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Building Central Plant System Performance Optimization through A Virtual Ambient Wet-bulb Temperature Sensor

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Abstract

Ambient wet-bulb temperature measurement is critical in the water-cooled chiller plant system to enhance the holistic energy efficiency through advanced control strategies, such as the cooling tower temperature relief, condenser water supply temperature reset, and so on. The outside air (OA) wet-bulb temperature is usually measured either by a psychrometer or a combination of an OA relative humidity sensor and an OA dry-bulb sensor. However, these conventional measuring devices are notoriously costly and frequently problematic in consideration of the accuracy and reliability. This paper proposes a black-box-based virtual ambient wet-bulb sensor through adopting a low-cost but relatively accurate dry-bulb temperature sensor and the local weather data, either the typical meteorological year (TMY) weather data or the real-time weather data available online. Further, a dynamic real-time calibration algorithm was simultaneously developed to minimize the measurement error. A case study in a ten-story office building in Austin, Texas was implemented to demonstrate the feasibility of this strategy. It reveals that the virtual sensor combined with the uniquely developed control algorithm could greatly improve the readings of the ambient wet-bulb temperature, thus guarantee the in-field chiller plant performance optimization as expected by the proposed control strategies.

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Keywords: Optimization; Wet-bulb Temperature Sensor; Virtual Sensor; Building Central Plant System

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1. Introduction

In large commercial buildings, the central chiller plant, especially the water-cooled type, is widely adopted as major cooling source, which includes chillers, cooling towers, the water distribution system and the condenser water distribution system. The energy performance of the water-cooled chiller plant could be improved through resetting the chilled water supply temperature (ChWST), resetting the condenser water supply temperature (CWST), using variable flow under partial load scenarios and optimizing the chiller staging control algorithm (Liu, Claridge and Turner 2009).

The measure of CWST reset is to decrease the CWST, which is realized through the optimal cooling tower control. The ambient wet-bulb temperature is frequently adopted as the indicator for the CWST setpoint reset schedule to maximize the chiller energy efficiency; therefore, both the ambient wet-bulb temperature sensor accuracy and long-term stability are critical during its implementation period. Currently, wet-bulb temperature is measured either by a psychrometer or a combination of the OA dry-bulb temperature (T_{db}) and relative humidity (RH) sensor. These traditional methods use physical sensors, which are notoriously costly and problematic considering the sensor accuracy and reliability.

Over the past decades, virtual meters or sensors have been rapidly developed and widely adopted within a number of different fields especially in the process controls and automobiles, and have enabled many intelligent features that would otherwise not be possible and economical. In the building section, virtual sensor technology also shows a promising application and provides a niche for replacing the conventional physical sensors to benefit from the unique advantages of the virtual sensors, such as low-cost, easy maintenance, high-accuracy guaranteed, etc. (Gawthrop, 2005; Gustafsson, 2001; Kestell, 2001; Jos de Assis 2000)

This study develops a virtual sensor for measuring the ambient wet-bulb temperature using the ambient dry-bulb temperature combined with a specific control algorithm, a real-time online dynamic calibration procedure to improve the sensor accuracy and minimize the error. The developed control algorithm could also be adopted as a stand-alone strategy to decrease the deviation of a physical ambient wet-bulb temperature sensor adopted for the CWST control of the water-cooled chiller plants.

Nomenclature

db	dry-bulb
dp	dew-point
wb	wet-bulb
CT	cooling tower
TMY	typical metrological year
VFD	variable frequency drive
CWST	condensing water supply temperature
ST	setpoint

2. Sensor development

Generally, according to the modeling methods utilized during the virtual sensors development process, it could be classified into three categories, black-box data driven method, grey-box method and the first principle model-driven (white-box) method. Black-box approaches utilize empirical correlations without any knowledge of the physical process. A grey-box method utilizes a combination of physical and empirical models in estimating the output of an unmeasured process. A first-principle (physical or white-box) virtual sensor is most commonly derived from fundamental physical laws and has parameters with some physical significance.

Figure 1 describes the general steps in the process of virtual sensor development. The process can be defined in terms of three major steps, data pre-processing, sensor development, and sensor calibration and implementation. The details of each step are illustrated in Figure 2 and 3 respectively.