Energy and Buildings 67 (2013) 97–107

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Analysis of the impact of using synthetic data correlated with measured data on the calibrated as-built simulation of a commercial building

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ARTICLE INFO

Article history:
Received 26 April 2013
Received in revised form 11 July 2013
Accepted 23 July 2013

Keywords:
Building energy simulations
Weather-normalized cooling energy use
Direct normal solar radiation
Recalibration
Calibration factors

ABSTRACT

Measured data has shown to be useful in improving the accuracy and reliability of building energy simulations. However, a certain level of measured data is often not available due to time and cost limitation. This study analyzes the impact of using synthetic data that was correlated to measured data on calibrated as-built simulation and demonstrates its use for a case-study building, such as synthetic weather-normalized cooling energy use derived from measured motor control center (MCC) data and synthesized direct normal solar radiation from measured global solar radiation. The model recalibration of the case-study building is also discussed with respect to using the proposed calibration factors, including: a weather data file with the synthesized direct normal solar radiation, internal loads and schedules, maximum supply air temperature, hot deck and cold deck air temperature, and chiller operation and preheat temperature. As a result, the recalibrated simulation was determined to have an overall daily 23.82% CV(RMSE) and a daily 0.41% MBE. Consequently, the synthetic models that were strongly correlated to measured data and the calibration factors proposed in this study are found to be effective for calibrating whole-building energy simulation within an acceptable level of accuracy.

1. Introduction

Building energy simulation has been widely used for the performance evaluation of new buildings and extended its use for energy retrofits and continuous commissioning in existing buildings. Simplified calculation (e.g., ISO 13790) and dynamic simulation (e.g., DOE-2 and Energy Plus) approaches have been studied with accurate aspects of energy performance evaluation under uncertainty [1–5]. Overall, measured data has shown to be useful in improving the accuracy and reliability of dynamic energy simulations, especially for commercial buildings [6–8], including: hourly measured data, packed weather data with solar radiation, and in-situ measurements of mechanical equipment.

Hourly measured data can be used not only to verify simulation outputs, but also to generate simulation inputs for developing a reliable simulation model. In early studies, Kaplan et al. developed “day-type schedules” to incorporate monitored lighting and equipment data into typical operating schedules in DOE-2 simulation [9]. Abushakra et al. further developed procedures to derive diversity factors and typical load shapes of lighting and receptacle loads in office buildings [10]. Song and Haberl developed an enhanced procedure for evaluating the energy performance of a newly constructed commercial building based on a calibrated as-built simulation, along with hourly whole-building energy monitoring [11,12]. Recently, Raftery et al. has discussed a systematic, evidence-based calibration methodology using hourly measured data and its application for a case-study building to investigate modeling assumptions against real building operation and to evaluate energy conservation measures (ECMs) [13,14]. However, a certain level of measured data is often missing due to time and cost limitation, even though it is essential for calibrating a whole-building simulation model with high accuracy.

Haberl et al. evaluated the impact of using measured weather data that was repacked into Test Reference Year (TRY) format vs. Typical Meteorological Year (TMY) format in a DOE-2 simulation by comparing the results of simulated energy use [15]. Huang and Crawley also compared the influence of the various weather data sets, including: TRY, TMY, TMY2, WYEC (Weather Year for Energy Calculations), and WYEC2, on simulated annual energy use and energy cost [16]. They recommended that TMY2 should be used in building energy simulations where solar radiation is critical to the results. Although direct normal solar radiation is a significant component of solar radiation, it is often not available for a specific site due to a high installation cost and reliability issue. Batlles

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http://dx.doi.org/10.1016/j.enbuild.2013.07.057

et al. estimated hourly values of direct irradiance by means of the decomposition models proposed by Orgill and Hollands, Erbs et al., Reindl et al., Skarveit and Olseth, and Maxwell, in terms of the clearness index (*kt*) and the solar elevation [17]. They concluded that if precise information about turbidity is not available for such a parametric model proposed by Iqbal [18], the decomposition models were a good choice to estimate direct irradiance under cloudless skies. In this study, hourly direct normal solar radiation was synthesized based on measured hourly global solar radiation using the decomposition model proposed by Erbs et al. [19] and then evaluated its reliability versus measured direct normal radiation for a case-study building.

