Framework Development and Case Study of a Real-time Weather Forecast Data-based Optimal Operating Strategy

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ABSTRACT

In addition to the MPC(Model Predictive Control) study in estimating in advance the control applicable to actual buildings based on a model in which a simulation tool is used, a variety of studies, including temperature control, lighting control, and operation strategy, have been conducted recently. Actual buildings are controlled and operated in the integrative mode, and, therefore, the impact of integrated operation and control should be investigated. Accordingly, a simulation framework, where it is possible to conduct real-time, integrated optimal operation, should be developed. The framework can make the simulation environment integrate real-time, building energy and optimal operation.

This study developed the optimal operation framework for building energy based on real-time weather forecasting data. The real-time weather forecasting data was established so that the real-time forecasting data from KMA(Korea Meteorological Administration) can be used. Through the data, the weather file which is necessary to implement EnergyPlus and GenOpt was created. The optimal operating strategy was identified through a simulation-optimization approach by coupling a calibrated EnergyPlus simulation model coupled with GenOpt. The optimal value found through GenOpt could calculate the building energy necessary to facilitate optimal operation. The framework environment, where the real-time weather forecasting data, EnergyPlus, and GenOpt could be applied, was designed by using BCVTB(Building Control Virtual Test Bed), a middleware linking heterogeneous software. In order to test the framework developed in this study, a case study on seeking optimal zone set-point temperature was conducted. The boundary applicable to an actual building had limitations, so the object function was set to calculate minimum energy consumption.

In the near future, energy reduction is expected to be implemented in actual buildings by applying the outcome identified through the simulation of this framework.

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KEYWORDS
Framework, Real-time Weather Forecasting Data, GenOpt, EnergyPlus, Energy Saving

INTRODUCTION

In recent years, MPC(Model Predictive Control) studies have been undertaken to predict controls that are applicable to actual buildings, based on a simulation model, and to examine controls over temperature, lighting, operating strategies, etc.

Several researchers have been developing the framework for MPC studies. Xu et al. (2004) studied a hybrid simulation environment for control tests and education. They constructed a dynamic simulation on the HVAC equipment and the building envelope through SPARK(Simulation Problem Analysis and Research Kernel). In addition, they implemented a simulation of natural ventilation control strategies, and tested each of them. Coffey et al. (2010) performed supervisory control strategies that were integrated into MPC, one of the advanced control strategies. With regards to this, it is required to develop the MPC optimization due to the needs of a low energy system and a DR(Demand Response) system. Therefore, MPC was developed using GenOpt with the revised GA(Genetic Algorithm). With concerns that the office temperature increases due to the flexible software framework, a case study on DR conducted. Pang et al. (2012) studied a framework that allowed the user to compare an actual building performance with real-time predicted performance. In this case, a way to address this problem may be to estimate the existence and location of defects by using the estimated energy use through the performance measured from the building and a planned simulation. A framework conducting use of EnergyPlus, BCVTB, and EMCS(Energy Management Control System) was then developed.

Previous researcher developed each framework for their research goal. However, in actual buildings where frameworks are controlled and operated in an integrated mode, it is necessary to make an analysis on the effects of integrated control. Additionally, it appears that the framework operates according to real-time weather forecasts so it needs to get accustomed to the environment to ensure the establishment of a proper operation strategy. Thus, it is necessary to develop an optimal operation framework. The role of such a framework is to form a simulation environment that integrates real-time, building energy, and optimal operation(Kwak et al. 2012).

To test the framework developed in this study, virtual weather conditions were used to proceed with a study on optimal zone set-point temperature resets in summer. The range of the zone set-point temperature applicable to buildings was a constraint condition, and an object function was set to output the minimal energy.

