LBNL Fault Detection and Diagnostics Data Sets: Dual Duct Air Handling Unit

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DISCLAIMER

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CONTACT INFORMATION

Website: https://faultdetection.lbl.gov/data/

Table of Contents

This documentation describes the curated dual duct air handling unit (DDAHU) fault detection and diagnostics data set (LBNL FDD Data Sets_DDAHU). In this documentation, the system information, data points specifications, and input scenarios for faulted and fault-free conditions represented in the data are detailed. The dataset and associated brick model ttl file can be downloaded from [https://faultdetection.lbl.gov/dataset/simulated-dd-ahu-dataset/.](https://faultdetection.lbl.gov/dataset/simulated-dd-ahu-dataset/)

1 Building and system information

1.1 System type and diagram

A dual-duct AHU is modeled in the HVACSIM+. Four dual duct variable air volume (VAV) terminal units are installed in four rooms (East B, South A, South B and West A) at the Energy Resource Station. The units are controlled by Johnson Control VMA-1420 controllers. The equipment configuration is illustrated in Figure 1.

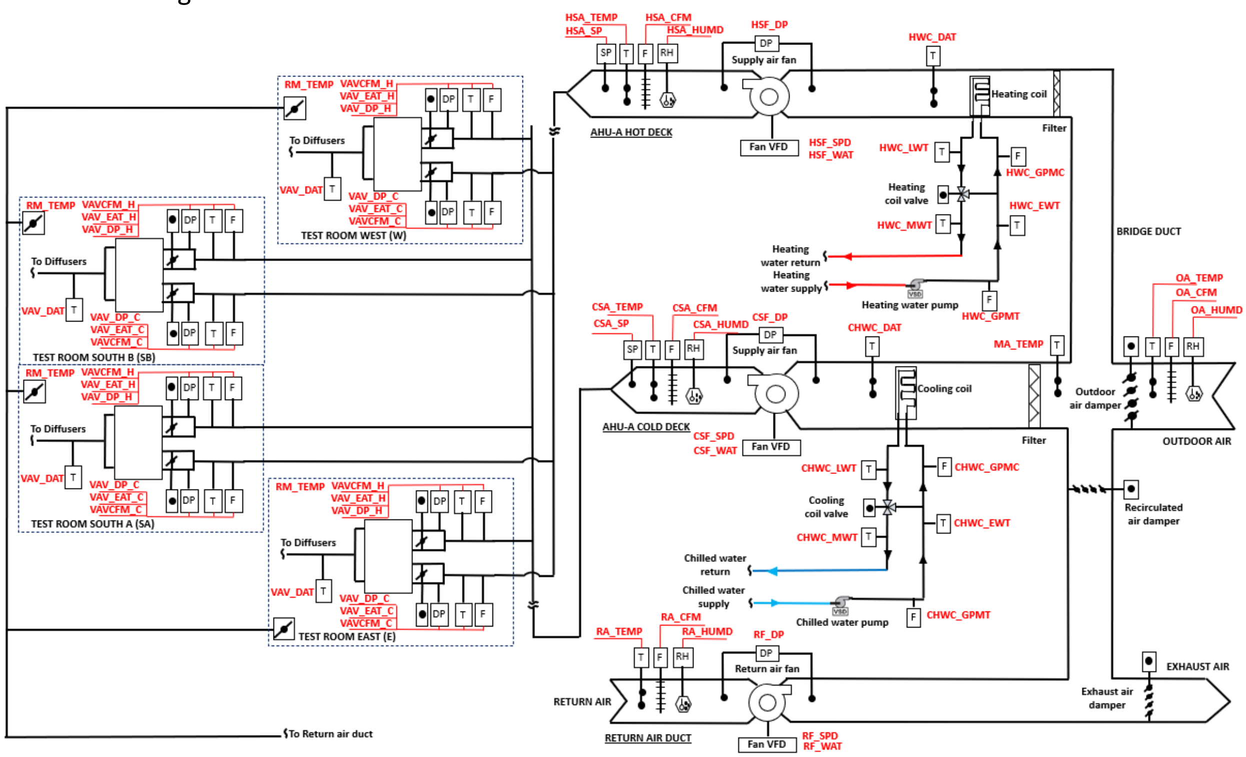

Figure 1 Schematic of a DDAHU system serving four perimeter zones (the meaning of point abbreviations is summarized in Table 2)

