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Prediction of cooling energy use in buildings using an enthalpy-based cooling degree days method in a hot and humid climate

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ABSTRACT

The cooling degree days (CDD) method has widely been used for predicting the cooling energy consumption of buildings with air conditioning. The conventional CDD values primarily are based on outdoor dry-bulb temperatures that neglect the influence of latent heat on the total energy load. This study proposes an enthalpy-based CDD method to account for latent heat as well as sensible heat. Two institutional buildings were used to examine the applicability and accuracy of the proposed enthalpy-based CDD, as compared to the conventional temperature-based CDD. To achieve this examination, multiple linear regression analyses were first performed to determine the base temperature/enthalpy points for each building during the different data periods (weekdays, weekends, and all week). Next, the CDD values were separately calculated using the determined base temperature/enthalpy points, and linear regression models were developed to predict the cooling energy use. Each individually-predicted cooling energy use employing the temperature- and enthalpy-based CDD methods was then compared to the measured cooling energy use. As a result, the comparison utilizing the enthalpy-based CDD method resulted in a percent error of approximately 2% less than that of the temperature-based CDD method.

1. Introduction

Energy consumption in buildings has been increasing globally, and associated concerns such as the impending exhaustion of energy resources and serious environmental impacts (e.g., ozone layer depletion and climate change) have been raised [1–4]. The reduction of building energy use has become one of the primary topics of interest for most developed/developing countries [2]. Various techniques and methods have been developed to predict building energy use. The predicted results facilitate the analysis of energy use and general energy efficiency in buildings before and after construction and/or energy retrofits. Furthermore, the results can be used to make decisions regarding how to minimize building energy consumption, as well as how to improve overall building energy performance.

Methods for predicting building energy use can be categorized into two types [5–7]: engineering methods and statistical methods. Engineering methods generally use physical calculations as principles for building energy use. A number of computer simulation programs based on engineering methods have been developed, such as DOE-2, eQUEST, EnergyPlus, TRNSYS, and ESP-r. On the other hand, statistical methods have also been developed to predict building energy use that use correlations among influencing variables such as weather data. Correlations are typically determined using a linear regression model that represents the relationship between the building's historical energy use and the corresponding weather data (e.g., outdoor temperature or cooling/heating degree days).

When the past measured data of a building system's performance and climate details are available, statistical methods have widely been used to predict building energy consumption; they tend to be simple and easily applicable to any type of building. The best known statistical methods used in the field of building energy simulation are the regression method [8–13] and degree day method [14–16]. When developing relationships useful to an analysis of building energy consumption, outdoor dry-bulb temperatures are most often referenced as the input variable typically used for both the regression and degree day methods. These methods appear to be the most useful in temperature-based analyses that account only for sensible heat. However, in order to better predict cooling energy use in buildings, latent heat should be considered in addition to sensible heat. Consequently, the authors believe that an enthalpy-based analysis that includes latent heat can advantageously be used to predict the cooling energy use of a building,

