CASE STUDIES ON HVAC SYSTEM PERFORMANCE USING A WHOLE BUILDING SIMULATION BASED REAL-TIME ENERGY EVALUATION APPROACH WITH BEMS

Hyeun Jun Moon[1], Min Seok Choi[1], Seung Ho Ryu[1], Jung Chul Lee[2], Dong Gu Kim[2]
[1]Department of Architectural Engineering, College of Architecture, Dankook University, Yongin-si, Gyeonggi-do, Republic of Korea
[2]R&D Division, Hyundai Engineering & Construction Co. Ltd., Yongin-si, Gyeonggi-do, Republic of Korea

ABSTRACT

Building systems in the operation stage consume more energy than building design intent due to various reasons (e.g., faulty construction, malfunctioning equipment, incorrectly configured control system and etc.). A whole building energy simulation can be used to evaluate building energy performance over the building operation stages. Recently, there is a great deal of research concerning real time performance evaluation using real-time simulation. In this study, real-time simulation is used for commissioning of HVAC system through a real-time comparison between simulation results and monitoring data. The real-time simulation system is applied to two existing buildings as case studies. A real-time building system performance is evaluated by comparing the building energy monitoring data with real-time simulation results. Results show that real-time simulation could help identify the abnormal operation of HVAC system.

INTRODUCTION

The building sector consumes about 40% of the energy used in the world. Knowing this, the theme of energy saving in buildings is receiving increasing attention from technical and scientific points of view with aim of minimizing the overall energy consumption and costs (Mirinejad et al. 2012). More than half of the energy consumption in a typical building results from heating, ventilation, and air conditioning (HVAC) systems (Scherer et al., 2014). Therefore, improvements in the energy efficiency of building thermal management have the potential for a large economic and environment impact (Chandan and Alleyne, 2014).

Earlier research shows that building systems consume more energy than design intent due to various reasons in existing buildings such as the faculty construction, malfunctioning equipment, incorrectly configured control systems or inappropriate operating procedures (O'Neill et al., 2009). One approach to addressing these problems is to compare the predictions of an energy simulation model of the building to the measured performance and analyse significant differences to infer the presence and location of faults. A whole building energy simulation can be continuously used to evaluate building energy performance over the building lifecycle, including the design and operation stages. Xu et al. (2004) have proposed a prototype a hardware-in-the-loop simulation environment for controls testing and training using SPARK (Simulation Problem Analysis and Research Kernel). They have described the mechanism that coupled the real-time SPARK simulation with a real building control system using a hardware interface. Lee et al. (2007) have conducted an examination of the use of the ASHRAE simplified energy analysis procedure in identifying significant deviations from expected building energy consumption and fault detection at the whole building level. Clarke et al. (2002) have developed a prototype control system to integrate simulation using ESP-r within real-time energy management control system (EMCS) operation to enhance control capabilities. Haves et al. (2001) have explored the application of model-based performance assessment at the whole building level. They have addressed the information requirements for a simulation to predict the actual performance of a particular building. They have also discussed the possibilities for using control system communication protocols to link real-time simulation and the EMCS. Moreover, recent advancements in a whole building energy simulation allow for real-time performance evaluation with monitored data in the operational stages (Dong et al., 2012, Moon et al., 2012). Pang et al. (2012) proposed a framework for simulation based real-time whole building performance assessment. Recently, many buildings have installed and operated building energy management systems (BEMS) which can real-time collect and monitor large amounts of data related to building energy consumptions in order to maximize building energy efficiency in the operation stage. BEMS would enable more utilization of real-time building system and energy data in operation stage.

The objective of this study is to demonstrate a suggested model based real-time energy performance system integrated with BEMS in existing buildings. The paper also tries to identify potential of the suggested system as a continuous commissioning tool in a boiler and HVAC systems. The results from a real-time simulation model reflecting the design intent is compared to the actual energy data measured from BEMS. In this study, the real-time simulation system is applied for two case buildings. The first building is a residential building equipped with a night electric boiler. The second building is an office building equipped with AHU.