In the dual duct system, both hot and cold air flows are separately carried by two parallel duct systems respectively. The hot deck is equipped with a heating coil, and the cold deck is equipped with a cooling coil. The two decks run in a parallel configuration throughout the building. In a terminal unit, the proper proportions of hot and cold air streams are modulated by cold air and hot air dampers before proceeding downstream to space. The simultaneous availability of hot and cold air enriches the flexibility of this system to handle zones with widely varying loads. Meanwhile, energy could be saved by utilizing outside air directly as hot air or cold air in different seasons.

Similar to the single duct AHU system, in the dual-duct dual-fan AHU system, three types of equipment as dampers, fan and valve are controlled to maintain desired airflow rates and supply air temperature.

1.2 Description of control sequence

This section describes the control sequence settings. The control sequences were set according to the occupied hours and unoccupied hours.

1) Occupied hours (Mon-Fri 6:00AM-6:00PM)

During occupied hours, the system is operated in the operating mode. Five control sequences such as fan control, minimum outdoor air control**,** cold deck supply air temperature control, hot deck supply air temperature control, zone temperature control, and frozen prevention control were set during the simulation. Meanwhile, the minimum outdoor air control, cold deck supply air temperature control, hot deck supply air temperature control, and zone temperature control are enabled according to different dates in three seasons (i.e., the winter, the summer and the transition seasons) as illustrated in Table 1.

Table 1 Dates in three seasons

	Start date	**End date**
Winter	12/1	3/31
Transition (Spring)	4/1	5/31
Transition (Fall)	9/1	11/30
Summer	6/1	8/31

The control sequences are described below.

(i) Fan control

Two PI controllers are used to adjust the speed of the supply air fan (SAF) in the cold deck and hot deck to maintain the deck static pressure at the static pressure setpoint (1.6 in.wg.) through Varied Frequency Driver (VFD). The return air fan (RAF) speed is adjusted through a VFD to ensure the air flow rate matches the summation of airflow rate from the cold deck and the hot deck.

(ii) Minimum outdoor air control

In the summer season, the economizer mode is disabled, and the minimum requirement for the outdoor air (OA) damper position is set to be 28% openness.

In the winter and transition season, the economizer mode is enabled and the minimum requirement for the OA damper position is set to be 45% openness.

(iii) Cold deck supply air temperature control

In the summer season, the cooling coil valve position is adjusted to maintain 55 °F supply air temperature at the cold deck.

In the transition season, the valve position and the OA damper position are adjusted to maintain 55 °F supply air temperature at the cold deck in mechanical cooling and mechanical and economizer cooling modes, and maintain 60 °F supply air temperature at the cold deck in economizer cooling mode

When the OA temperature > 60 °F, the system is operated under the mechanical cooling mode. The cooling coil valve position is adjusted from 0% - 100% (OA damper at the minimum open position).

When the OA temperature < 60 °F and PI controller output is higher than 100, the system is operated under the mechanical and economizer cooling mode. The cooling coil valve position is adjusted from 0% - 100% (OA damper at 100% open position).

When the OA temperature < 60 °F and PI controller output is lower than 100, the system is operated under the economizer cooling mode, cooling coil valve position is fully closed (OA damper is adjusted between 0% to 100% open position).

In the winter season, the cooling coil valve is fully closed. The OA damper is adjusted between 0% to 100% open position to maintain 60 °F supply air temperature.

(iv) Hot deck supply air temperature control

In the summer season, the heating coil valve is fully closed.