METHOD

In this study, a framework is developed to enable the development of a variety of optimal operation strategies based on real-time weather forecasts. The framework makes it possible to use various software by using BCVTB(Anon.) as middleware. The software coupled with BCVTB includes KMA(Anon. A), MATLAB(Anon. B), EnergyPlus(Anon. C), GenOpt(Anon. D), etc., as shown in Figure 1. The detailed description is as follows:

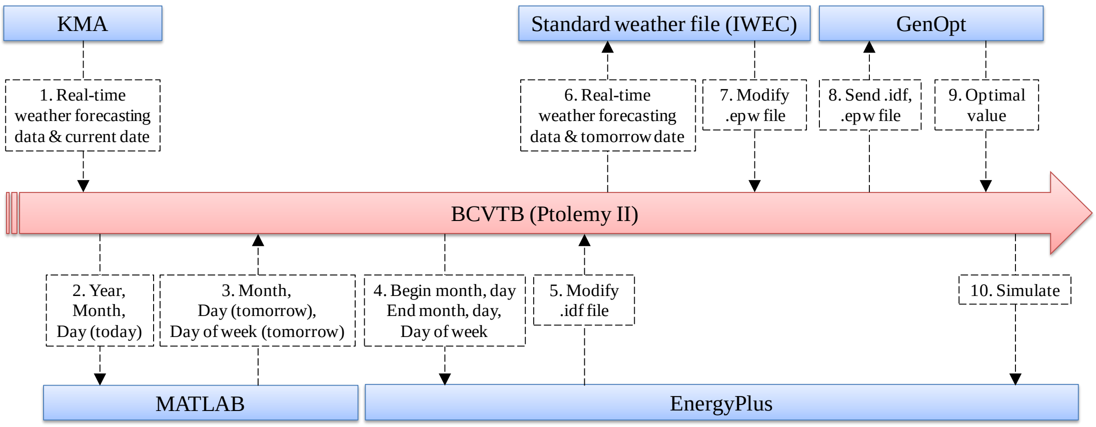


Figure 1. *Flow diagram of the framework*

KMA(Korea Meteorological Administration)

Real-time weather data can be received from the KMA website. The weather data is forecasted every three(3) hours – at least from 42 to 48 hours ahead. The elements of the weather forecast data include outdoor temperature, relative humidity, wind direction, wind speed, cloud cover, and etc.

In the meantime, the weather data input in real-time are in XML(eXtensible Markup Language) form, and sent to BCVTB. Using the ACTOR(`XSLTransformer`) related to XML, the weather data corresponding to the current(year, month, day), and weather data at three hour intervals are extracted. Later, the weather forecast data at a three-hour interval is calculated hourly by using interpolation. Forecasted weather data of the following day are used to establish weather files(.epw) for simulations.

MATLAB

Once real-time weather data are input from KMA, BCVTB sends date information to MATLAB. The weather forecast data are used for the following day(tomorrow), so the following day was planned to be calculated by using the corresponding year, month, day(today) through MATLAB. In addition, a leap year, which occurs every four years, is not recognized in EnergyPlus, so it was excluded. Using the deployment tool of MATLAB, execution files(.exe) were created through coded files, and batch files(.bat) were made to ensure the execution in BCVTB.

Standard Weather File(IWEC)

The weather file for “tomorrow” was made for the user to apply it in EnergyPlus and GenOpt by using the weather data input in real-time. In the weather file used in EnergyPlus, there are 28 types of weather data elements, of which nine(9) are the main types. They include six(6) types of real-time data, such as dry-bulb temperature, relative humidity, direct normal radiation, diffuse horizontal radiation, wind direction, and wind speed, and three(3) types of data, such as atmospheric pressure, horizontal infrared radiation intensity from the sky, and dew point temperature calculated in EnergyPlus. In the meantime, other weather data were processed by using “missing” data, and the “missing” data in the weather data were replaced by “appropriate” data(EnergyPlus 2011). This way, weather data file was composed with combinations of main data and other data on the text file.

EnergyPlus

An EnergyPlus program was used in two(2) functions to help complete weather data files and to perform a dynamic simulation through whole building modeling. First, the weather forecast data, corresponding date, and a day of the week input into EnergyPlus to revise RunPeriod. Then, the program was used to make weather data files and to help the process with the calculation of the weather data. Next, a building dynamic simulation is performed, coupled with BCVTB for optimal operation. Before the simulation was performed, ExternalInterface:Schedule of EnergyPlus was set to be the input for the hourly optimal zone set-point temperature. Its ExternalInterface:Actuator was set as input real-time weather data.

