assumption of inputs (Macdonald, 2002). For these reasons, uncertainty analysis has not effectively applied in the design process although more than 10 years have passed since its first appearance in IBPSA 2001 (de Wit & Augenbroe, 2001).

ISSUE #4. LACK OF VERIFICATION

The expertise and experience of a simulationist is a significant factor in appropriate modeling assumption and judgment, decision-making, output reliability and accuracy (Augenbroe et al., 2008). The building simulation tools rely on various disciplines and knowledge domains, such as heat transfer, numerical analysis, system dynamics, controls, optimization, programming skills, etc. Thus, it is not easy for a simulationist to have in-depth understanding of all relevant domain knowledge of simulation tools.

In this context, IBPSA in association with ASHRAE has tried to provide a sort of eligibility examination so called 'Building Energy Modeling Professional Certification'. However, the test is being provided only inside the USA and there is no certification test provided in South Korea as well as many other countries. There is no rational method or process to validate whether the model is correct enough as well as the simulationist of the model is eligible.

For objective and transparent performance simulation, the following characteristics must be retained in simulation model and process: repeatability, transparency, reliability, objectivity, reproducibility (Park, 2006). However as mentioned in Issues #2-3, a single building can be modeled in many different ways, resulting in many different outputs. It is difficult to evaluate the level of expertise, experience, and know-how of a simulationist required in modeling and simulation process, as well as reliability of simulation results.

The dynamic simulation tools can represent the reality with a significant level of accuracy, but it is difficult to expect that the result would match the energy use of the building due to uncertain inputs (e.g. occupants' patterns, weather data, system control, etc.). In other words, even a proven and well-experienced simulationist with sufficient expertise and knowledge is likely to make a wrong prediction. This means that certifying a simulationist and certifying a simulation model is very orthogonal or irrelevant.

However, in the context of the tight simulation process, a client asks a simulationist to deliver simulation result (usually not 'performance translation' but 'a number') within a specific time period without asking any validation task for the simulation model. This brings a vulnerable reliability issue. Sometimes, this causes an 'evil approach' (e.g. manipulating simulation inputs or assumptions to produce the number that a client wants). Thus, the simulation model must be validated by other peers.

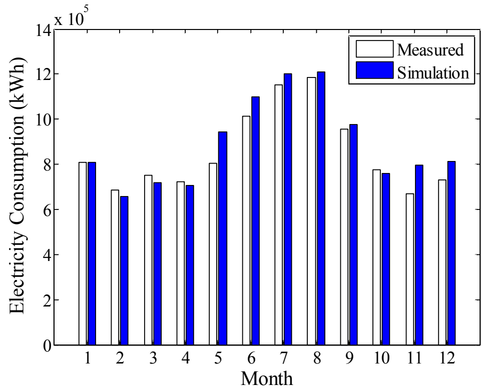
After several 'trial and error' methods, the authors came up with the final results. Table 2 and Figure 5 show comparison between measured monthly energy use in Year 2010 and simulation results. The simulated electricity consumption (Figure 5 (a)) has a similar pattern to actual measured data, and the MBE and CVRMSE are 4.0% and 7.6% respectively. In contrast to the electricity, the MBE and CVRMSE of gas consumption (Figure 5 (b)) are -38.4% and 46.5%, which shows a significant difference. The reasons for the difference were presumed as follows: (1) a wrong input for the boiler efficiency, (2) no inclusion of the manager's subjective manual control (e.g. outdoor airflow rate to supply air), (3) no accurate estimation of infiltration, and (4) a wrong input for setpoint indoor temperature in heating season.

Even though there is good agreement in electricity consumption as shown in Table 2 and Figure 5(a), it doesn't guarantee that the simulation model in cooling season is good enough. Because there was no sub-metered data (fan, chillers, boilers, pumps, lights, equipment, etc.), the aggregated simulation result had to be compared to the aggregated measured data. In other words, there is no way whether simulation prediction perfectly matches sub-metered real energy consumption or not.