In the winter season and the transition season, the heating coil valve is operated to provide 90 °F supply air at the hot deck when PI controller output is smaller than 0. Meanwhile, the OA damper is operated at the minimum open position.

(v) Zone temperature control

The controller determines the control mode, i.e., the heating mode, deadband mode, or the cooling mode by comparing the zone temperature to the active heating temperature setpoint and active cooling temperature setpoint. Figure 2 illustrates three control modes for VAV terminals. The room temperature setpoint for the four test rooms is constant during the test and is 68°F for heating setpoint and 72°F for cooling setpoint.

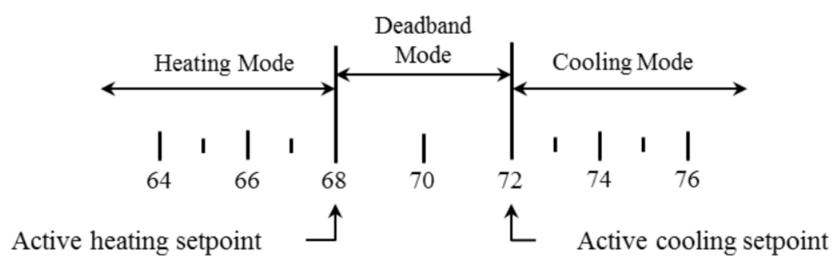

Figure 2 Control mode of VAV terminal (occupied mode)

The cold deck damper and the hot deck damper are controlled by the controller as described below.

(a) Cold deck damper control

The zone will call for cooling when the zone temperature equals or is greater than the active cooling temperature setpoint. Under this condition, the cold deck damper will modulate open in order to satisfy the space temperature setpoint (from 100 CFM to 1000 CFM).

When the zone calls heating, the cold deck damper will remain at its minimum position 10% (for 100 CFM)

(b) Hot deck damper control

The zone will call for heating when the zone temperature is equal to or less than the active heating temperature setpoint. Under this condition, the hot deck damper will modulate open in order to satisfy the space temperature setpoint (from 100 CFM to 400 CFM)

When the zone calls for cooling, the hot deck damper will remain at its minimum position 25% (for 100 CFM).

(vi) Frozen prevention control

This control sequence is used to protect the coils in the AHU when the outdoor air temperature is very low. When the AHU mixed air temperature is below 35°F and persists for 300 seconds, the system will be shut down (i.e., switch to the shutdown mode) to prevent freezing coils. The shutdown mode will last until the end of the current day, and the system will be turned back on at the beginning of the next day.

2) Unoccupied hours (Mon-Fri 6:00PM - 6:00AM, Sat-Sun 24-hour)

During unoccupied hours, the system is operated in the setback mode and the shutdown mode as described below.

(i) Setback mode

If the air temperature of one of the four zones is below the zone heating setpoint or above the zone cooling setpoint, the system will operate for 30 minutes. The system operation is similar to the occupied mode, except the following three conditions: (a) the zone cooling setpoint is 85 °F and the heating setpoint is 55 °F; (b) the economizer is disabled; and (c) the outdoor air (OA) damper is fully closed.

(ii) Shutdown mode

The system will switch to the shutdown mode when all zone temperatures are within the setpoints, or after being in setback mode for 30 minutes. In addition, the fans and the valves will stop operating. The zone airflow demand will be stopped.

2 Data point summary

A total of 114 data points (including 54 data points from the DDAHU and 60 data points from four associated VAV terminal units respectively) are included in the data sets. The data point descriptions are summarized in Table 2. In the table, the “Basic point” column indicates if the data point is commonly employed in the existing building automation system to monitor the system.