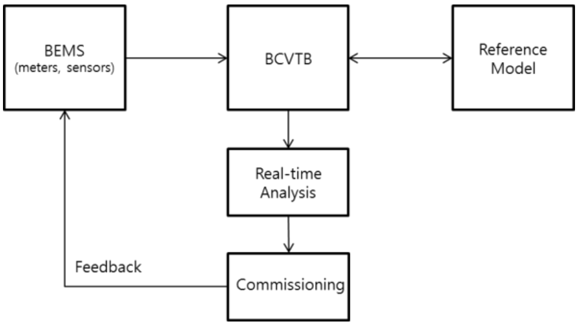

Figure 1 A framework of commissioning method using real-time energy performance

COMMISSIONING USING REAL TIME ENERGY SIMULATION MODEL

Figure 1 shows a framework of the continuous commissioning approach using real-time energy performance assessment with a whole building simulation. Real-time building simulation refers to the use of a reference (virtual) model whose simulation time is synchronized in real time. This real-time simulation model utilizes measured weather data at each time step. The actual weather data are used as input values in real-time building energy simulation through BCVTB (Building Controls Virtual Test Bed). BCVTB is an open-source software environment developed for co-simulation and data exchange among hardware/software. This software couples different simulation tools for co-simulations, and enables data exchange with building automation systems and databases (Wetter, 2011). In the previous study, Moon (2013) evaluated the effect of weather data in an integrated real-time building simulation.

A simulation model reflecting the design intent can be used for commissioning by comparing to the measured data. For newly constructed buildings, a design intent baseline model can be applied to identify and quantify the building energy consumption deviations from design intent by comparing to the measured data. Also, when the system (e.g., HVAC, lighting etc.) or operation condition are changed in the existing buildings, the baseline model that represents these changes can be used to compare with actual performance.

CASE STUDIES

In this study, real-time simulation reflecting the design intent is applied to the two buildings. The first building is a residential building equipped with a night electric boiler. The second building is an office building equipped with AHU. In this study, the results from a real-time simulation model reflecting the design intent is compared to the actual energy data measured from BEMS. This real-time energy evaluation enables to identify the abnormal operation of the HVAC systems in real-time.

Case Study 1 : Residential building equipped with a night electric boiler

The selected residential building is a two stories rectangular shape house. The first floor is mainly used as a dining space and the second floor is used as a residential space for children. The second floor has eight conditioned zones (1~7 rooms and a living room). The heating system of this building is configured to the radiant floor heating system with a night storage electric boiler as shown in Figure 2.

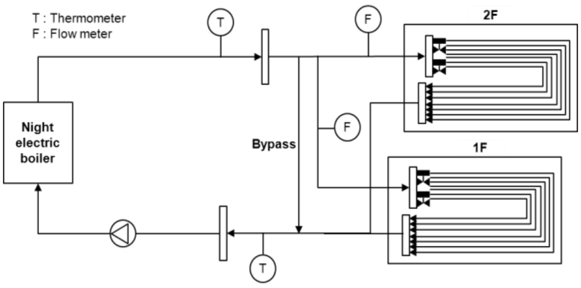

Figure 2 Schematic diagram of a radiant floor heating system with a night storage electric boiler in the 1st case building

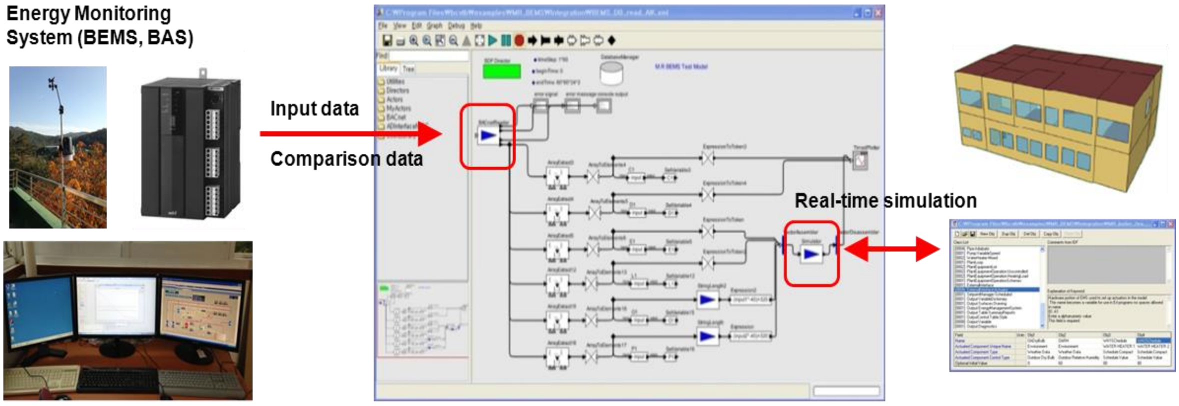

Figure 3 Real-time simulation system in the 1st case study

This building is collecting a large amount of building energy data through BEMS. Additionally, we installed a BCVTB server connected to BEMS based on a BACnet/IP. The BCVTB was configured to receive the data associated with a heating system and environment as shown in Figure 3. The BACnetReader actor reads building energy data from BACnet devices, and these data are sent to a database program (i.e., PostgreSQL) through the SQL Statement actor.

