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Cross-level fault detection and diagnosis of building HVAC systems

Siyu Wu*, Jian-Qiao Sun

School of Engineering, University of California, Merced, CA 95343, USA

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ABSTRACT

This paper presents a cross-level fault detection method. Two key features of the proposed method are 1) an energy description of all the units in an HVAC system and 2) a spatial–temporal partition strategy, which allows us to apply the FDD strategy to the entire building in a uniform manner. Energy flow models for HVAC units at all levels are presented. The concept of absolute and relative references for monitoring the energy performance is introduced. We have discussed the inherent complexity of HVAC systems, and proposed a grouping strategy of VAVs via correlation analysis. Examples of the temporal and spatial partitions are presented. Numerical examples are given to demonstrate the cross-level detection of two faults on AHU level and one fault on VAV level.

1. Introduction

Buildings represent one of the fastest growing energy consuming facilities on the earth. According to the U.S. Department of Energy 2009 Building Energy Databook, buildings use 72% of nation's electricity, and 38.9% of nation's total energy consumption, valued at $392 billion [1–3]. Currently, the heating, ventilating, and air conditioning (HVAC) systems account for 57% of the energy used in U.S. commercial and residential buildings. Unfortunately, HVAC may fail to meet the performance expectations due to various faults, thus wasting more than 20% of the energy it consumes. Therefore, it is of great potential to develop automatic, quick-responding, accurate and reliable fault detection and diagnosis (FDD) schemes to ensure the normal operations of HVAC in order to save energy. According to the National Institute of Standards and Technology (NIST), FDD methods have a potential to save 10–40% of HVAC energy consumption [4]. An FDD package for HVAC can help to establish construction and renovation standards for new and existing buildings. In light of the worldwide energy crisis and increasing environmental awareness, and the current limited usage of renewable energy in buildings [5], FDD for HVAC is critical to increase the energy efficiency of buildings.

HVAC is a complex and highly integrated system. For example, the HVAC system for buildings on the UC Merced campus has a three-level structure with a top level bridge, a middle level air handling unit (AHU) and air distributors at lower level, called variable air volume (VAV) unit. Each level includes a large number of components, such as sensors, controllers, actuators and air dampers. The hardware and software of the HVAC system are coupled across different levels. Environmental and architectural factors lead to different energy consumptions among units at the same level. A single component may have a fault which degrades the entire system performance [6]. This inherent complexity greatly increases the difficulty for FDD of the HVAC system.

Existing FDD methods on HVAC systems can be divided into two categories: statistical method and simulation based approach. The statistical methods implement fault detection algorithms to analyze current conditions in comparison with past normal conditions. Within VAV, Qin et al. adopted a hybrid approach utilizing expert rules to detect ten types of faults in VAVs [7]. Song et al. invented a handy tool to detect faults in VAVs based on indoor temperature fluctuations [8]. Yang et al. used fractal correlation dimension to detect relatively small bias component faults under noisy conditions [9]. Cho et al. considered the transient pattern of fan, sensor, and damper faults [10]. By setting proper thresholds learned from trainings, Du et al. could detect flow sensor faults in air dampers and VAV terminals [11,12]. As for AHU, Schein et al. found twenty-eight rules to detect five typical faults in AHUs [4,13]. Ghiaus developed a bond graph to detect faults in the air conditioning system [14]. Chen et al. developed an easy-to-implement FDD method for detecting faults in rooftop air conditioners [15]. Wang and Xiao applied the principal component analysis (PCA) to detect sensor faults in AHUs [16–18]. There are also relevant researches such as Carling and Haves compared three fault detection methods with the field data [19]. Norford et al. evaluated fault detection methods on the basis of their sensitivity, robustness, the

* Corresponding author.
E-mail address: swu8@ucmerced.edu (S. Wu).

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