Automation in Construction 44 (2014) 197–211

Contents lists available at ScienceDirect

Automation in Construction

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

A BIM-enabled information infrastructure for building energy Fault Detection and Diagnostics

Bing Dong [a,*], Zheng O'Neill [b], Zhengwei Li [c]

[a] Department of Mechanical Engineering, The University of Texas at San Antonio, San Antonio, TX 78249, USA
[b] Department of Mechanical Engineering, The University of Alabama, Tuscaloosa, AL 35401, USA
[c] School of Mechanical and Energy Engineering, Tongji University, PR China

ARTICLE INFO

Article history:
Received 12 November 2013
Revised 24 March 2014
Accepted 12 April 2014
Available online 10 May 2014

Keywords:
Building Information Modeling
Fault Detection and Diagnostics
Information infrastructure
Real-time implementation
Data schema

ABSTRACT

Although energy-efficient building technologies are emerging, a key challenge is how to effectively maintain building energy performance over the evolving lifecycle of the building. Field experience shows that energy savings of 5–30% are typically achievable simply by applying energy Fault Detection and Diagnostics (FDD) and correcting faults diagnosed in buildings. Model-based FDD in buildings is a challenging task, not only because the task itself is difficult, but also because the workflow and information exchange behind the task is very complex and error prone. This complexity arises from several aspects. Firstly, creating a baseline building energy performance model suitable for FDD is both time and labor consuming. Secondly, the FDD module typically has its own ad-hoc platform, and the integration of this platform with the existing Building Energy Management System (BEMS) is technically challenging due to the incompatible interoperability. Finally, the information exchange itself is complex due to the existence of multiple functioning modules to make FDD workflow happen. To perform an efficient and effective FDD with the BEMS in buildings, information is needed to flow among an as-built building static information module, a building energy performance simulation module, a building operational data acquisition module and a FDD module. In such a complex process, it is challenging to ensure the information integrity and consistence. In this paper, we propose a Building Information Modeling (BIM) enabled information infrastructure for FDD, which streamlines the information exchange process and therefore has the potential to improve the efficiency of similar works in practice. The proposed information infrastructure was deployed and implemented in a real building for a FDD case study.

1. Introduction and motivation

The commercial and residential building sector consumed 40.1% (4.12×10^{18} J) of U.S. primary energy in 2011 [1]. In a 2005 report [2], it was estimated that the overall building faults could increase commercial building primary energy consumption by approximately one quad (1.05×10^{18} J), or accounted for about 11% energy consumed by Heating, Ventilation and Air-conditioning (HVAC), lighting, and large refrigeration systems in commercial buildings. In another source, it was stated that "*faults relating to HVAC systems represent between 1% and 2.5% of total commercial building consumption*" [3]. Building energy Fault Detections and Diagnostics (FDD), particularly, HVAC FDD has been proved to be an efficient and effective means to reduce energy consumption in buildings during Operation and Maintenance (O&M) stages [4–6]. However, the implementation of FDD in practice is challenging due to the complexities of underlying FDD algorithms, relevant workflow and required building information exchanges. There is a need for an information infrastructure to facilitate information exchange for FDD. We will start from a review of the current state-of-the-art building FDD methodologies and associated workflow. This will be followed by a comprehensive review of Building Information Modeling (BIM) for O&M in the HVAC industry.

1.1. Reviews on building Fault Detection and Diagnostics

Depending on the FDD approach, the FDD workflow is different. According to the categorization presented by Katipamula and Brambley [6], there are mainly three types of FDD methods: quantitative model-based, qualitative model-based and process history based.

For the *quantitative model-based method*, the typical workflow process is the following. Energy modelers extract building architectural and mechanical system information relevant to whole building energy usage from design and/or as-built drawings and documents, then create and calibrate the energy performance models in certain software for whole building and/or HVAC system based on first principles. The first principles refer to the basics of heat transfer and thermodynamics

* Corresponding author.
E-mail addresses: bing.dong@utsa.edu (B. Dong), zoneill@eng.ua.edu (Z. O'Neill), zhengwei_li@tongji.edu.cn (Z. Li).

http://dx.doi.org/10.1016/j.autcon.2014.04.007
0926-5805/Published by Elsevier B.V.