GenOpt

For the optimization algorithm of GenOpt that was used in this study, “GPSPSOCCHJ” was adopted. “GPSPSOCCHJ” is a hybrid algorithm of the Particle Swarm Optimization(PSO) algorithm and the Hooke-Jeeves(HJ) algorithm. This algorithm seeks a global minimum through the PSO algorithm and a local minimum through the HJ algorithm. To test the framework that was used in this study, the minimal energy consumption was set up as an objective function, as shown in Equation (1). Then, an hourly zone set-point temperature was set as a variable, and the constraint condition was not supposed to exceed the zone set-point temperature of the actual building, 28 ℃. In case the zone temperature was below 28 ℃, this study attempted to seek the zone temperature range resulting in the lower energy consumption than baseline model.

$$\mathrm{Min}\ J = E_{Cooling} + E_{Fan} + E_{Pump} \qquad (1)$$

where J, $E_{Cooling}$, E_{Fan}, and E_{Pump} are total energy consumption [kWh], cooling energy consumption [kWh], fan energy consumption(including cooling towers) [kWh], and pump energy consumption [kWh], respectively.

BCVTB(Building Control Virtual Test Bed)

The framework environment where real-time weather forecast data, EnergyPlus, and GenOpt, which was constructed by using BCVTB that was developed in LBNL(Lawrence Berkeley National Laboratory). BCVTB is a middleware that links heterogeneous software, and was studied by a number of researchers recently. Figure 2 shows an example of “10. simulate” as the last step in Figure 1. In the figure, the ellipse on the left is the input of the weather data in real-time, and the square in the lower on the left is the hourly optimal zone set-point temperature value calculated from GenOpt.

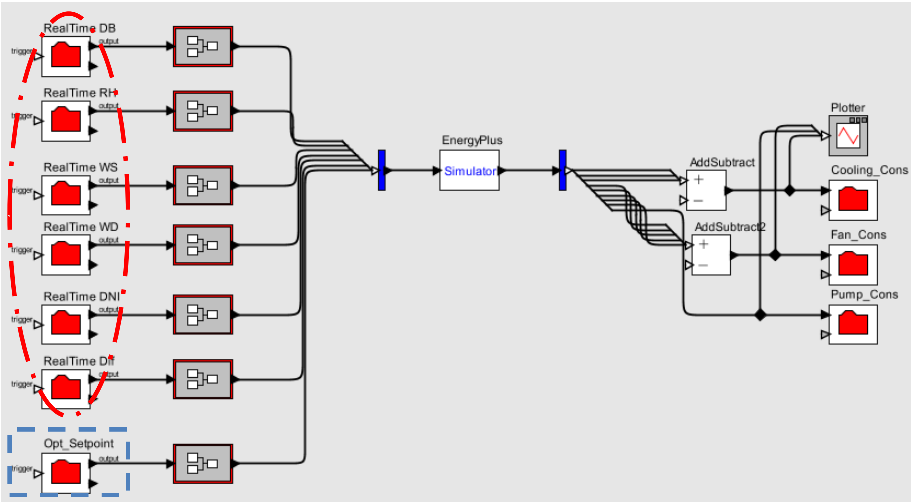
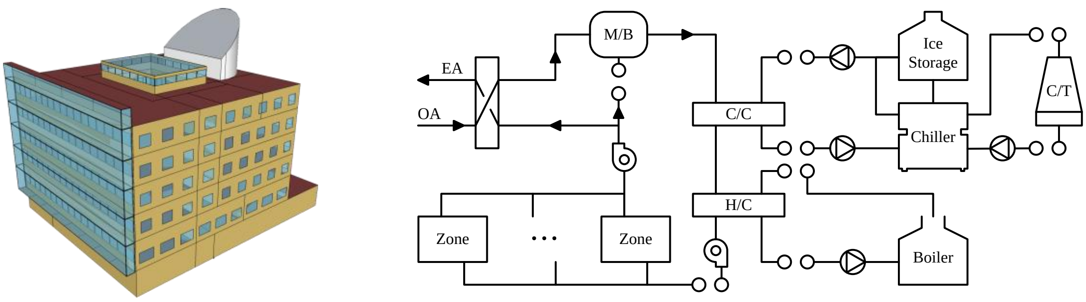


