ESL-IC-13-10-47

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Development of self-correcting algorithms for complete failure of supply air temperature sensors

by

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INTERNATIONAL CONFERENCE FOR ENHANCED BUILDING OPERATIONS
ICEBO 2013 – October 9, 2013

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Introduction

- Different approaches for fault detection and diagnosis (FDD) of heating, ventilation and air conditioning (HVAC) building equipment
  - physical models
  - analytical models
  - methods driven by performance data
    - artificial intelligence
    - statistical techniques

Introduction (cont'd)

- Few attempts to isolate and identify faults successfully and propose corrective measured or if possible automatically fix the system faults
- Self-correction algorithms
  1. Diagnostic of faults by improving passive testing and creating active tests to isolate faults
  2. Development of self-correction algorithms to create virtual information when faults occur
  3. Integration of the algorithms to the control system

Literature review

- Lee et al. (1997): two-stage neural network approach

$$T_{sa}(i) = f(Q_{sa}(i), Q_{sa}(i-1), Q_{sa}(i)^2, Q_{sa}(i-1)^2, T_{ma}(i), T_{ma}(i-1), T_{chws}(i),$$
$$T_{chws}(i-1), \varphi_{ma}(i), \varphi_{ma}(i-1), U_{cc}(i), U_{cc}(i-1), U_{cc}(i)^2, U_{cc}(i-1)^2,$$
$$Q_{sa}(i) \cdot T_{ma}(i), Q_{sa}(i-1) \cdot T_{ma}(i-1))$$

- House et al. (1999): classification techniques for FDD of AHU

Literature review (cont'd)

- Kumar et al. (2001): FDD using single-input/single-output recursive auto regressive exogenous (RARX) system identification methodology with forgetting factor
- Lee et al. (2004): General regression neural-networks (GRNN)
- Wang et al. (2012): online model-based, previous 10h of operating data using a genetic algorithm

Objective

- Self-correction algorithms for complete failure of supply air temperature sensors
  - Development: seven correlations are proposed
  - Implementation: creation of virtual sensors
  - Proof of concept

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Self-correction of HVAC controls

- Pacific Northwest National Laboratory (PNNL) has initiated research (Fernandez et al., 2009a)
  - Passive and proactive tests
  - Rule-based algorithms
  - Tested using virtual sensors

- Self-correction approach for the total failure of supply air temperature sensors

Self-correction of HVAC controls – proposed approach

1. Fault Diagnostic
   - Constant sensor value
   - Much larger or lower than the expected value
2. Algorithm Development
   - Data monitored on the AHU-M3 at the CanmetENERGY building in Varennes, QC.
   - Data set divided into two subsets:
     1. Training data set: July 2012
     2. Testing data set: August and September 2012

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Self-correction of HVAC controls – proposed approach

2. Algorithm Development (cont'd)
   - Monitored data pre-processing
     1. Remove transient state conditions
     2. Mechanical cooling operation mode
     3. Extract occupancy data from 8:00 to 18:00
   - Preliminary algorithms developed for the supply air temperature

Self-correction of HVAC controls – proposed approach

– Proposed correlations

$$aT_{sa} = a_1 \cdot Q_{sa} + a_2 \cdot Q_{sa}{}^2 + a_3 \cdot T_{ma} + a_4 \cdot T_{chws} + a_5 \cdot U_{cc} + a_6 \cdot U_{cc}{}^2 + a_7 \cdot Q_{sa} \cdot T_{ma}$$

$$bT_{sa} = b_1 \cdot Q_{sa} + b_3 \cdot T_{ma} + b_4 \cdot T_{chws} + b_5 \cdot U_{cc} + b_6 \cdot U_{cc}{}^2 + b_7 \cdot Q_{sa} \cdot T_{ma}$$

$$cT_{sa} = c_1 \cdot Q_{sa} + c_3 \cdot T_{ma} + c_4 \cdot T_{chws} + c_5 \cdot U_{cc} + c_7 \cdot Q_{sa} \cdot T_{ma}$$

$$dT_{sa} = d_1 \cdot Q_{sa} + d_3 \cdot T_{ra} + d_4 \cdot T_{chws} + d_5 \cdot U_{cc}$$