Table 2 Data points summary of the DDAHU system

NO.	Data Point Name	Description	Unit	Basic Points?
Dual Duct Air Handling Unit				
1	SYS_CTL	System control mode*	0-Shutdown; 1-Operate; 2-Setback	N
2	OA_CFM	Outdoor air flow rate	CFM	N

3	OA_DMPR	Outdoor air damper position signal	Open(0-1)	N
4	OA_DMPR_DM	Outdoor air damper control signal (command)	Open(0-1)	Y
5	OA_HUMD	Outdoor air humidity	%RH	N
6	OA_TEMP	Outdoor air temperature	°F	Y
7	MA_TEMP	Mixed air temperature	°F	Y
8	RA_CFM	Return air flow rate (sum of all zones returns)	CFM	N
9	RA_DMPR	Return air damper position signal	Open(0-1)	N
10	RA_DMPR_DM	Return air damper control signal	Open(0-1)	Y
11	RA_HUMD	Return air humidity	%RH	N
12	RA_TEMP	Return air temperature	°F	Y
13	RF_DP	Return fan differential pressure	in.w.g.	N
14	RF_SPD	Return fan VFD speed	Speed(0-1)	Y
15	RF_WAT	Return fan power	Watt	N
16	EA_DMPR	Exhaust air damper position signal	Open(0-1)	N
17	EA_DMPR_DM	Exhaust air damper control signal (command)	Open(0-1)	Y
18	HSA_SPSPT	Hot deck supply air duct static pressure setpoint	in.w.g.	Y
19	HSA_SP	Hot deck supply air duct static pressure	in.w.g.	Y
20	HSA_HUMD	Hot deck supply air humidity	%RH	N
21	HSA_CFM	Hot deck supply air flow rate	CFM	N
22	HSA_TEMPSPT	Hot deck supply air temperature setpoint	°F	Y
23	HSA_TEMP	Hot deck supply air temperature	°F	Y
24	HSF_CS	Hot deck supply fan status (On/Off)**	0-Off;1-On	Y
25	HSF_DP	Hot deck supply fan differential pressure	in.w.g.	Y
26	HSF_SPD	Hot deck supply fan VFD speed	Speed(0-1)	Y
27	HSF_WAT	Hot deck supply fan power	Watt	N
28	CSA_SPSPT	Cold deck supply air duct static pressure setpoint	in.w.g.	Y
29	CSA_SP	Cold deck supply air duct static pressure	in.w.g.	Y
30	CSA_HUMD	Cold deck supply air humidity	%RH	N
31	CSA_CFM	Cold deck supply air flow rate	CFM	N
32	CSA_TEMPSPT	Cold deck supply air temperature setpoint	°F	Y
33	CSA_TEMP	Cold deck supply air temperature	°F	Y
34	CSF_CS	Cold deck supply fan status (On/Off)**	0-Off;1-On	Y
35	CSF_DP	Cold deck supply fan differential pressure	in.w.g.	Y
36	CSF_SPD	Cold deck supply fan VFD speed	Speed(0-1)	Y
37	CSF_WAT	Cold deck supply fan power	Watt	N
38	HWC_DAT	Heating water coil discharge air temperature	°F	N
39	HWC_EWT	Heating water coil entering water temperature	°F	N
40	HWC_LWT	Heating water coil leaving water temperature	°F	N
41	HWC_MWT	Heating water coil mixed water temperature	°F	N
42	HWC_VLV	Heating water coil valve position signal	Open(0-1)	N
43	HWC_VLV_DM	Heating water coil valve control signal	Open(0-1)	Y
44	HWP_GPMC	Heating water pump water flow rate through coil	GPM	N
45	HWP_GPMT	Heating water pump total water flow rate	GPM	N
46	CHWC_DAT	Cooling coil discharge air temperature	°F	N
47	CHWC_EAH	Cooling coil entering air relative humidity	%RH	N