In addition, a weather station is installed on the site and collects information including outdoor air dry bulb and relative humidity, wind speed and direction, direct normal solar radiation, solar radiation, which are suitable for energy simulation with EnergyPlus.

The actual data about boiler operation statuses, boiler set temperature and weather data were used for the input values in real-time building energy simulation. The weather data including solar irradiation, outside air temperature and RH and wind speed and direction were collected from the on-site weather station. The real-time monitoring data on boiler water supply and return temperature are compared with the simulation results (Table 1). The real-time simulation is performed during 10^{th} ~12^{th} in Febrary, 2013. This climate condition is a heating season and The distribution of the outdoor dry bulb are about -5˚C~10˚C.

Table 1 Real time input data and comparison data in the residential building case

REAL TIME INPUT DATA	REAL TIME COMPARISON DATA
outdoor air dry bulb dew point temperature relative humidity diffuse solar, direct solar, wind speed, and wind direction	boiler supply water temperature boiler return water temperature

The real-time simulation was conducted to compare the simulation results and monitoring data of boiler supply water temperatures and return water temperatures in real time.

As a result, simulation results for the boiler supply water temperature agreed to monitoring data for the boiler supply water temperature (Figure 4). However, simulation results for the boiler return water temperature did not correspond with the actual return water temperature (Figure 5). The reason for this was that the actual flow control valves were not set to a variable flow rate, but to a constant flow rate. These have been set to a constant flow rate ever since the control valves were installed.

Thus, we could confirm that the actual flow control valves were not operated according to the design intent. It can be seen that the energy is wasted as an ineffective system setting. After we change to a variable flow rate and correctly connect the pipes with the flow control valves, the simulation results of supply and return water temperature matched with the actual results. Figure 6 shows a comparison of measured and simulated zone temperature. Actual zone air temperatures ranged from 23˚C~27˚C. However, Simulated result for the zone air temperatures were maintained close to the set temperature (24˚C). Through this difference, we could confirm the mismatching between control valves and pipes. Zone air temperatures were maintained close to the set temperature (24˚C) after commissioning.

