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Review

A review of fault detection and diagnosis methodologies on air-handling units

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ABSTRACT

Faults occurring in improper routine operations and poor preventive maintenance of heating, ventilating, air conditioning, and refrigeration systems (HVAC&R) equipment result in excessive energy consumption. An air-handling unit (AHU) is one of the most extensively operated equipment in large commercial buildings. This device is typically customized and lacks of quality system integration, which can result in hardware failures and controller errors. This paper aims to provide a systematic review of existing fault detection and diagnosis (FDD) methods for an AHU therefore inspire new approaches with high performance in reality. For this goal, the background of AHU systems, general FDD framework and typical faults in AHUs, is described. Ten desirable characteristics used in a review of FDD in chemical process control are introduced to evaluate the methodologies and results. A new categorization method is proposed to better interpret the different and most recent approaches. The main FDD methodologies and hybrid approaches are described and commented to illustrate the use of evaluation standard parameters for improving the performance of FDD on AHUs.

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Nomenclature

ANN	artificial neural network
AHU	air-handling unit
AFDD	automated fault detection and diagnosis
APAR	air handling unit performance assessment rules
BAS	building automation system
BPNN	back-propagation neural network
CAV	constant air volume system
CV	cooling coil valve
CVA	canonical variate analysis
DC-1	damper controller
D-1	damper of a VAV box
DWT	discrete wavelet transform
EA	exhaust air
ENN	Elman neural network
F	flow sensor
FDD	fault detection and diagnosis
FTC	fault tolerant control
FC-1	return air flow rate controller
FC-2	flow rate setpoint controller
FC-3	flow rate controller
FDA	Fisher discriminant analysis
FFT	fast Fourier transformation
HV	heating coil valve
H	humidity sensor
HMM	hidden Markov model
JAA	joint angle analysis
M-1	damper motor
MA	mixing air
OA	outdoor air
P	pressure sensor
PC-1	supply air static pressure controller
PV	preheating coil valve
PCA	principal component analysis
PLS	partial least squares
Q	air flow rate
RA	return air
RTU	rooftop unit
RF	return air
SA	supply air
SF	supply fan
SDG	signed directed graph
TC-1	supply air temperature controller
T	temperature
ΔT	temperature difference
UIO	unknown input observer
u	control signal
VAV	variable air volume
VFD	variable speed drive

Greek symbols

ε_t	threshold parameter for errors of temperature measurements
ε_{cc}	threshold parameter for the control signal of the cooling coil valve
ε_{hc}	threshold parameter for the control signal of the heating coil valve
ε_f	threshold parameter for errors relayed to airflows

Subscripts

cc	cooling coil valve
co	changeover switch between modes 3 and 4
hc	heating coil valve
i	count number
MA	mixing air
min	minimum
OA	outdoor air
RA	return air
rf	return fan
SA	supply air
sa,s	supply air set point
sf	supply fan

1. Introduction

According to U.S. Department of Energy, building HVAC systems, included space heating, space cooling and ventilation, consumed nearly 40% of the total energy used in commercial-building sector at 18.35 Quads (quadrillion Btu) [1]. This issue significantly challenges the current status of energy efficiency in buildings. Even building automation system or advanced controllers are applied to enhance system efficiency, faults can develop during the installation, routine operations or scheduled preventive maintenances in systems and result in excessive energy waste. In a survey of UK buildings, the data showed 25–50% of energy wasted from faults in building HVAC systems. This range could be reduced below 15% whenever those faults could be detected and identified early in the premature stage before unacceptable damages occur [2]. These fault problems will be more difficult to examine in complex systems without applying smart technologies.

To tackle these problems, automated fault detection and diagnosis (AFDD) as the automated procedure of investigating faults and identifying the location and causes of abnormal symptoms has been developed in fields such as chemical process controls, automobiles and power plants. Also, this application has been applied to HVAC&R for detecting and evaluating fault occurrence and improper operations of equipment. AFDD has been included in control systems through building automation system (BAS) or embedded into HVAC equipment such as rooftop air-conditioning units (RTUs) [3]. Along with the evolvement of energy-efficient HVAC in commercial buildings, the broad scope of FDD in HVAC fields has been increased continuously because various

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