LBNL Fault Detection and Diagnostics Data Sets: Fan Power Unit

Jessica Granderson, Guanjing Lin, Yimin Chen, Armando Casillas

Lawrence Berkeley National Laboratory

Jin Wen, Zhelun Chen

Drexel University

U.S. Department of Energy, Building Technologies Office

September 1, 2022

Please cite as:
Lawrence Berkeley National Laboratory, LBNL FDD Data Sets. DOI: https://dx.doi.org/10.25984/1881324

DISCLAIMER

ACKNOWLEDGEMENT

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Office, of the U.S. Department of Energy (DOE) under Contract No. DE-AC02-05CH11231. The authors thank all data providers and partners who helped to develop and evaluate the data sets.

CONTACT INFORMATION

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

Table of Contents

This documentation describes the curated fan power unit fault detection and diagnostics data sets (LBNL FDD Data Sets_FPU). 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-pfpu-sfpu/.

1 Building and system information

1.1 System type and diagram

The test data was generated by simulating a variable air volume (VAV) heating ventilation and air condition system (HVAC) system. In the system, an air handling unit (AHU) and four associated fan powered VAV terminal units in (FPU) (four parallel FPUs (PFPU) or four series FPUs (SFPU)) in four speratae zones were simulated in the HVACSIM+ software tool. Figures 1 and 2 illustrate the PFPU and the SFPU configuration and data point diagram respectively.

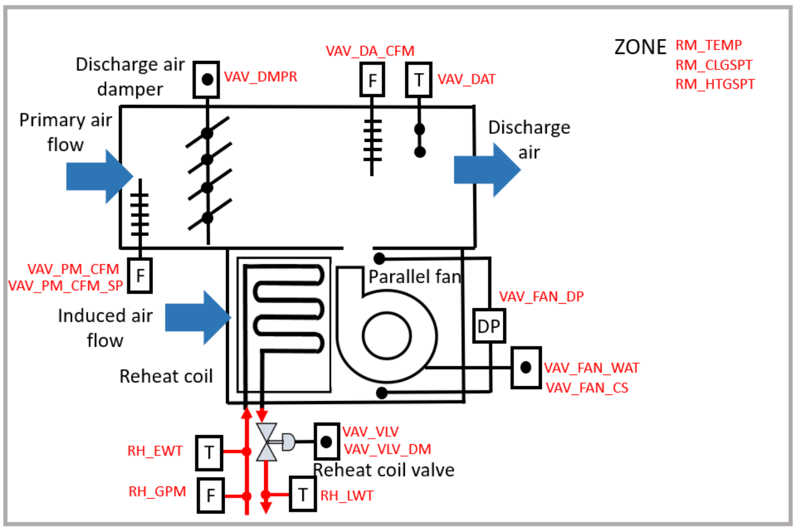

Figure 1 Schematic of a PFPU (the meaning of point abbreviations is summarized in Table 1)

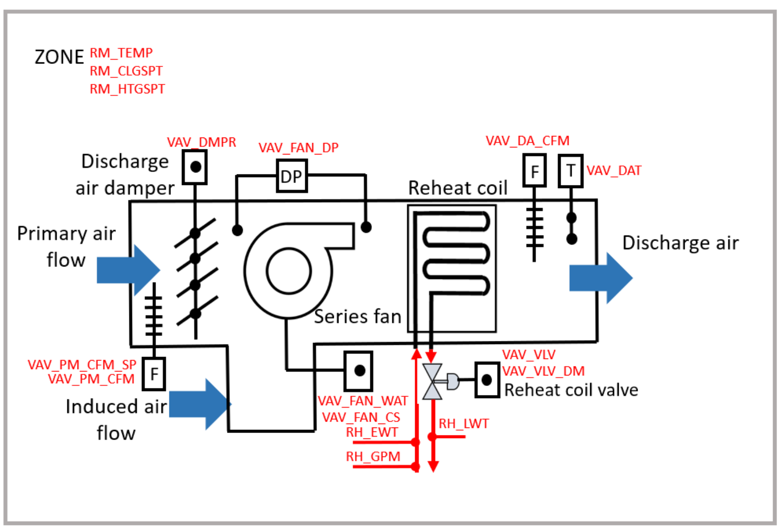

Figure 2 Schematic of a SFPU (the meaning of point abbreviations is summarized in Table 1)

Figure 3 shows the configuration and data points in the upstream AHU.