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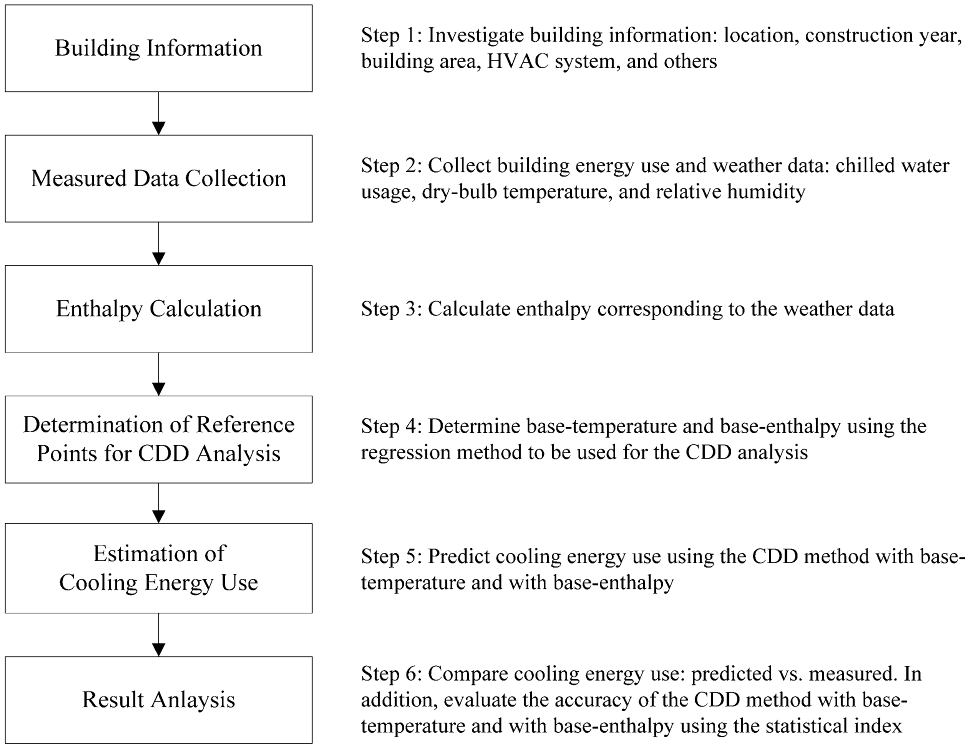

Fig. 1. Overall research methodology

especially buildings located in cooling-dominated areas in hot and humid climates.

This study examines a building's cooling energy use as it is predicted with outdoor dry-bulb temperature versus outdoor enthalpy. To develop a mathematical linear relationship between the cooling energy use and weather data (i.e., either temperature or enthalpy in this study), the regression method and cooling degree day method are used. Then, the developed relationships are used to predict the building's cooling energy use at a given condition of temperature or enthalpy. To evaluate the goodness-of-fit of the predicted values against the measured values, this study uses statistical indices such as the percent error, *R*-Squared, and Coefficient of Variation of Root Mean Square Error (CV-RMSE) values.

2. Methodology

The case-study buildings and methodology of this analysis are described in this section. Fig. 1 shows that this study is based on actual energy consumption data, corresponding outside dry-bulb temperature data, and relative humidity data for one year. Enthalpy values were calculated using dry-bulb temperature and relative humidity data. All of these measured and calculated data were used in a multiple linear regression analysis to estimate the base temperature and enthalpy in each case. Thereafter, these values were used to calculate the cooling degree days for each of the case-study buildings. The cooling energy uses of each of the case-study buildings were predicted using a regression model with the estimated cooling degree days, based on the temperature and enthalpy data. Finally, the predicted and measured cooling energy use were compared to each other in order to investigate which cooling degree day method was more accurate.

2.1. The case-study buildings

Two case-study buildings were selected for use in evaluating the cooling energy prediction procedure through the cooling degree day method, based on the outdoor dry-bulb temperature and enthalpy data. Both buildings were located on the Texas A&M University—College Station campus. Texas is located in a cooling-dominated climate, and the majority of annual energy consumption stems from cooling energy use. Thus, a determination of the cooling degree days was important to accurately predicting the cooling energy use. The selected buildings had a variety of functions: laboratory, office, and classroom. The heating, ventilation, and air-conditioning (HVAC) systems in these buildings consisted of single-duct variable air volume (SDVAV) air handling units (AHUs). In addition, each building had a direct digital control (DDC) system that operated the AHUs and pumps, while the terminal boxes were pneumatically controlled. All of the AHUs had pre-heating and cooling coils controlled through the energy management control system (EMCS). Further information about the case-study buildings can be found in Table 1.

2.2. Data collection: Weather and building energy consumption data

A regression analysis is typically performed using the measured weather data available from hundreds of weather stations across the United States. The weather variables required for this analysis

Table 1
General information about the case-study buildings.

	Building A	Building B
Construction year	2011	2005
Building function	Laboratory, office, classroom	Laboratory, office, classroom
Conditioned area [m^2]	13,928	9950
Number of floors	2	3
Occupancy schedule	08:00–17:00	24 h (laboratory) 06:00–22:00 (office) 06:00–21:00 (classroom)
Building system	SDVAV with reheat	SDVAV with reheat