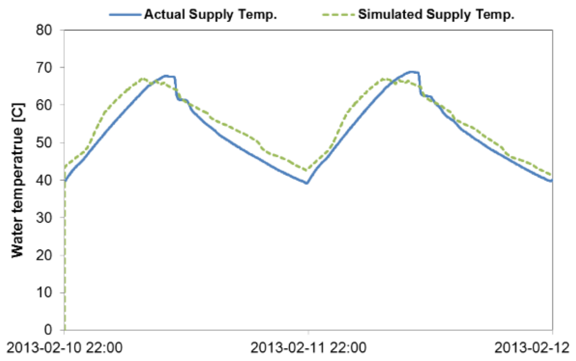

Figure 4 Comparison of measured and simulated boiler supply water temperatures

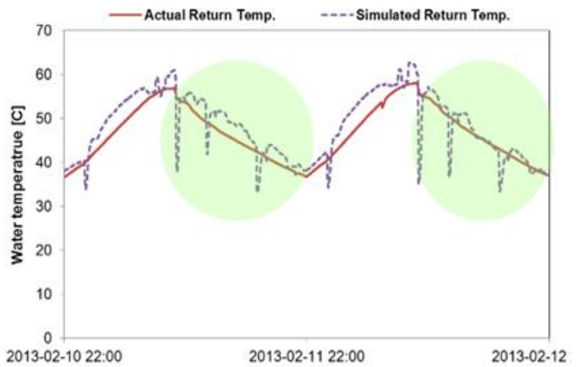

Figure 5 Comparison of measured and simulated boiler return water temperatures

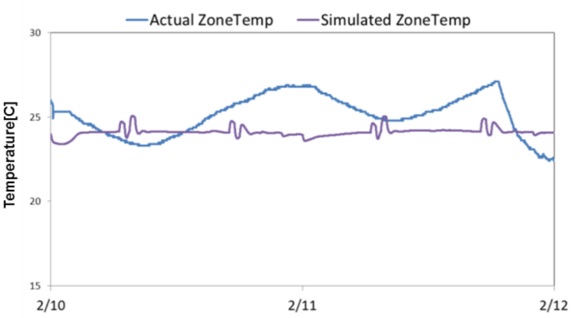

Figure 6 Comparison of measured and simulated zone temperature

Case Study 2 : Office building equipped with the AHU system

The selected office building is located in Yongin, Korea. This building is equipped with two air handling unit (AHU) with an absorption chiller heater (Figure 7). This building is collecting a large amount of building energy data through BEMS. We installed a BCVTB server connected to the BEMS based on LabVIEW. We installed a BCVTB server connected to the BEMS (LabVIEW) through XML files.

Figure 8 shows the real-time simulation system using BCVTB in the 2nd case study. This real-time simulation system is composed of four modules; BEMS, Simulation, Comparison, and Database. BEMS module reads monitoring data from BEMS system (based LabVIEW) through XML files at each time step (10 min.). The monitoring data include the real-time input data and comparison data. Simulation module performs simulation reflecting the actual weather data at each time step. The results from the real-time simulation are sent to the comparison module and database module. Comparison module compares monitoring data and simulation results. Database module store monitoring data and simulation results. Database module is based on a customized XML schema to store building information, building operation data, simulation data and analysis results.

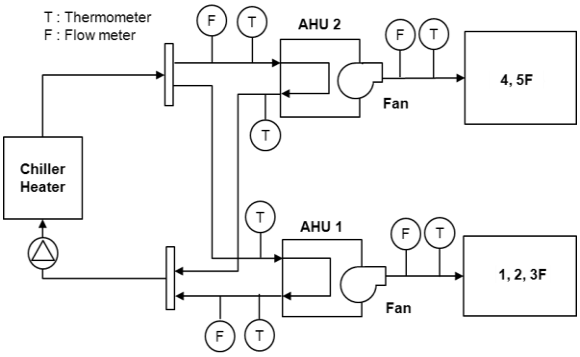

Figure 7 Schematic diagram of AHU systems with a chiller heater in the 2nd case building

The comparison module is constructed to compare data associated with the AHU and an absorption chiller (such as AHU supply and return fan power, AHU supply air temperature, AHU supply water temperature, AHU return water temperature, AHU supply air flow rate, AHU water flow rate, CHW pump power, zone temperature, and so on). Table 2 shows input data and comparison data used in the case study.

Table 2 Real time input data and comparison data in the office building case

REAL TIME INPUT DATA	REAL TIME COMPARISON DATA
outdoor air dry bulb dew point temperature relative humidity diffuse solar, direct solar, wind speed, and wind direction	AHU supply / return fan power AHU supply air temperature AHU supply / return water temperature Zone temperature CHW pump power Water flow rate

Figure 9 shows comparison results from measured CHW pump power and simulated CHW pump power. The highlighted areas enclosed by the dashed line represent the differences between measured and simulated results. As shown in the figure, The CHW pump operated in the simulation, although it was not operated in the actual operation. However, at that same time, AHU 1 supply fan power and simulated AHU 1 supply fan power operated as shown in figure 10. It can be seen that the energy is wasted about 30% due to ineffective operation of the AHU system. If the actual CHW pump power is monitored without simulation, it would be difficult to identify the abnormal operation of AHU system. By comparing with the simulation results, it could be easily be found the abnormal operation of the AHU system.