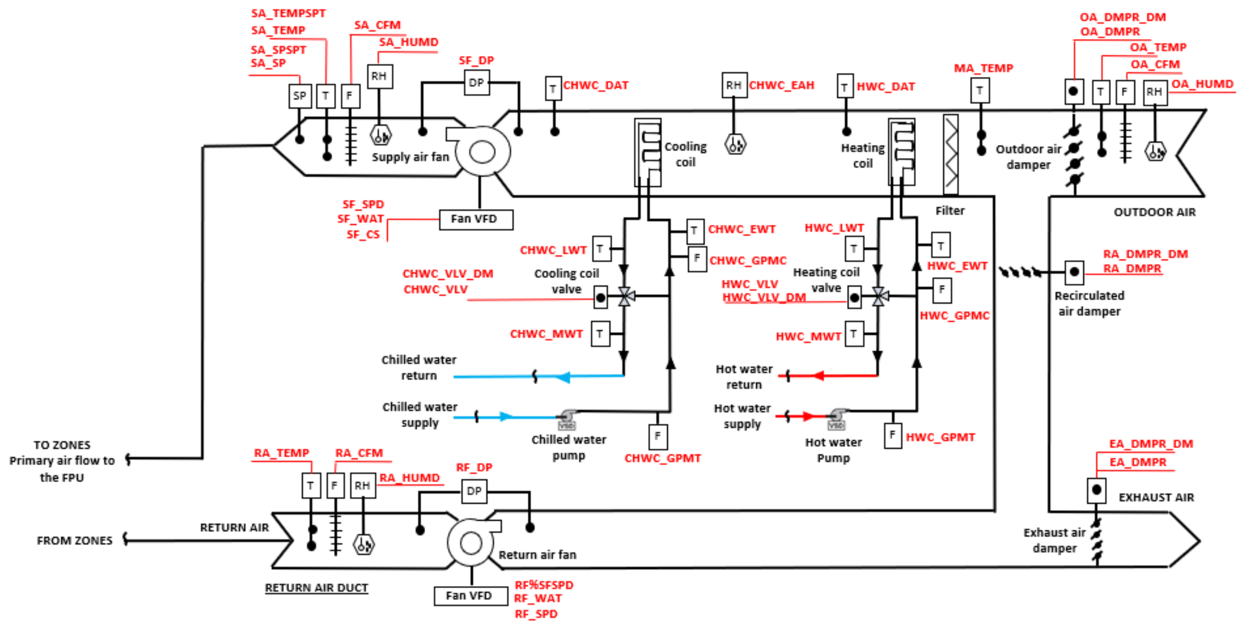

Figure 3 Schematic of the upstream AHU (the meaning of point abbreviations is summarized in Table 1)

1.2 Description of control sequence

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

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

During these hours, the system is in the operating mode**.** Four control sequences (i.e., AHU fan control, AHU supply air temperature control, terminal (zone temperature) control, and low temperature protection), were set for the AHU and for the FPU respectively during the simulation.

(i) AHU fan control

Under this control sequence, a PI controller is used to adjust the speed of the supply air fan (SAF) to maintain the static pressure at the static pressure setpoint through the Varied Frequency Driver (VFD). The static pressure setpoint for the PFPU system and SFPU system are:

- PFPU: 1.40+/-0.13 in.w.g
- SFPU: 0.7+/-0.13 in.w.g

In addition, the return air fan (RAF) is under the speed tracking mode in which the return fan speed is 80% of the supply fan speed.

(ii) AHU supply air temperature control

This control sequence used to maintain supply air temperature at supply air temperature setpoint is divided into four control regions, namely, mechanical cooling, mechanical and economizer cooling, economizer cooling, and mechanical heating, as shown in Figure 4. In the figure, each operating model region depends on whether or not the outdoor air temperature is higher or lower than a reference temperature (i.e., 60 °F), and whether the supply air temperature is above or below its setpoints.