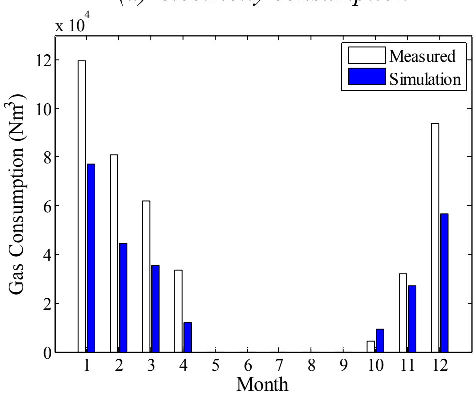
If there is a measured building energy use, anyone can make a simulation model similar to the reality throughout calibration. Modeling of the high-rise complex building requires extensive simplification of the reality and numerous assumptions. To reduce such gap between the measurement and simulation prediction, a crude manual calibration technique had to be introduced in our project. In general, the calibration can be done in three different ways: (1) trial and error, (2) solving for an optimization problem to find unknown parameters which minimize the difference between the measurement and prediction (Yoon et al., 2011), (3) Bayesian calibration which accounts for stochastic nature of uncertain parameters. The trial and error method was used in this project due to computation time. More details on the calibration work will be reported elsewhere.

Table 2 Comparison of measurement to simulation

ENERGY	ELECTRICITY	GAS
Simulated	10,667,711 *kWh*	262,383 Nm^3
Measured	10,257,547 *kWh*	426,132 Nm^3
MBE	4.0 %	-38.4 %
CVRMSE	7.6 %	46.5 %



(a) electricity consumption



(b) gas consumption

Figure5 Comparison of measurement to simulation

ISSUE #5. ANTE MORTEM AND POSTMORTEM USE OF SIMULTION MODEL

Developing a dynamic energy simulation model occurs at a certain time period in design process. Enough time and knowledge work for modeling and simulation is essential for quality assurance. To make the best use of simulation tools for better design and decision making, performance assessment of design alternatives should be instantaneously available in light of continuous design feedback to the design team. Thus, most people want to have an instantly-ready simulation model. However, as mentioned in Issues #1-3, it takes a quite long time and intensive efforts to develop a reliable simulation model. Besides, building design is knowingly or unknowingly being changed like a moving target in the design process. Thus, a simulation model, which is made at a certain point of time in the design process, is unlikely to be identical to a final set of construction drawings. Due to such disagreement between the simulation model and drawings/reality, there is approximately 20 percent difference between simulation prediction and actual energy use (GreenBuildingAdvisor, 2012).

With this in mind, the simulation model has to be continuously modified and calibrated during whole building life cycle. Building information (system, internal heat gains, operation schedule, controls, etc.) should be systematically managed, and transparently delivered to a simulationist. Recently, real-time building energy management has been built (e.g. Database for Analyzing Sustainable and High-Performance Building (DASH, 2012), California Commercial End Use Survey (CEUS, 2012)). Unfortunately, most building energy simulation models, which have been made in the design stage, are not fully utilized for energy management and operation throughout the whole life cycle. In addition, as described in Issue #1, building information relevant to modeling and simulation has not been well managed and shared. In other words, the dynamic simulation model, which requires significant time and efforts during the design stage, has not properly been utilized in the operation stage.

CONCLUSIONS

The dynamic simulation tools have contributed to green building design, optimal controls, and rational decision-making, but many challenges and problems still remain to be solved. This paper touches on a significant area in building simulation and highlights issues for consideration by building owners and simulators. There are also implications for policy makers and regulators to take into consideration the limitations of building simulation. The purpose of this paper was to share the experiences and lessons learned from an energy simulation project.

In particular, the authors pointed out five issues based a case study as follows: (1) immature simulation environment, (2) subjective assumption and judgment, (3) uncertainty, (4) lack of verification, and (5) ante mortem and postmortem use of simulation model. With regard to what has been discussed above, the authors inform many simulationists that the simulation works need careful attention due to imperfect capabilities and information according to the aforementioned issues. The BEPS community (e.g. IBPSA) has to pay careful attention to the aforementioned issues occurring in current simulation environment.

Over the last 20-30 years, the precision of dynamic simulation tools has sufficiently improved through efforts by academia (e.g. IBPSA) and industries. For better and more practical application of building energy simulation to a variety of designs and optimal building maintenance, the aforementioned issues should be solved in the next decades.

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