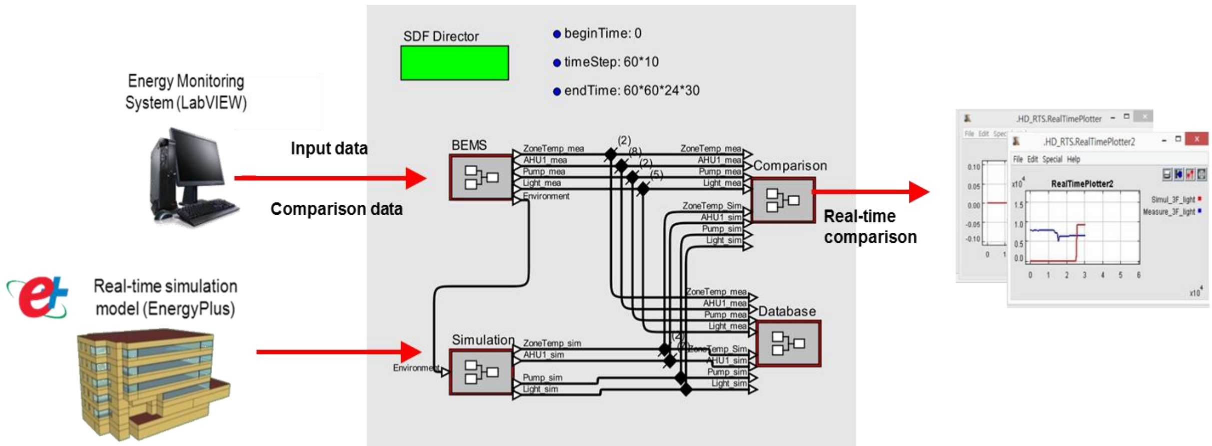

Figure 8 Real-time simulation system in the 2nd case study

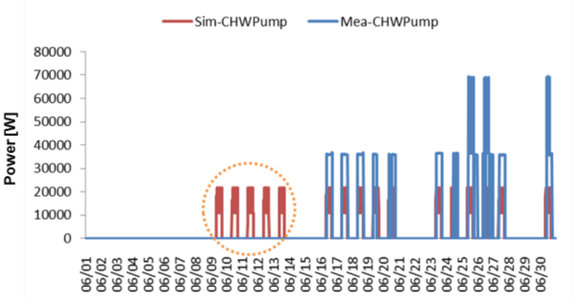

Figure 9 Comparison of measured and simulated CHW pump power

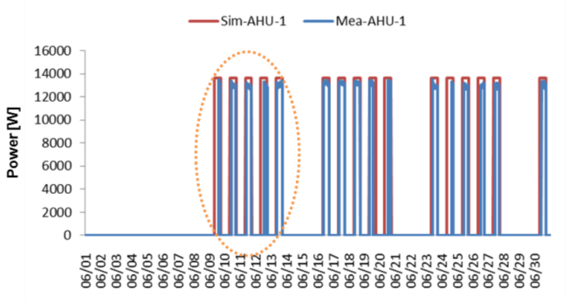

Figure 10 Comparison of measured and simulated AHU 1 fan power

In addition, figure 11 and 12 show the comparison of measured and simulated zone temperature. The highlighted areas as shown in figure 11 and 12 represent the differences between measured and simulated results. Through the differences, we could identify and confirm sensor errors of the zone temperature sensors.

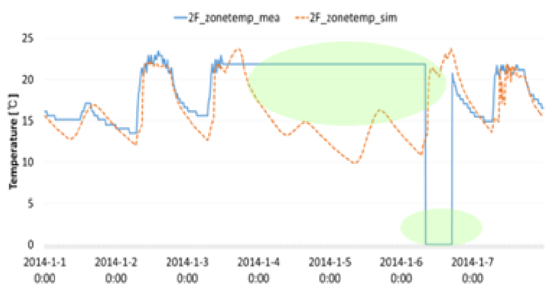

Figure 11 Comparison of measured and simulated 2F zone temperature

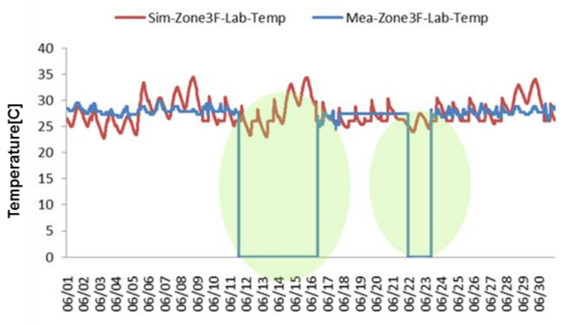

Figure 12 Comparison of measured and simulated 3F zone temperature

CONCLUSION

This study successfully demonstrated the integrated whole building simulation based real-time energy evaluation with BEMS in two case studies. Using the comparison between simulation results and monitoring data in real time, we could identify faulty operation, control problems, sensor errors. The key findings from two case studies are summarized as follows:

1. Two case studies showed that real-time simulation system can help identify the abnormal operation of HVAC systems and sensor errors.
2. Through the suggested real-time simulation-based commissioning approach, anomalies in the heating system and AHU system were corrected and potential energy savings were identified.

In the future study, we will use the integrated real-time simulation approach for FDD in existing buildings and analyze causes of problems. It is required the evaluation criteria from the difference between measured and simulated data that can determin the abnormal operation or errors of building systems.

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