Self-correction of HVAC controls – proposed approach

– Proposed correlations (cont'd)

$$eT_{sa} = e_1 \cdot Q_{sa} + e_2 \cdot Q_{sa}^{\ 2} + e_3 \cdot T_{ma} + e_4 \cdot T_{chws} + e_5 \cdot U_{cc} + e_6 \cdot U_{cc}^{\ 2} + e_7 \cdot Q_{sa} \cdot T_{ma} + e_8 \cdot VFD_{P,chw} + e_9 \cdot VFD_{P,chw}^{\ 2} + e_{10} \cdot VFD_{P,chw} \cdot T_{chws}$$

$$fT_{sa} = f_1 \cdot Q_{sa} + f_3 \cdot T_{ma} + f_4 \cdot T_{chws} + f_5 \cdot U_{cc} + f_6 \cdot U_{cc}^{\ 2} + f_7 \cdot Q_{sa} \cdot T_{ma} + f_8 \cdot VFD_{P,chw} + f_9 \cdot VFD_{P,chw}^{\ 2} + f_{10} \cdot VFD_{P,chw} \cdot T_{chws}$$

$$gT_{sa} = g_1 \cdot Q_{sa} + g_3 \cdot T_{ma} + g_4 \cdot T_{chws} + g_5 \cdot U_{cc} + g_6 \cdot U_{cc}^{\ 2} + g_7 \cdot Q_{sa} \cdot T_{ma} + g_8 \cdot VFD_{P,chw} + g_9 \cdot VFD_{P,chw}^{\ 2}$$

Self-correction of HVAC controls – proposed approach

3. Implementation approach

   - Creation of virtual sensors for the proposed correlations
   - Three of the seven correlations
     - bT_{sa}
     - dT_{sa}
     - gT_{sa}
   - Real time monitoring using DABO™ for comparison

Results and discussion

Table 1
Identified coefficients for T_{sa} - mechanical cooling occupied data: July 2012

item	a_i	b_i	c_i	d_i	e_i	f_i	g_i
Q_{sa}, i=1	3.3628E-3	**3.1471E-3**	2.9086E-3	**3.7051E-4**	2.8432E-3	3.1091E-3	**3.0935E-3**
Q_{sa}^2, i=2	-5.1823E-8				6.2477E-8		
T_{ma} or T_{ra}^1, i=3	5.4754E-1	**5.8701E-1**	5.4280E-1	**5.197E-1**	6.1702E-1	5.7061E-1	**5.6787E-1**
T_{chws}, i=4	3.0410E-1	**3.0404E-1**	2.8792E-1	**3.0304E-1**	2.8634E-1	2.8444E-1	**2.9076E-1**
U_{cc}, i=5	-7.5082E-2	**-7.4716E-2**	-2.6452E-2	**-2.6844E-2**	-7.6030E-2	-7.6453E-2	**-7.6445E-2**
U_{cc}^2, i=6	3.8465E-4	**3.8188E-4**			3.9058E-4	3.9378E-4	**3.9376E-4**
$Q_{sa} \cdot T_{ma}$, i=7	-1.0936E-4	**-1.1900E-4**	-1.1012E-4		-1.2133E-4	-1.1004E-4	**-1.0940E-4**
$VFD_{P,chw}$, i=8					1.2863E-2	1.2199E-2	**1.3633E-2**
$VFD_{P,chw}^2$, i=9					-2.2134E-4	-2.1708E-4	**-2.2139E-4**
$VFD_{P,chw} \cdot T_{chws}$, i=10					7.2871E-5	1.1003E-4	
R^2	99.69	**99.69**	99.68	**99.68**	99.71	99.71	**99.71**

Results and discussion

Table 2
Evaluation criteria for T_{sa} – mechanical cooling occupied data: August and September 2012

Correlation	RMSE, °C	MBE, °C
aT_{sa}	1.63	-0.754
bT_{sa}	**1.62**	**-0.747**
cT_{sa}	1.68	-0.887
dT_{sa}	**1.64**	**-0.864**
eT_{sa}	1.58	-0.753
fT_{sa}	1.57	-0.738
gT_{sa}	**1.58**	**-0.738**

Table 3
Evaluation criteria for T_{sa} – mechanical cooling occupied data: May 2013

Correlation	RMSE, °C	MBE, °C
bT_{sa}	2.57	-1.70
dT_{sa}	2.23	-1.41
gT_{sa}	2.62	-1.76