In-situ performance measurements of mechanical equipment are sometimes required for developing an effective calibrated simulation. Phelan et al. developed a set of in-situ testing methods for pumps, fans, and chillers to evaluate annual energy consumption and to account for part-load operations that are affected by overall system controls [20,21]. Liu et al. developed a procedure to determine the in-situ performance of commonly used HVAC systems [22]. They developed a simplified model calibration procedure from short-term field measurements and validated the calibration procedure using a simulation program developed with the ASHRAE modified bin method. In this study, in-situ measurements for a typical air handling unit (AHU) in the case-study building were also performed to verify the HVAC operation changes during the periods of model calibration.

Statistical models have been used to develop the baseline energy use normalized for routine adjustments such as weather, occupancy levels, process loads, and so on [23,24]. The use of weather-normalized models has been one of the noteworthy features of developing energy baseline models. In relation, Kissock et al. developed the Inverse Modeling Toolkit (IMT) for developing regression models as heating and cooling energy baselines [25]. The IMT can find best-fit models according to the number of change points. In this study, using a 4P change-point regression model, a daily cooling energy use was derived from a correlation of previously measured cooling energy use and motor control center (MCC) electricity use for the period of missing chiller data of the case-study building.

This study enhances the previous studies by analyzing the impact of using the synthetic data that was strongly correlated to measured data on calibrated as-built simulation and demonstrates its use for the model recalibration of a case-study building within an acceptable level of accuracy, including: synthetic weather normalized cooling energy use derived from measured MCC data, a weather data file with synthesized direct normal solar radiation derived from measured global solar radiation, internal load and schedules derived from measured data, measured maximum supply air temperature, measured hot deck and cold deck air temperature, and chiller operation change and preheat temperature adjustments.

2. Measure and synthetic data analysis

2.1. Case-study building description

The case-study building is a six-story, 303,389 ft^2 (28,196 m^2) state office building including a large print shop and data processing center, which is located in Austin, Texas in the United State. Table 1 summarizes the weather conditions of the building location characterized by hot summers and mild winters for the periods of 2001 and 2004. In 2001, cooling degree days (i.e., CDD 65 °F (18.3 °C): 2965 days) in summer were almost twice as many as heating degree days (i.e., HDD 65 °F (18.3 °C): 1664 days), and maximum hourly solar radiation was up to 317 Btu/h ft^2 (1000 W/m^2) in 2001,

Table 1
Summary of weather conditions in Austin, Texas in the U.S.A.

Items	Weather conditions		Remarks
	2001	2004	
Max. dry-bulb temp.	104 (40.0)	100 (37.8)	°F (°C)
Min. dry-bulb temp.	27 (−2.8)	24 (−4.4)	°F (°C)
Heating deg. day	1664	1373	HDD 65 °F (18.3 °C)
Cooling deg. day	2965	2917	CDD 65 °F (18.3 °C)
Max. hourly solar radiation	317 (1000)	321 (1013)	Btu/h ft^2 (W/m^2)
Min. hourly solar radiation	197(621)	206 (650)	Btu/h ft^2 (W/m^2)

which were similar to those of 2004. The building contains over 50% windows in the façade consisting of two types of low-e glazing as shown in Fig. 1. The majority of the conditioned area in the case-study building is served by the Dual-duct, Variable Air Volume (DDVAV) systems with preconditioned outside air. The building contains high efficiency mechanical equipment, including: two low-NOx boilers, three high efficiency centrifugal chillers, two oversized cooling towers, etc. In addition, a permanent energy monitoring system with sub-meters was also installed to measure the whole-building energy use and the mechanical equipment operation, in terms of whole-building electricity use, motor control center (MCC) electricity use, lighting and receptacles electricity use, cooling energy use, and heating energy use. Unfortunately, a new chiller was added to the case-study building after the monitoring system was completely installed, and it had no additional supply and return temperature sensors to measure cooling energy use.

2.2. Measured data analysis

Fig. 2 shows the whole-building electricity (WBE) and motor control center (MCC) electricity use for the case-study building from January 1 to December 31 in 2001 and from January 1 to December 31 in 2004. The electricity use of the motor control center (MCC) includes all the chiller electricity use and the electricity use of the associated equipment such as pumps and fans. The whole-building electricity use varied from about 750 kWh/h in the winter to about 1300 kWh/h in the summer. This variation is due to the loads from the cooling plant as shown in Fig. 3. The pumps electricity use is relatively constant for the entire period of the measured year, especially in the summer. Unfortunately, there was no measured data for the new chiller (i.e. chiller #3), which was installed in 2003. In 2001, chiller #1 was operated as a primary chiller and chiller #2 as a secondary chiller. However,

Fig. 1. Case-study building with deciduous trees.