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A middleware platform for the validation and utilization of short-term weather forecast data for office buildings

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ABSTRACT

Simulations are widely used to calculate the thermal environment and energy consumption of buildings. The results of these simulations are affected by weather data, thus making the selection of appropriate weather data essential. Typical weather data are used to analyze a building's thermal performance, but this is not appropriate for analyzing the performance of an actual building controlled by a building energy management system, which responds to real-time weather conditions. Such a building needs short-term weather forecast data to calculate the energy consumption. However, an evaluation of the validity of weather forecast data has not been performed. This study quantitatively analyzes the validation of real-time weather forecast data. A middleware platform was developed to combine weather forecast data and the EnergyPlus software using Grasshopper software. In addition, weather forecast data and actual weather data were compared to evaluate the forecast validation and a predictive control method using weather forecast data was devised. The application of real-time control was found to reduce the electricity costs incurred for cooling by 10% relative to there being no control, and by 2% relative to fixed temperature control.

1. Introduction

Energy simulations are commonly undertaken for buildings. They assist engineers and architects in determining a building's shape, the window-to-wall ratio, and the envelope properties in the early design stages. They can also be utilized for subsequent building retrofits and ongoing operation [1–5]. To improve the efficiency of a building, valid weather data and a simulation that reflects the actual building conditions are essential [6–9]. Hong et al. [10] compared the energy consumption obtained for an office building when applying Actual Meteorological Year (AMY) and Typical Meteorological Year 3 (TMY3) data for every U.S. state, and determined that the weather data affects the HVAC costs by up to 30% and the total building costs by up to 10%. Chan [11] forecast future weather changes in Hong Kong and found that the resulting weather data indicated energy consumption increases of 2% to 14%. Zhu et al. [12] predicted an annual difference of 1.5 °C after 80 years, which will cause energy consumption to vary by up to 40%.

Many studies have shown that the weather data greatly impacts the results of a simulation, but typical weather data is limited in terms of its application to every region. EnergyPlus divides the weather data for South Korea into four regions [13], while the Korean Solar Energy Society (KSES) divides it into seven regions [14]. Therefore, for any region for which specific weather data is not available, it is necessary to approximate by using the data for the nearest location for which data is available. As such, the accuracy of the simulation results will be adversely affected. Furthermore, typical weather data such as Test Reference Years (TRY), Typical Meteorological Year (TMY), Weather Year for Energy Calculations (WYEC), and International Weather for Energy Calculations (IWEC) differ from the actual weather conditions because they are produced from weather statistics data covering 20 or 30 years [14–19]. This weather data can be used to analyze the thermal properties of buildings, but cannot be applied to energy management system (EMS) control such as load shifting or prediction control, both of which are strongly influenced by real-time weather conditions.

To control a building energy management system (BEMS), weather forecast data is imported from the Korea Meteorological Administration (KMA) and then used to estimate the short-term future energy consumption of the building. Unfortunately, although a previous study has addressed the real-time weather

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analysis modeling system [29], a quantitative analysis of the validation of weather forecast data in terms of building energy has not been performed. Since weather data have a significant impact on building energy consumption, it is important to quantify the accuracy of the weather forecast data. In addition, when applying real-time control using weather forecast data, it is necessary to analyze the building energy while being aware of the uncertainty associated with the weather data, so that engineers can devise an effective building control method. Therefore, this study set out to quantitatively analyze the validation of weather forecast data and we expect our results to be used as a reference for analyzing the uncertainty associated with forecasting building energy consumption based on weather forecast data. To address this issue, we took the following approach:

1) We configured a middleware platform that allows weather forecast data in extensible markup language (XML) format, as received from KMA, to be used with the EnergyPlus software.
2) We compared the hourly and daily weather forecast data, as monitored by the middleware platform, with actual measured weather data received from KMA and typical weather data to determine the degree of validity.
3) To enable the reduction of a building's energy consumption, we devised a predictive control method for application to BEMS using short-term weather forecast data. Various types of predictive control exist, including pre-cooling, pre-heating, and nighttime ice storage systems, etc. In the EnergyPlus software, however, only differences in the system modeling are supported. The method of platform composition does not change. Therefore, we set out to analyze the cooling energy consumption of office buildings using a pre-cooling control.

Consequently, the validation of weather forecast data was quantitatively examined and the cooling energy savings of a building were analyzed by applying a pre-cooling control strategy using weather forecast data to BEMS.