Results and discussion

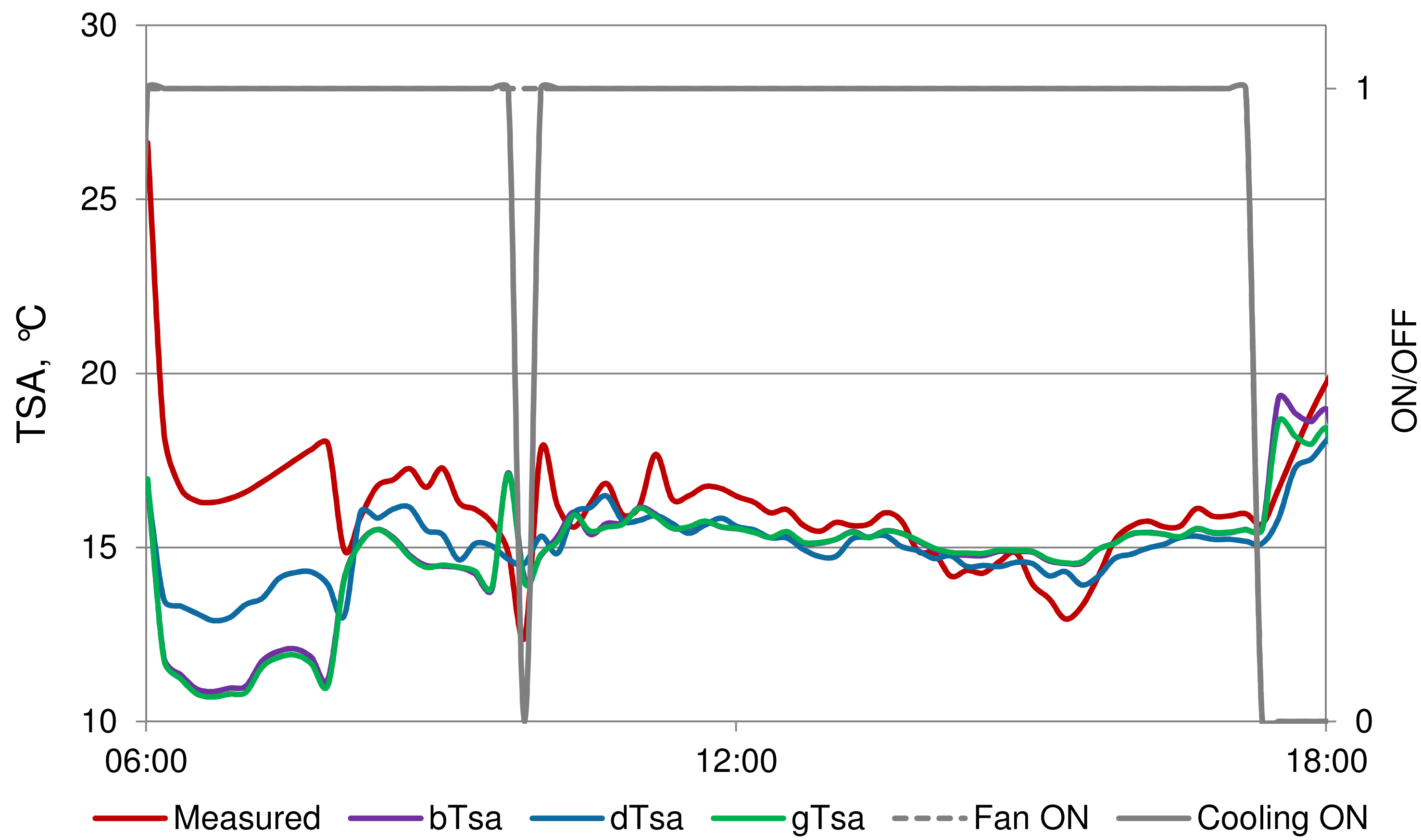

Figure 1. Virtual sensors output versus measured supply air temperature for AHU M3: 6 May 2013