48	CHWC_EWT	Cooling coil entering water temperature	°F	N
49	CHWC_LWT	Cooling coil lLeaving water temperature	°F	N
50	CHWC_MWT	Cooling coil mixed water temperature	°F	N
51	CHWC_VLV	Cooling coil valve position signal	Open(0-1)	N
52	CHWC_VLV_DM	Cooling coil valve control signal	Open(0-1)	Y
53	CHWP_GPMC	Chilled water pump water flow rate through coil	GPM	N
54	CHWP_GPMT	Chilled water pump total water flow rate	GPM	N
Room (Room variables are followed by _W, _SB, _SA, _E, respectively):				
1	RM_TEMP	Room temperature	°F	Y
2	RMCLGSPT	Room cooling setpoint	°F	Y
3	RMHTGSPT	Room heating setpoint	°F	Y
4	VAV_DAT	Mixing box discharge air temperature	°F	N
5	VAV_SP_C	Mixing box cold deck dynamic pressure	in.w.g.	Y
6	VAV_SP_H	Mixing box hot deck dynamic pressure	in.w.g.	Y
7	VAV_DMPR_C	Mixing box cold deck control signal	Open(0-1)	Y
8	VAV_DMPR_H	Mixing box hot deck control signal	Open(0-1)	Y
9	VAVCFM_C_DM	Mixing box cold deck demanded air flow rate	CFM	N
10	VAVCFM_H_DM	Mixing box hot deck demanded air flow rate	CFM	N
11	VAVCFM_C	Mixing box cold deck air flow rate	CFM	N
12	VAVCFM_H	Mixing box hot deck air flow rate	CFM	N
13	VAVCFM_T	Mixing box total air flow rate	CFM	N
14	VAV_EAT_C	Mixing box cold deck entering air temperature	°F	N
15	VAV_EAT_H	Mixing box hot deck entering air temperature	°F	N

* In the data set, using 0 to represent 'Shutdown', 1 to represent 'Operate', and 2 to represent 'Setback'.
** In the data set, using 0 to represent 'Off', 1 to represent 'On'.

It is noted that, for sensor related faults (i.e., Zone air temperature sensor bias fault), the value of the faulty sensor logged is the faulty value.

A LBNL_FDD_Data_Sets_DDAHU.ttl file was also developed to present the data points and their relationships according to the Brick Schema[1] (version 1.2). Figure 3 shows the DDAHU data point relations created under the Brick schema model (version 1.2).