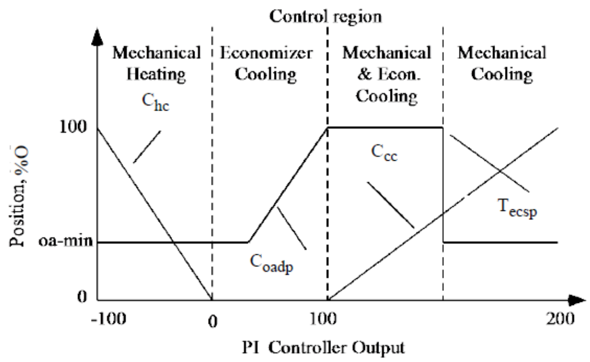

Figure 4 AHU supply air temperature control sequence

Under this control sequence, the heating and cooling valves positions, as well as the OA damper position are adjusted to maintain the supply air temperature to be 55 °F. The minimum OA damper position is set to be 40% openness.

When the AHU provides cooling, the PI controller output is higher than 0. With the 60 °F economizer temperature setpoint, the following cooling modes are available:

(a) When the OA temperature is higher than 60 °F, the AHU is operated under the mechanical cooling mode. The cooling coil valve position is adjusted from 0% - 100% (OA damper at the minimum open position) to maintain the supply air temperature setpoint.
(b) When the OA temperature is lower than 60 °F and the PI loop output is higher than 100, the AHU is operated under the mechanical and economizer cooling mode. The cooling coil valve position is adjusted from 0% - 100%. The OA damper is controlled at 100% open position
(c) When the OA temperature is lower than 60 °F and PI loop output is lower than 100, the AHU is operated under the economizer cooling mode. The cooling coil valve position is fully closed. The OA damper is adjusted between 0% to 100% open position to provide the desired supply air temperature.

When the AHU provides heating, the PI controller output is lower than 0.

(iii) Terminal (zone temperature) control

Two control sequences are used to control the FPU and SFPU respectively as illustrated in Figure 5 and Figure 6. In this simulation, the cooling setpoint (Tc,spt) (i.e., the cooling setpoint) and the heating setpoint (Th,spt) are 72 °F and 68 °F, respectively. Both the PFPU and the SFPU use two PI control loops. The first PI loop determines the required reheat coil valve position (VLV) and FPU airflow setpoint

(CFMspt). The second PI control loop determines the demand damper motor speed (DMPRmotor). For both FPUs, the minimum airflow setpoint (CFMmin) is set to be 200 CFM. The maximum airflow (CFMmax) for the internal zone served by both systems is set to be 400 CFM. The CFMmax for perimeter zones served by the parallel FPU and the series FPU are 700 CFM and 1000 CFM respectively.

The PI output of the first control loop (PI_1) is, $u1 = max\ (k_{p1}\epsilon_1 + k_i \int \quad \epsilon_1, 0)$, where ϵ_1 is equal to Th,spt-Tzone for heating, and Tzone-Tc,spt for cooling.

The PI output of the second control loop (PI_2) is, $u2 = k_{p2}\epsilon_2$, where ϵ_2 is equal to the difference between the airflow setpoint and the measured airflow value (i.e., CFMspt- CFMact). The calculated u2 will be sent to the damper driver (DMPRmotor) to control the damper position.