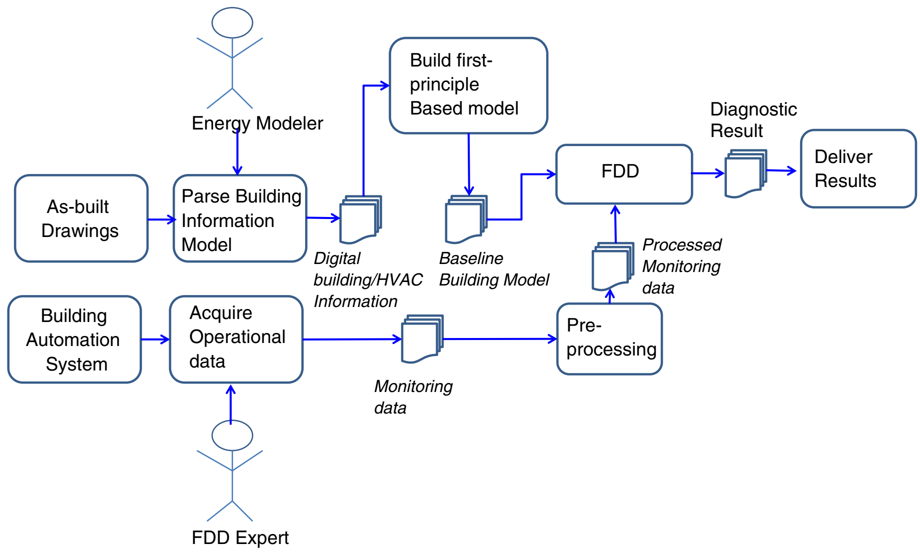

Fig. 1. Quantitative model based FDD workflow process.

when constructing building envelope and HVAC system models. The FDD experts select and take the operational data from Building Energy Management System (BEMS), compare it with the baseline or reference data which comes from aforementioned building energy performance models. Then FDD modules are applied to detect and identify possible building and HVAC system problems. After the FDD task is finished, the results are sent back to the central work station, which hosts the BEMS, to help building facility operation personnel make decisions. This process is illustrated in Fig. 1. Some real projects in which this process or a part of this process is followed can be found in [7–10].

For the *qualitative model-based method* and the *process history based method*, the work flow is different from that in a quantitative model-based method. Firstly, the targeted system is monitored for a period. Sufficient data is collected to either train thresholds used for the fault detection or the process history models (e.g., Statistical Process Control (SPC) model [11]). After this, the trained model and corresponding threshold settings are applied to the real operational data. This process is illustrated in Fig. 2. The main difference between qualitative model-based (rule based) and process history based FDD methods is that the latter will need significant efforts to collect the historical data and train the model. While the rule based method requires no data or much less data just for getting some thresholds used in the rules. Projects where this workflow applies can be found in [12–15].

The workflow processes shown in Figs. 1 and 2 have several limitations. Firstly, because of the proprietary BEMS, the implementation of FDD technology within commercial BEMS is often restricted to off-line cases. Therefore, the potential benefit of FDD technology through a real-time implementation cannot be fully realized. Secondly, in a quantitative model based method, manually parsing the design drawings and documentations to set up energy performance models is both time and labor consuming, which increases the implementation cost of FDD and prohibits it from being widely used. In addition, because human involved process is error prone, some uncertainties are introduced into both building baseline model and final FDD results, which dramatically affect the credibility of this technology. Finally, current central building data management system is designed for building controls and it cannot be directly used for an effective FDD in O&M: 1) Control sequences and schedules are not stored in the BEMS explicitly. It is often that users need to understand specific control programs to extract these control sequences. 2) Trending data in most BEMS is selected for control purpose, for example, some virtual points (e.g., intermediate outputs from the control loop) are not often stored. These points are important for root-cause analysis of controls related faults. 3) Sampling frequency in the current BEMS most of the time is 5 min. For FDD, sometimes, the high sampling frequency is desired. This leads to 1) inconsistent and questionable inputs for energy performance baseline

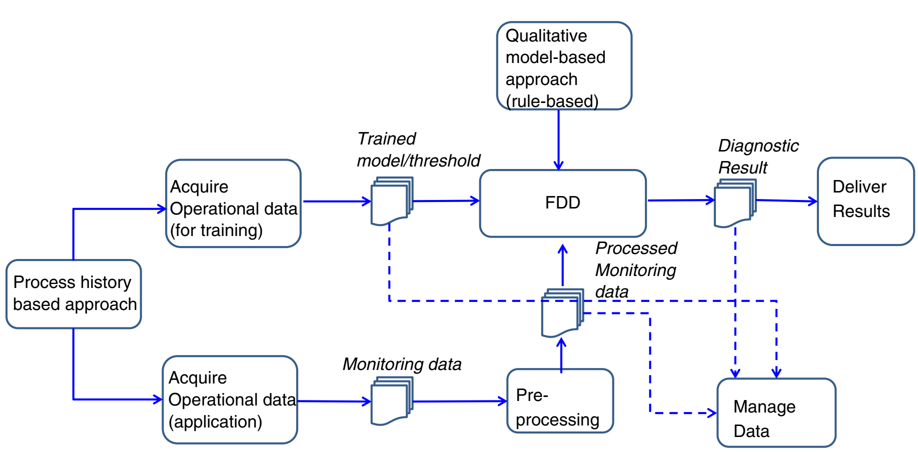

Fig. 2. Rule based/process history based FDD workflow process.