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Automatic assisted calibration tool for coupling building automation system trend data with commissioning

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ABSTRACT

A very large number of measurement points are required to calibrate building energy models for the purpose of ongoing commissioning in HVAC systems. Building automation systems (BASs), common in many commercial and institutional buildings, can provide a large fraction of the required data. To reduce the time for BAS trend data analysis and export, a proof-of-concept prototype, called the Automatic Assisted Calibration Tool (AACT) was developed. The tool is a first step toward developing software that can automatically couple trend data for use in ongoing commissioning and calibrating building energy models. The AACT was tested using a case study institutional building, which proved its capacity to extract useful data and calculate indices of energy performance.

1. Introduction

Building systems are often poorly maintained and improperly controlled, resulting in an estimated 15–30% energy waste [1]. Commissioning helps reduce the energy waste by assuring the energy and environmental control performance of a building meets or exceeds the design intent after construction is complete. As a building is used, equipment degrades, faults occur, requirements change and operators change control settings for a variety of reasons, which may improve or impair energy and/or environmental control performance.

Generally, there are two types of commissioning: process and technical. Process commissioning relates to project management by ensuring the designers and contractors followed the owner's requirements and code specifications. Technical commissioning verifies the proper functioning of building systems based on inspections and physical testing. Ongoing commissioning is realized after initial commissioning to periodically or, ideally, continuously monitor and assess system performance. Heating, ventilation and air-conditioning (HVAC) system operational values and performance indices derived from these are compared with: (a) benchmark values such as minimum heat transfer effectiveness of a heat exchanger (i.e., limit sensing) or (b) estimates from calibrated building energy models or data-driven models based on normal operation free of known problems (i.e., discrepancy detection).

Calibrated building energy modeling is one of the most promising and powerful tools to assist in the commissioning process. A calibrated building energy model generates estimates that match the measured energy use and other variables (e.g., air flow rates and temperature) with acceptable accuracy. Calibrated models are difficult to create because they are underdetermined [2] (i.e., the number of model inputs exceeds the number of measured inputs that are regularly available). One approach to overcome this issue is to increase the amount of measured data used in model creation. Building automation systems (BASs), which are installed in many commercial and institutional buildings, record trend data that can be extracted and processed to become inputs to building energy models, or to generate indices of energy performance used for purposes of ongoing commissioning.

BASs, building management systems (BMSs), and building automation and control systems (BACs) are computerized systems used to monitor and control building services such as HVAC systems, security, and lighting. The nomenclature varies but the tasks are the same. Buildings may also have automated energy management systems, referred to as energy management control systems (EMCSs), building energy management systems (BEMSs), or energy information systems (EISs), which focus on monitoring energy use. This function may be incorporated within the former type of system. BAS is used herein to refer to a management system that includes energy management features.

BASs typically have the capacity to record historical operating data, referred to as "trend" data. BAS trending is a common base system feature [3]. Typical trend data include temperature, humidity, valve

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and damper positions, on/off control signals, and air flow rates; rarely are thermofluid flow rates and sub-hourly electric demand available. The number of BAS sensors in buildings is very large, so manual commissioning is labor-intensive and, therefore, automatic tools using trend data to aid in the commissioning process are preferred [4]. The computing power and wireless capacity of BASs has made them economical and feasible for widespread adoption in buildings; however, trend data are rarely used effectively to maintain optimal energy performance. Currently, BASs perform poorly when diagnosing HVAC faults, yet are essential to provide data for commissioning [5].

There is a need for automatic software tools to retrieve HVAC trend data to understand operation and performance, analyze variables of interest or performance indices required for ongoing commissioning, and automatically update the input files of energy analysis programs to assist in the calibration process.

This paper continues with a literature review on use of trend data in ongoing commissioning and calibrated simulation. That section will be followed by a presentation of the HVAC system in a case study building, and the trend data available from the BAS. Subsequently, a proof-of-concept prototype, called the Automatic Assisted Calibration Tool (AACT), will be presented, with examples of how this tool can assist in ongoing commissioning and generate inputs for building simulation. The paper finishes with a discussion of the AACT and its current limitations.

2. Literature review

2.1. Use of trend data in ongoing commissioning

Use of trend data in ongoing commissioning was researched and developed over the past 15 years with a focus on fault detection and diagnosis (FDD) [6–12]. These FDD studies found that BASs were practical and cost-effective in providing the necessary data to conduct FDD research.