Results and discussion

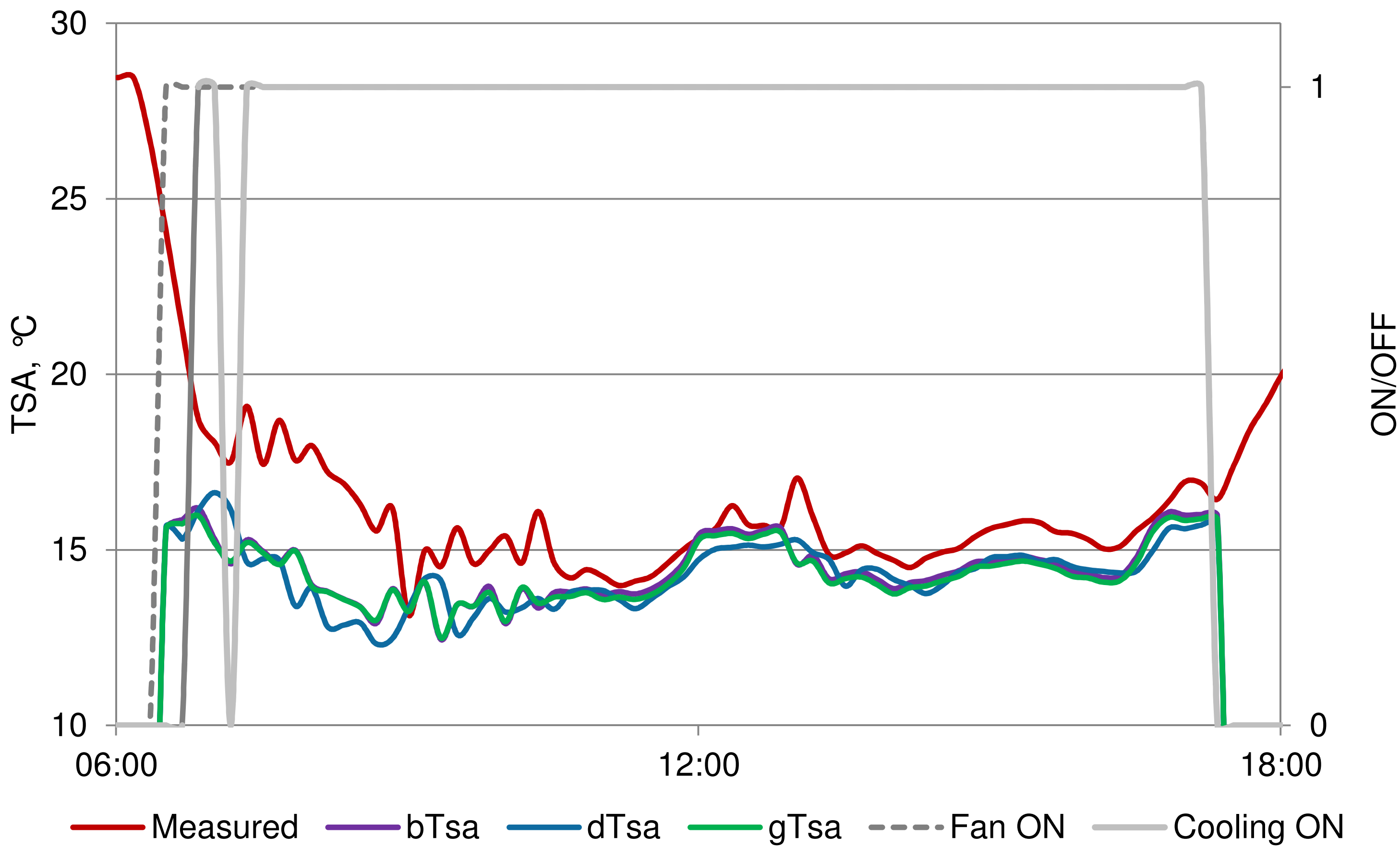

Figure 2. Virtual sensors output versus measured supply air temperature for AHU M3: 30 May 2013

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Conclusions

- Evaluation of different correlations for the development of self-correction HVAC controls for the complete failure of supply air temperature sensors in an air handling unit
- Testing of the approach in the air handling unit of an actual building
- Proof of concept for the development of additional algorithms for self-corrections and its impact on energy use in buildings

Future work

- Identify the size of the data set and which monitored data period should be used to develop the correlations
- Determine which data should be used for self-correction when it is not possible to identify and isolate the fault as soon as it occurs
- Develop more general algorithms that would cover the full range of operation, including heating and free cooling. This might require adding independent variables to be included in the correlations
- Identify robust statistical criterion for the selection of independent variables
- Explore the use of other model types, such as artificial neural network

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