***Figure 2.** Example "10. simulate" in the final step of the framework*

RESULTS AND DISCUSSION

Model Description(simulation site)

The target building was modeled by using OpenStudio and EnergyPlus. It was zoned on a basis of an air handling units(AHUs), and specified into an interior zone and a perimeter zone. Internal loads were measured and applied through drawings and an on-site survey. In addition, the occupant schedule was applied by considering actual used hours. Concerning the building features, a double skin facade is installed on the southern side, and the ice storage is also installed in the basement. The air conditioning system is designed with a VAV system operating through four(4) AHUs. Figure 3 shows completed model figure (a) and schematic system diagram (b).



(a) Modeling *(b) Schematic system diagram*

***Figure 3.** Building model to test the framework*

To draw out a baseline model, the monthly error in the simulation energy consumption was calculated based on electric use (from July to December) that was actually measured from chillers, cooling towers, EHPs, fans, pumps, lighting, and plug of the target building. It was analyzed that the (Mean Bias Error) and

Cv(RMSE)(Coefficient of variation(Root Mean Square Error)) value of the total energy use were -1.75% and 4.84%, respectively. This suggested that the results met the error criterion(U.S. DOE 2008, Cheon et al. 2012).

Virtual test and results

To test a framework that was developed in this study, the optimal operation strategy was applied to the aforementioned calibration model through hourly zone set-point temperature resets. This study, through the framework test, attempts to determine the zone set-point temperature values that match real-time weather conditions, wherein virtual weather data were assumed as real-time weather data, and the analysis was conducted. To reset hourly zone set-point temperature during occupancy in the summer, two(2) virtual days were selected. The first virtual day is the "hot day," which is relatively hot and humid. The second virtual day is "cool day," which is relatively cool with low humidity, as shown in Figure 4.

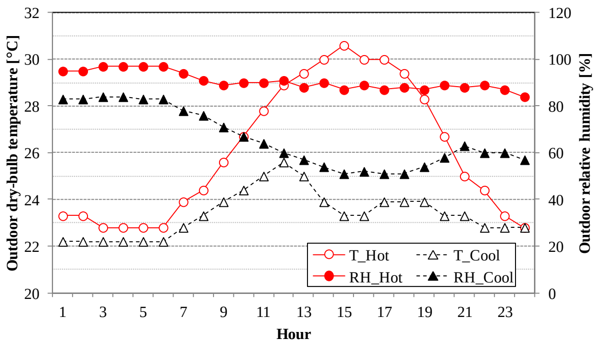
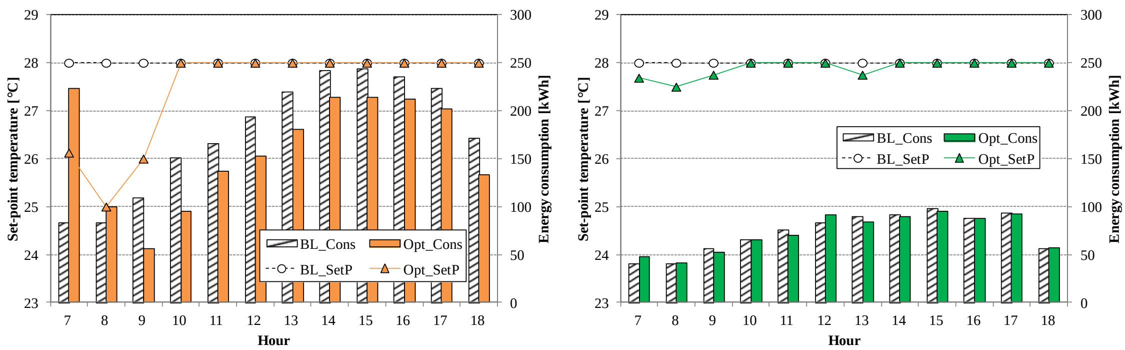


Figure 4. *Two(2) days for the framework test*

Figure 5 shows the results of the framework test. The set-point temperature of the Baseline(BL) is constant with 28 ℃ during occupancy.