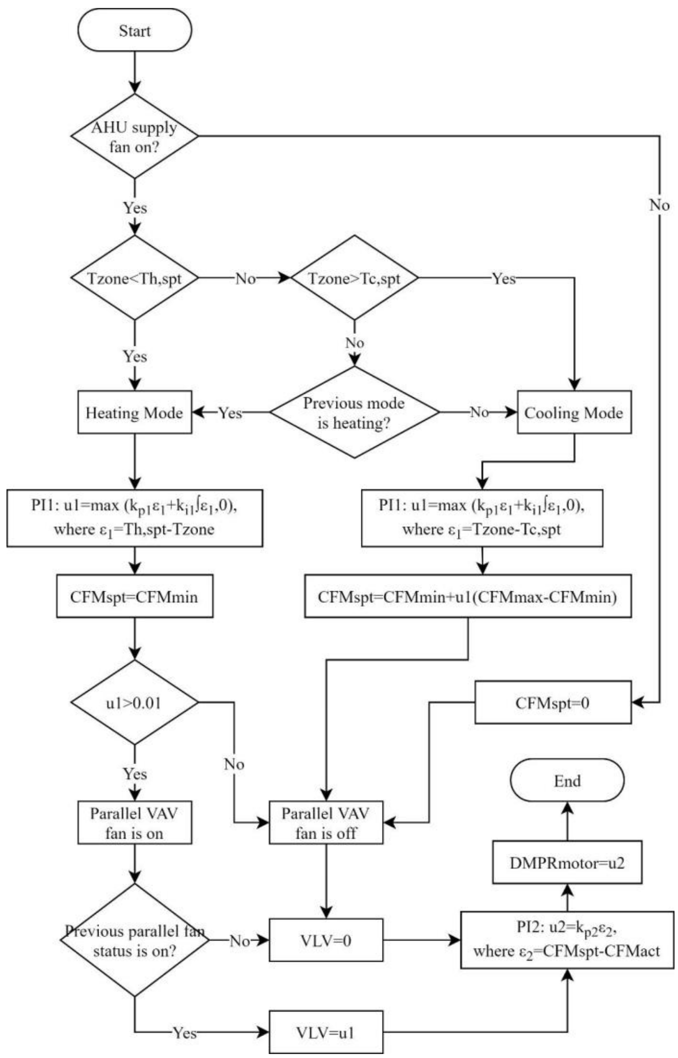

Figure 5 Parallel FPU control logic

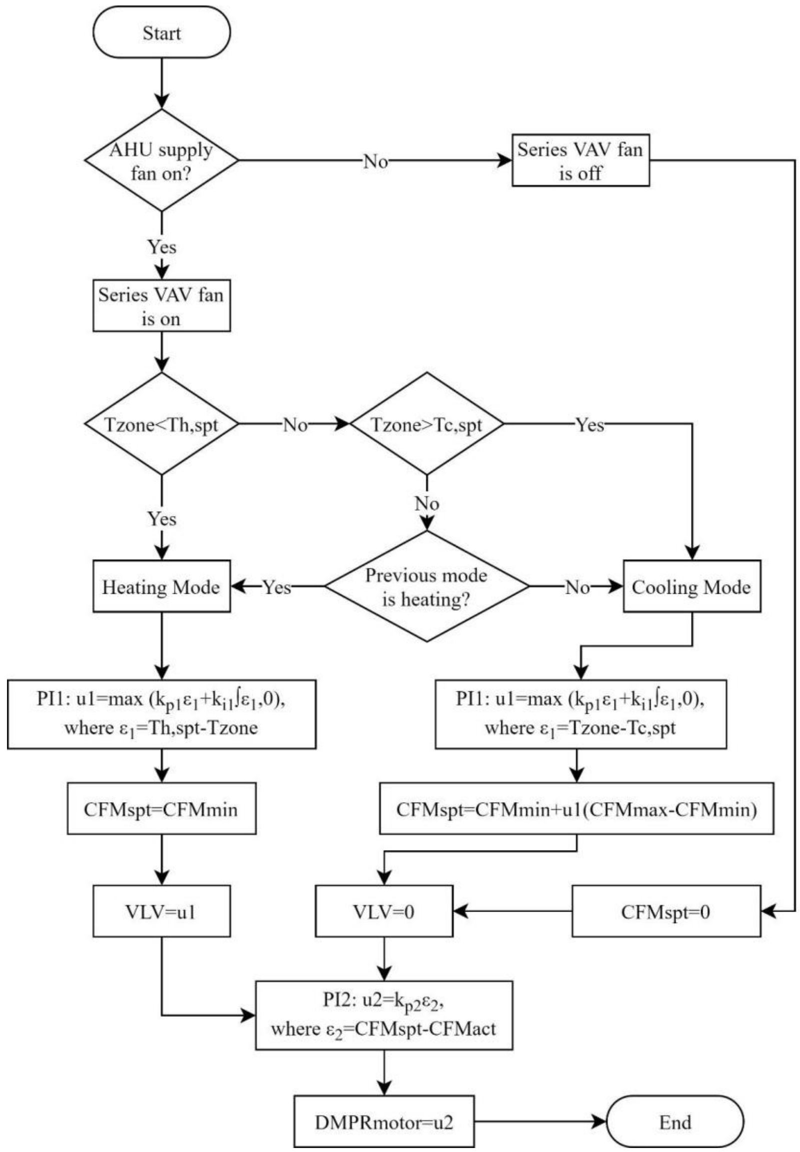

Figure 6 Series FPU control logic

(iv) Low temperature protection

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 109 data points (i.e., 64 data points for four FPUs and 45 data points for the AHU respectively) are included in the data sets. The data point descriptions are summarized in Table 1. 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 1 Data points summary of the FPU