[1] Ref: Brick Schema website https://brickschema.org/ Access: May 01, 2022

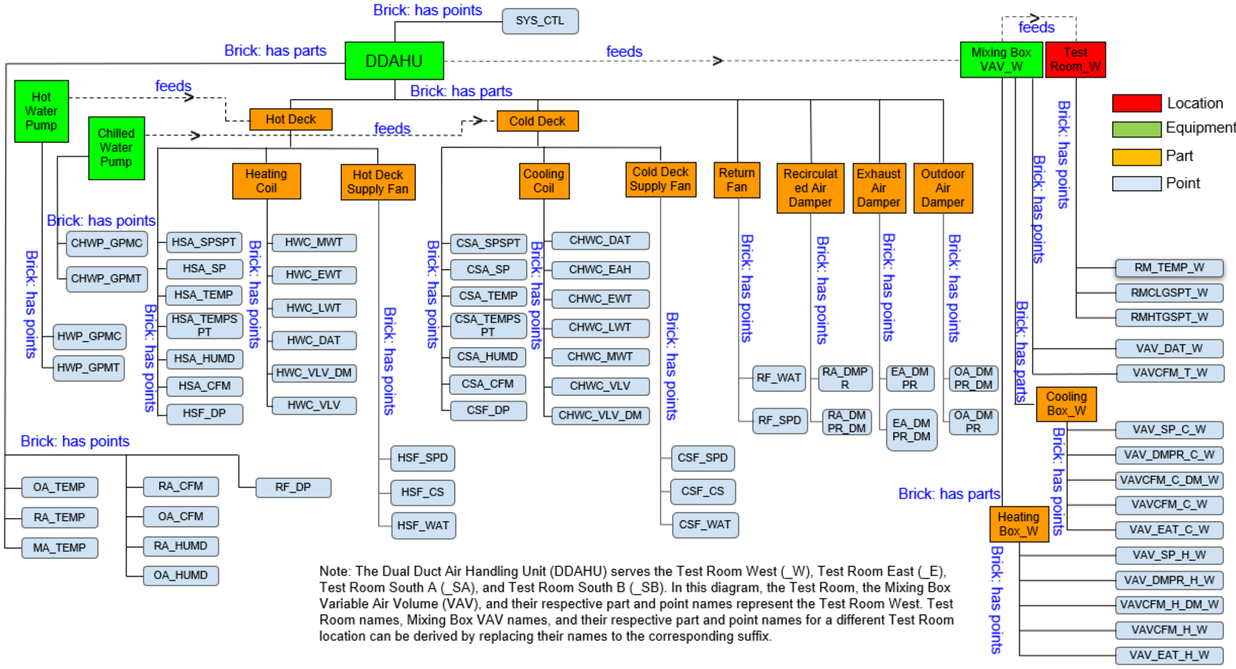

Figure 3 The schematic diagram of DDAHU Brick model

3 Faulty and fault-free scenarios

Faulty and fault-free scenarios included in the data set are shown in Table 3. There are a total of 55 faulted cases and 1 fault-free case. Each faulted case lasts for one year. The TMY weather data for Des Moines, IA is used as the weather inputs. The internal load density was varied to simulate a typical commercial building occupancy and was similar to those described in [1].

Table 3 Simulated input scenarios included in the dataset for the DDAHU system

Input scenarios		**Method of fault imposition**
Fault type	**Fault intensity**	
Heating coil fouling water-side	(1) Severe: increase water flow pressure resistance such that the water flow rate decreases by 50% when valve is fully open; decrease heat transfer rate by 50%; (2) Moderate: increase water flow pressure resistance such that the water flow rate decreases by 30% when valve is fully open; decrease heat transfer rate by 30%; (3) Minor: increase water flow pressure resistance such that the water flow rate decreases by 10% when valve is fully open; decrease heat transfer rate by 10%	Increase water flow pressure resistance; decrease heat transfer rate
Heating coil fouling air-side	(1) Severe: increase airflow resistance by 200%, decrease heat transfer rate by 10%; (2) Middle: increase airflow resistance by 50%, decrease heat transfer rate by 5%; (3) Minor: increase airflow resistance by 10%	Increase air flow pressure resistance; decrease heat transfer rate

Cooling coil fouling water-side	(1) Severe: increase water flow pressure resistance such that the water flow rate decreases by 50% when valve is fully open; decrease heat transfer rate by 50%; (2) Moderate: increase water flow pressure resistance such that the water flow rate decreases by 30% when valve is fully open; decrease heat transfer rate by 30%; (3) Minor: increase water flow pressure resistance such that the water flow rate decreases by 10% when valve is fully open; decrease heat transfer rate by 10%	Increase water flow pressure resistance; decrease heat transfer rate
Cooling coil fouling air-side	(1) Severe: increase airflow resistance by 200%, decrease heat transfer rate by 10%; (2) Middle: increase airflow resistance by 50%, decrease heat transfer rate by 5%; (3) Minor: increase airflow resistance by 10%	Increase air flow pressure resistance; decrease heat transfer rate
Cold deck supply air temperature sensor bias	-4°C, -2°C, +2°C, +4°C	Add bias to sensor output
Hot deck supply air temperature sensor bias	-4°C, -2°C, +2°C, +4°C	Add bias to sensor output
Cold deck supply air pressure sensor bias	-0.4, -0.2, +0.2, +0.4 in.wg	Add bias to sensor output
Hot deck supply air pressure sensor bias	-0.4, -0.2, +0.2, +0.4 in.wg	Add bias to sensor output
Cooling damper stuck	Fully open, fully closed, partial open at 20%, 50%, and 80% respectively	Assign a fixed simulated controlled device position
Heating damper stuck	Fully open, fully closed, partial open at 20%, 50%, and 80% respectively	Assign a fixed simulated controlled device position
Cooling coil valve stuck	Fully open, fully closed, partial open at 20%, 50%, and 80% respectively	Assign a fixed simulated controlled device position
Heating coil valve stuck	Fully open, fully closed, partial open at 20%, 50%, and 80% respectively	Assign a fixed simulated controlled device position
Outdoor air damper Stuck	Fully open, fully closed, partial open at 28%, 45%, and 80% respectively	Assign a fixed simulated controlled device position
Heating sequence unstable control	NA	Increase proportional band until unstable (-45.7K >>> -4K)
Cooling sequence unstable control	NA	increase proportional band until unstable (-45.7K >>> -4K)
Fault-free		NA