Friedman and Piette [3] compared manual and automated FDD tools using HVAC trend data. They noted that one of the advantages of these tools was their capacity to reduce data management and analysis time to obtain information from trend data. Piette et al. [13] developed a prototype system using dedicated sensors, data acquisition software and hardware, and data visualization software including a web-based remote system. Their system included sensors additional to those available in common BASs. They used their system to identify control problems and faults specific to HVAC systems. Seidl [14] documented his experience with troubleshooting control systems using trend data. He calculated how much a trend point deviated from its set point or from a benchmark to identify faulty trend points.

Wang and Wang [15] presented an automatic commissioning software tool that used a large trend database to verify and diagnose the sensors used by the refrigeration systems during normal operation and during the commissioning stage. They found the software provided a convenient and reliable means for the engineers to check and diagnose the BMS measurement devices.

Katipamula and Brambley [1] stated that trend data are rarely used in industry because FDD is rarely built into BASs and there is a lack of infrastructure to gather data from existing BASs for add-on applications. Increasing the automation of FDD methods with BASs was strongly advocated [4,8,16].

Xiao et al. [17] presented an online diagnostic tool to monitor the condition of sensors used in an air-handling unit, applying FDD to trend data. Schein [18] developed an information system for a medium-sized office building BAS; the information system collected design, operation and maintenance data about mechanical, electrical, and plumbing systems. The system was designed to extract trend data for other applications such as energy simulations and building commissioning.

Choiniere [19] presented Diagnostic Agent for Building Operation (DABO) developed by Natural Resources Canada that could be integrated into existing BASs to aid in automating ongoing commissioning. DABO automatically analyzed trend data to identify faults using a rule-based reasoning module, provided suggestions to improve performance and generated energy and comfort profiles.

Wang et al. [20] presented an online fault diagnosis tool for VAV terminals that used commonly available sensor and control signal trend data.

The accuracy of trend data has often been questioned. The use of dedicated and calibrated sensors was expected to provide higher quality data than those installed in BASs. Haves et al. [21] listed the main issues with sensors: improper positioning, inadequate calibration during commissioning, and drift during operation. Torcellini et al. [22] recommended the use of dedicated systems for sub-utility monitoring but this presents challenges in terms of additional cost and complexity.

2.2. Use of trend data in calibrated simulation

Use of trend data in calibration appears to have first been reported by Carling et al. [23]. The trend data they used included BAS set points and control signals, sub-metered electricity, air temperatures in the AHU and zones, and slab temperatures. They identified multiple faults that might have been missed without trend data.

Monfet et al. [24] used trend data to calibrate an energy model for AHU supply air flow rates and supply and return air temperatures, and the supply and return temperatures for hot and chilled glycol. They noted that trend data revealed operational faults and improved their initial input file.

Pang et al. [25] used trend data to create inputs for real-time use of an already calibrated model.

Gestwick and Love [26] used trend data to estimate lighting, equipment, and fan schedules and compared hourly plant heating load trend data to simulation outputs. They noted that offsetting errors would likely have occurred if hourly plant heating load trend data were unavailable due to the use of a steady state model for boiler efficiency versus load, which is common in the most widely used whole building simulation programs. These errors could have led to erroneous tuning of boiler efficiency and heat recovery effectiveness. They also stated that high resolution data were crucial for understanding the performance of energy systems.

Kandil and Love [27] used trend data to generate inputs to simulate fan and pump electrical demand and schedules; domestic hot water schedule and capacity; boiler efficiency; and AHU air flow rate. They noted that hourly data were essential to reliably calibrate the model.

Mihai [28] calibrated zones using zone supply air flow rates and indoor air temperature trend data. Trend data provided the study with sufficient information to focus the calibration on zone and system level models.

Mustafaraj et al. [29] reported model calibration using trend data including set points, on/off values, schedules, underfloor heating flow rate, hot water temperatures, and room indoor air temperatures, as well as pump electrical use. They noted that the use of trend data improved the model calibration.

Coakley et al. [30] anticipated that automatic tools integrating trend data with building simulation software may reduce the calibration time, however, such tools remained to be developed at the time they published.

The use of trend data during calibration in many studies was obscure in terms of how inputs were generated from trend data and how these values were transferred to the model. It also remained uncertain if the commonly available trend data points were used to their full potential. Trend data has bias and random errors, which often create a cloud of points. It was rarely stated whether the input values were approximated based on manual inspection or quantified using mathematical/statistical techniques.

This paper presents a proof-of-concept prototype tool that automates the analysis of trend data and generates inputs for a detailed building