2. Method

2.1. Building conditions

The target building was a research building at a public institution. Therefore, it fully conformed to the building codes and featured a general design without a free-form structure. This building is located in Dae-Jeon, South Korea, and was constructed in 2010. It has seven floors (Table 1), with a total floor area of approximately 16,000 m^2 and has both electric heat pumps (EHP) and a BEMS installed. The internal heat gain and schedule conform to the standards laid down for offices in ASHRAE 90.1 (American Society of Heating, Refrigerating, and Air-Conditioning Engineers 90.1) [27], and the envelope properties are described in the construction documents for the building. The coefficient of performance (COP) of the heating, ventilation, and air-conditioning (HVAC) system is calculated by the BEMS.

2.2. Platform composition based on weather forecast data

2.2.1. Grasshopper software as middleware platform

The middleware software is required to enable the use of weather forecast data with energy analysis software in real-time. In this study, the Grasshopper open-source software was utilized to configure the middleware platform. This offers a graphical algorithm editor that is tightly integrated with the Rhino3D modeling tools while supporting Visual Basic, C#, and the Python language for the development of components [20,21]. As such, it can be used as middleware that can interact with other software such as Radiance, Daysim, EnergyPlus, and Openstudio [22–24]. Reinhart et al. [25] successfully combined EnergyPlus with Radiance software using Grasshopper to evaluate the thermal, lighting, and walkability properties of cities. Jin and Jeong [26] used a genetic algorithm (GA) realized in Grasshopper in the early stages of the design of freeform buildings to minimize energy consumption.

Table 1
Building conditions.

Category	Parameters	Conditions
Building conditions	Location	Dae-Jeon, South Korea
	Number of stories	7 above-ground and 1 basement
	Orientation	South-facing
	Floor area/Volume [m^2/m^3]	16,500/43,000
	Heating set point [°C]	20
	Cooling set point [°C]	26
Internal heat gain conditions	Occupancy [P/m^2]	0.05
	Lighting [W/m^2]	8.8
	Equipment [W/m^2]	8.06
Envelope conditions	Wall [W/(m^2K)]	0.58
	Window [W/(m^2K)]	2.8
	Floor [W/(m^2K)]	0.64
	Roof [W/(m^2K)]	0.35
	SHGC [–]	0.516
	Window to wall ratio [%]	40
	Infiltration [ACH]	0.1
	Ventilation [ACH]	0.5
	Heating COP	4.5
HVAC conditions	Cooling COP	3.9

2.2.2. Middleware platform process

A schematic diagram illustrating how the middleware platform uses real-time weather data is shown in Fig. 1. First, the KMA weather forecast data is imported into Grasshopper in XML format (Step 1). Then, in Step 2, Grasshopper calculates those weather elements which are not provided by the weather forecast data. In Step 3, a modified EPW (mEPW) is derived using the original EPW (oEPW) and the weather data is calculated according to the computer clock time for real-time applications. Finally, in Step 4, a hourly simulation is performed using the mEPW file and IDF file in Grasshopper. When the simulation processing time exceeds 1 h, an error occurs. So, it is necessary to confirm the simulation processing time. If no error occurs, the simulation results are then exported.

In Figs. 2–4, the gray boxes are the calculation modules and the yellow boxes represents the input and output values. Lines connect the modules.

2.2.2.1. Import of weather forecast data (Step 1). The weather forecast data provided by KMA is in XML format [28]. Weather forecasts are produced at a district level, eight times a day at 02:00, 05:00, 08:00, 11:00, 14:00, 17:00, 20:00, and 23:00. Any one forecast contains data for 3-h blocks, starting 4 h after the issue of the forecast [29]. For example, at 02:00, forecasts are produced for 06:00, 09:00, 12:00, and so on for the next two days. Here, the first forecast is for 06:00, which is 4 h after the forecast is issued. The elements of the forecast are the outdoor dry-bulb temperature, relative humidity, wind speed, wind direction, sky cover, precipitation, and snow cover. The outdoor dry-bulb temperature, relative humidity, wind speed, and sky cover are utilized to produce an EPW file [16,30]. In addition, the weather elements for the first forecast are used because the degree of uncertainty increases as time passes [31].

Grasshopper has no component to support the import of XML files, so a component would either have to be coded using C# or Visual Basic [21] or downloaded [32,33]. In this study, the XML