The data set is provided in a set of the csv files. Each .csv file represents one-year data of a fault with a specific fault intensity or a fault-free case. The data set uses 1-minute measurement frequency so the data sets can be converted into input samples of any time horizon larger than 1 minute. Table 4 lists the csv file description for each faulty case and fault-free case.

Table 4 File inventory

No.	File name	Fault description	Fault intensity
1	DualDuct_CoolSeqUnstable.csv	Cooling sequence unstable control	NA
2	DualDuct_HeatSeqUnstable.csv	Heating sequence unstable control	NA
3	DualDuct_DMPRStuck_Cold_0.csv	Cooling damper stuck	Stuck at 0%
4	DualDuct_DMPRStuck_Cold_20.csv	Cooling damper stuck	Stuck at 20%
5	DualDuct_DMPRStuck_Cold_50.csv	Cooling damper stuck	Stuck at 50%
6	DualDuct_DMPRStuck_Cold_80.csv	Cooling damper stuck	Stuck at 80%
7	DualDuct_DMPRStuck_Cold_100.csv	Cooling damper stuck	Stuck at 100%
8	DualDuct_DMPRStuck_Hot_0.csv	Heating damper stuck	Stuck at 0%
9	DualDuct_DMPRStuck_Hot_20.csv	Heating damper stuck	Stuck at 20%
10	DualDuct_DMPRStuck_Hot_50.csv	Heating damper stuck	Stuck at 50%
11	DualDuct_DMPRStuck_Hot_80.csv	Heating damper stuck	Stuck at 80%
12	DualDuct_DMPRStuck_Hot_100.csv	Heating damper stuck	Stuck at 100%
13	DualDuct_DMPRStuck_OA_0.csv	AHU OA damper stuck	Stuck at 0%
14	DualDuct_DMPRStuck_OA_28.csv	AHU OA damper stuck	Stuck at 20%
15	DualDuct_DMPRStuck_OA_45.csv	AHU OA damper stuck	Stuck at 50%
16	DualDuct_DMPRStuck_OA_80.csv	AHU OA damper stuck	Stuck at 80%
17	DualDuct_DMPRStuck_OA_100.csv	AHU OA damper stuck	Stuck at 100%
18	DualDuct_Fouling_Cooling_Airside_Minor.csv	Cooling coil fouling air-side	Minor
19	DualDuct_Fouling_Cooling_Airside_Moderate.csv	Cooling coil fouling air-side	Moderate
20	DualDuct_Fouling_Cooling_Airside_Severe.csv	Cooling coil fouling air-side	Severe
21	DualDuct_Fouling_Cooling_Waterside_Minor.csv	Cooling coil fouling water-side	Minor
22	DualDuct_Fouling_Cooling_Waterside_Moderate.csv	Cooling coil fouling water-side	Moderate
23	DualDuct_Fouling_Cooling_Waterside_Severe.csv	Cooling coil fouling water-side	Severe
24	DualDuct_Fouling_Heating_Airside_Minor.csv	Hydronic heating coil fouling air-side	Minor
25	DualDuct_Fouling_Heating_Airside_Moderate.csv	Hydronic heating coil fouling air-side	Moderate
26	DualDuct_Fouling_Heating_Airside_Severe.csv	Hydronic heating coil fouling air-side	Severe
27	DualDuct_Fouling_Heating_Waterside_Minor.csv	Hydronic heating coil fouling water-side	Minor
28	DualDuct_Fouling_Heating_Waterside_Moderate.csv	Hydronic heating coil fouling water-side	Moderate
29	DualDuct_Fouling_Heating_Waterside_Severe.csv	Hydronic heating coil fouling water-side	Severe
30	DualDuct_SensorBias_CSA_-2C.csv	Cold deck supply air temperature sensor bias	-2 °C
31	DualDuct_SensorBias_CSA_-4C.csv	Cold deck supply air temperature sensor bias	-4 °C