No.	Data Point Name	Description	Unit	Basic Points?
Room variables followed by zone identifier _I, _W, _S, _E, respectively				
1	RM_TEMP	Room temperature	°F	Y
2	RMCLGSPT	Room cooling setpoint	°F	Y
3	RMHTGSPT	Room heating setpoint	°F	Y
4	RH_VLV	Reheating coil valve position	Open(0-1)	N
5	RH_VLV_DM	Reheating coil valve position control signa (command)	Open(0-1)	Y
6	RH_GPM	Reheating coil water flow rate	GPM	N
7	RH_EWT	Reheating coil entering water temperature	°F	N
8	RH_LWT	Reheating coil leaving water temperature	°F	N
9	VAV_DAT	VAV discharge air temperature	°F	N
10	VAV_DMPR	VAV damper position	Open(0-1)	N
11	VAV_PM_CFM_SP	VAV primary air flow rate setpoint	CFM	N
12	VAV_PM_CFM*	VAV primary air flow rate	CFM	N
13	VAV_DA_CFM*	VAV discharge air flow rate	CFM	N
14	VAV_FAN_CS	VAV fan status (On/Off)**	0-Off;1-On	Y
15	VAV_FAN_DP	VAV fan differential pressure	in.w.g.	Y
16	VAV_FAN_WAT	VAV fan power	Watt	N
Air Handling Unit				
1	SYS_CTL	System control mode (Operate/Setback/Shutdown)*	0-Shutdown;1-Operate; 2-Setback	Y
2	OA_CFM	Outdoor air flow rate	CFM	Y

3	OA_DMPR	Outdoor air damper position	Open(0-1)	N
4	OA_DMPR_DM	Outdoor air damper position control signal (command)	Open(0-1)	Y
5	OA_HUMD	Outdoor air humidity	°F	N
6	OA_TEMP	Outdoor air temperature	°F	Y
7	MA_TEMP	Mixed air temperature	°F	Y
8	RA_CFM	Recirculated air flow rate	CFM	N
9	RA_DMPR	Recirculated air damper position	Open(0-1)	N
10	RA_DMPR_DM	Recirculated air damper position control signal (command)	Open(0-1)	Y
11	RA_HUMD	Return air humidity	%RH	N
12	RA_TEMP	Return air temperature	°F	Y
13	RF%SFSPD	Return fan % of supply fan speed	Speed(0-1)	Y
14	RF_DP	Return fan differential pressure	in.w.g.	N
15	RF_SPD	Return fan VFD speed	Speed(0-1)	Y
16	RF_WAT	Return fan power	Watt	N
17	EA_DMPR	Exhaust air damper position	Open(0-1)	N
18	EA_DMPR_DM	Exhaust air damper control signal (command)	Open(0-1)	Y
19	SA_SPSPT	Supply air duct static pressure setpoint	in.w.g.	Y
20	SA_SP	Supply air duct static pressure	in.w.g.	Y
21	SA_HUMD	Supply air humidity	%RH	N
22	SA_CFM	Supply air flow rate	CFM	N
23	SA_TEMPSPT	Supply air temperature setpoint	°F	Y
24	SA_TEMP	Supply air temperature	°F	Y
25	SF_CS	Supply fan status (On/Off)**	0-Off;1-On	Y
26	SF_DP	Supply fan differential pressure	in.w.g.	Y
27	SF_SPD	Supply fan VFD speed	Speed(0-1)	Y
28	SF_WAT	Supply fan power	Watt	N
29	HWC_DAT	Heating water coil discharge air temperature	°F	N
30	HWC_EWT	Heating water coil entering water temperature	°F	N
31	HWC_LWT	Heating water coil leaving water temperature	°F	N
32	HWC_MWT	Heating water coil mixed water temperature	°F	N
33	HWC_VLV	Heating water coil valve position	Open(0-1)	N
34	HWC_VLV_DM	Heating water coil valve control signal (command)	Open(0-1)	Y
35	HWP_GPMC	Heating water pump water flow rate through coil	GPM	N
36	HWP_GPMT	Heating water pump total water flow rate	GPM	N
37	CHWC_DAT	Cooling coil discharge air temperature	°F	N
38	CHWC_EAH	Cooling coil entering air relative humidity	%RH	N
39	CHWC_EWT	Cooling coil entering water temperature	°F	N

40	CHWC_LWT	Cooling coil leaving water temperature	°F	N
41	CHWC_MWT	Cooling coil mixed water temperature	°F	N
42	CHWC_VLV	Cooling coil valve position	Open(0-1)	N
43	CHWC_VLV_DM	Cooling coil valve control signal (command)	Open(0-1)	Y
44	CHWP_GPMC	Chilled water pump water flow rate through coil	GPM	N
45	CHWP_GPMT	Chilled water pump total water flow rate	GPM	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', and 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.