(a) Hot day *(b) Cool day*

Figure 5. *Comparison of framework test results*

First, in the case of the "hot day" in Figure 5, the optimal set-point temperature (Opt_Setp) in the morning was calculated as lower than the baseline set-point temperature(BL_SetP), with a 2-3 ℃ difference. This caused the energy consumption

in optimal set-point temperature(Opt_Cons) in the morning to record higher energy consumption than the energy consumption in baseline set-point temperature (BL_Cons). However, after a while, generally, the Opt_Cons was lower than the BL_Cons in energy consumption. Furthermore, it was observed that if all the AHUs were in charge of higher load due to the low zone set-point temperature, the load is calculated as less than that on the baseline in the afternoon. The results suggest regeneration due to over-cooling in the morning. Next, in the case of the "cool day," the dry-bulb temperature shows relatively low distribution(see Figure 4), and the energy consumption indicates a noticeably lower rate than that of the case of the "hot day." The optimal zone set-point temperature shows less change than that of the "hot day," and the changes in energy consumption were minor.
As a result of the optimal operation strategy in the zone set-point temperature resets in the summer, the "hot day" performed better than the "cool day." Table 1 shows the total energy consumption. In the case of the "hot day," it showed that 10% was expected in potential energy savings, and in the case of the "cool day," the potential energy savings was rated at 1%.

Table 1. *Energy consumption comparison*

Days	*Baseline[kWh]*	*Optimization[kWh]*	*Saving [kWh] (%)*
Hot day	2,127	1,920	207 (9.7)
Cool day	884	873	11 (1.2)

Discussion

To perform optimization, the PSO algorithm was generated 10 times, through which the initial point of the local minimum was found. Later, it was used in the HJ algorithm. Using Intel Core i5-CPU and 4GB RAM, the optimization was implemented for 55 minutes. The simulation lasted for one day only, but whole building was modeled. If another optimization strategy is continuously added, it may take longer to execute the optimization.
In the meantime, this framework operates according to the real-time weather forecast. It was set up to enable synchronization for real-time simulation, as shown in Figure 6. The framework started operating at 05:00 P.M. every day, and was designed for the simulation to operate every 24 hours, including the simulation execution hours. It appears that, in this way, proper operation is feasible, depending on the environment changes on a daily basis.

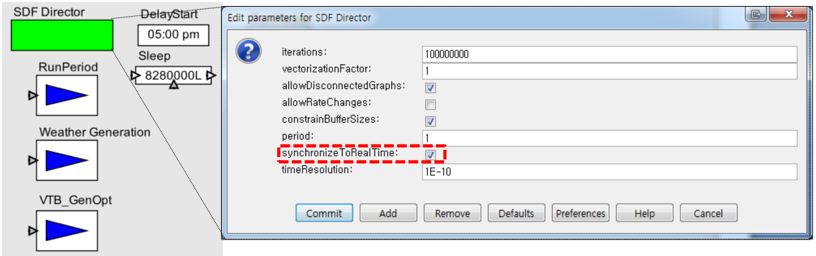


Figure 6. *Synchronization for real-time simulation*

CONCULSIONS AND FUTURE WORK

In this study, a framework was developed for the user to combine various types of software by using the BCVTB developed in LBNL, and to perform the optimal operation strategy by using real-time weather forecast data. Whole building was used to develop a framework to perform the strategy. However, it is surely likely to perform the general operation strategy. This means that not only one or two optimal operation method(s) but also a totally integrated optimal operation strategy was devised, leading to the invention of this framework. Additionally, the framework was designed to be able to establish the proper operating strategy that can respond to changing environments, and to enable real-time weather forecasting and synchronization.

As case study of the result of testing this framework by virtually applying the optimal operation strategy in the summer, it was deduced that the potential energy saving rate during a "hot day" was at 10%, and during a "cool day," it was 1%.

In this study, potential energy consumption is forecasted by using a simulation tool. In the near future, verification will be performed by applying the proposed framework to actual buildings. Also, various strategies and thermal comfort will be added to achieve the optimal integrated operations in further studies.

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