32	DualDuct_SensorBias_CSA_+2C.csv	Cold deck supply air temperature sensor bias	+2 °C
33	DualDuct_SensorBias_CSA_+4C.csv	Cold deck supply air temperature sensor bias	+4 °C
34	DualDuct_SensorBias_CSP_-2inwg.csv	Cold deck supply air pressure sensor bias	-2 in.wg
35	DualDuct_SensorBias_CSP_-4inwg.csv	Cold deck supply air pressure sensor bias	-4 in.wg
36	DualDuct_SensorBias_CSP_+2inwg.csv	Cold deck supply air pressure sensor bias	+2 in.wg
37	DualDuct_SensorBias_CSP_+4inwg.csv	Cold deck supply air pressure sensor bias	+4 in.wg
38	DualDuct_SensorBias_HSA_-2C.csv	Hot deck supply air temperature sensor bias	-2 °C
39	DualDuct_SensorBias_HSA_-4C.csv	Hot deck supply air temperature sensor bias	-4 °C
40	DualDuct_SensorBias_HSA_+2C.csv	Hot deck supply air temperature sensor bias	+2 °C
41	DualDuct_SensorBias_HSA_+4C.csv	Hot deck supply air temperature sensor bias	+4 °C
42	DualDuct_SensorBias_HSP_-2inwg.csv	Hot deck supply air pressure sensor bias	-2 in.wg
43	DualDuct_SensorBias_HSP_-4inwg.csv	Hot deck supply air pressure sensor bias	-4 in.wg
44	DualDuct_SensorBias_HSP_+2inwg.csv	Hot deck supply air pressure sensor bias	+2 in.wg
45	DualDuct_SensorBias_HSP_+4inwg.csv	Hot deck supply air pressure sensor bias	+4 in.wg
46	DualDuct_VLVStuck_Cooling_0%.csv	Cooling coil valve stuck	Stuck at 0%
47	DualDuct_VLVStuck_Cooling_20%.csv	Cooling coil valve stuck	Stuck at 20%
48	DualDuct_VLVStuck_Cooling_50%.csv	Cooling coil valve stuck	Stuck at 50%
49	DualDuct_VLVStuck_Cooling_80%.csv	Cooling coil valve stuck	Stuck at 80%
50	DualDuct_VLVStuck_Cooling_100%.csv	Cooling coil valve stuck	Stuck at 100%
51	DualDuct_VLVStuck_Heating_0%.csv	Heating coil valve stuck	Stuck at 0%
52	DualDuct_VLVStuck_Heating_20%.csv	Heating coil valve stuck	Stuck at 20%
53	DualDuct_VLVStuck_Heating_50%.csv	Heating coil valve stuck	Stuck at 50%
54	DualDuct_VLVStuck_Heating_80%.csv	Heating coil valve stuck	Stuck at 80%
55	DualDuct_VLVStuck_Heating_100%.csv	Heating coil valve stuck	Stuck at 100%
56	DualDuct_FaultFree.csv	Fault free	NA

References

[1] Jin Wen, Shokouh Pourarian, Xuebin Yang and Xiwang Li. NIST 10D243 Tools for Evaluating Fault Detection and Diagnostic Methods for HVAC Secondary Systems of a Net Zero Building. National Institute of Standard & Technology. U.S. June 2015