Two .ttl files, including the LBNL_FDD_Data_Sets_PFPU_ttl.ttl file and LBNL_FDD_Data_Sets_SFPU_ttl.ttl file, were developed to present the data points and their relationships according to the Brick Schema[1](version 1.2). Figure 3 shows the FPU data point relations created under the Brick schema model (version 1.2)[2].

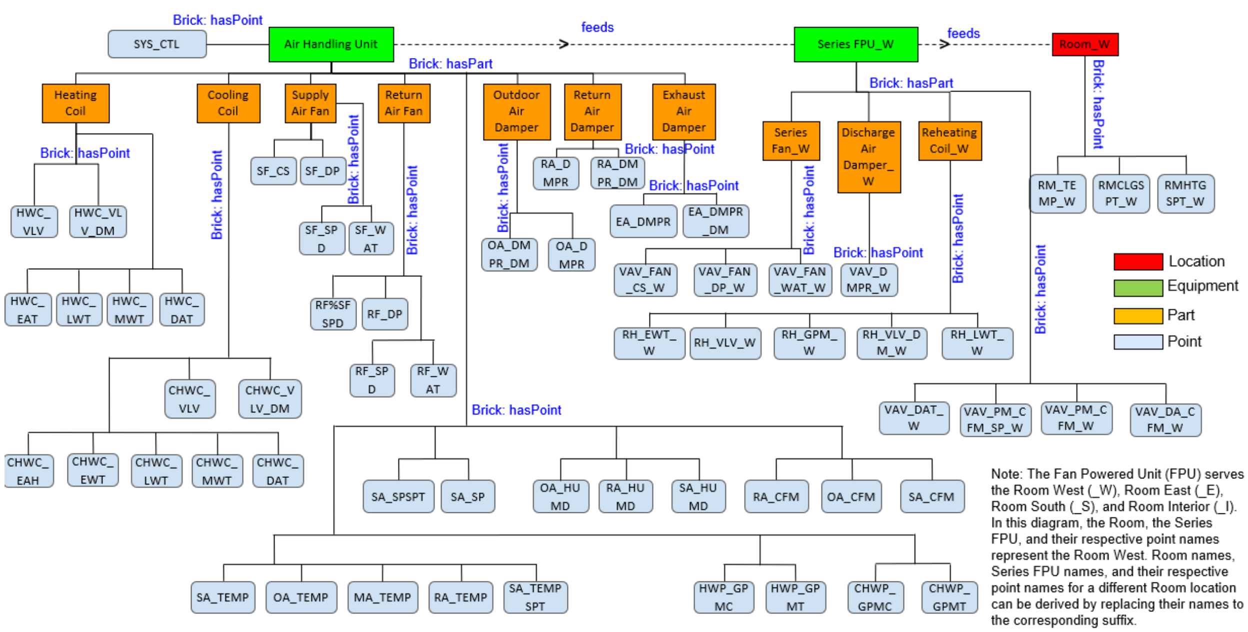

Figure 7 The schematic diagram of FPU Brick model

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

[2] The brick schema model is the same for the PFPU and SFPU. Therefore, we only present one model.

3 Faulty and fault-free scenarios

For the PFPU and SFPU systems, the fault was performed in the PFPU and SFPU in the **west zone** (i.e., one FPU out of four FPUs was imposed faults and its variables are followed by zone identifier _W). Faulty and fault-free scenarios included in the data set are shown in Table 2. There are a total of 30 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 2 Simulated input scenarios included in the dataset for fan coil unit

Input scenarios		**Method of fault imposition**
Fault type	**Fault intensity**	
Room temperature sensor bias	-4°C, -2°C, +2°C, +4°C	Add a bias to the sensor output
VAV airflow sensor bias	-400CFM, -200CFM, +200CFM, +400CFM	Add a bias to the sensor output
VAV box fan restricted flow	Increase plenum resistance (for PFPU) or VAV outlet resistance (for SFPU)	Increase FPU resistance to 1000% of normal value
Hydronic reheat coil fouling water-side*	Severe, moderate and minor	(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%
Hydronic reheat coil fouling air-side**	Severe, moderate and minor	(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%
Reheat valve stuck	Full open, full closed, partial open at 20%, 50%, and 80%	Assign a fixed simulated controlled device position
Reheat valve leaking	20%, 50%, 80% of the max flow	Assign a 20%, 50%, 80% of the max flow.
VAV damper stuck	Full open, full closed, partial open at 20%, 50%, and 80%	Assign a fixed simulated controlled device position

Room air temperature control sequence unstable (PI1)	100 to 0.1 (for the PFPU) 30 to 0.3 (for the SFPU)	Decrease proportional band (increase controller gain kp) until unstable
Room VAV damper control (PI2)	9.99 to 99999	Increase controller gain kp until unstable
Fault-free		NA

*The severity levels of the coil water-side fouling are determined based on [2].
*The severity levels of the coil air-side fouling are determined based on [3, 4].
***The reheat coil max flow is 0.38kg/s for parallel FPU, and 0.236kg/s for series FPU.

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 3 and Table 4 list the csv file description for each faulty case and fault-free case.

Table 3 PFPU data file inventory

No.	Fault file name	Fault type	Fault intensity
1	PFPU_ReheatCoilFouling_Airside_Minor.csv	Hydronic reheat coil fouling air-side	Minor
2	PFPU_ReheatCoilFouling_Airside_Moderate.csv	Hydronic reheat coil fouling air-side	Moderate
3	PFPU_ReheatCoilFouling_Airside_Severe.csv	Hydronic reheat coil fouling air-side	Severe
4	PFPU_ReheatCoilFouling_Waterside_Minor.csv	Hydronic reheat coil fouling water-side	Minor
5	PFPU_ReheatCoilFouling_Waterside_Moderate.csv	Hydronic reheat coil fouling water-side	Moderate
6	PFPU_ReheatCoilFouling_Waterside_Severe.csv	Hydronic reheat coil fouling water-side	Severe
7	PFPU_ReheatVLVLeak_20%MaxFlow.csv	Reheat valve leaking	Leakage at 20%
8	PFPU_ReheatVLVLeak_50%MaxFlow.csv	Reheat valve leaking	Leakage at 50%
9	PFPU_ReheatVLVLeak_80%MaxFlow.csv	Reheat valve leaking	Leakage at 80%
10	PFPU_ReheatVLVStuck_0%.csv	Reheat valve stuck	Stuck at 0%
11	PFPU_ReheatVLVStuck_20%.csv	Reheat valve stuck	Stuck at 20%
12	PFPU_ReheatVLVStuck_50%.csv	Reheat valve stuck	Stuck at 50%
13	PFPU_ReheatVLVStuck_80%.csv	Reheat valve stuck	Stuck at 80%
14	PFPU_ReheatVLVStuck_100%.csv	Reheat valve stuck	Stuck at 100%
15	PFPU_RMTEMPUnstable.csv	Room air temperature control sequence unstable (PI1)	NA
16	PFPU_SensorBias_RMTEMP_-2C.csv	Room temperature sensor bias	-2°C
17	PFPU_SensorBias_RMTEMP_-4C.csv	Room temperature sensor bias	-4°C
18	PFPU_SensorBias_RMTEMP_+2C.csv	Room temperature sensor bias	+2°C
19	PFPU_SensorBias_RMTEMP_+4C.csv	Room temperature sensor bias	+4°C
20	PFPU_SensorBias_VAVAirflow_-200CFM.csv	VAV airflow sensor bias	-200CFM
21	PFPU_SensorBias_VAVAirflow_-400CFM.csv	VAV airflow sensor bias	-400CFM

22	PFPU_SensorBias_VAVAirflow_+200CFM.csv	VAV airflow sensor bias	+200CFM
23	PFPU_SensorBias_VAVAirflow_+400CFM.csv	VAV airflow sensor bias	+400CFM
24	PFPU_VAVDMPRStuck_0%.csv	VAV damper stuck	Stuck at 0%
25	PFPU_VAVDMPRStuck_20%.csv	VAV damper stuck	Stuck at 20%
26	PFPU_VAVDMPRStuck_50%.csv	VAV damper stuck	Stuck at 50%
27	PFPU_VAVDMPRStuck_80%.csv	VAV damper stuck	Stuck at 80%
28	PFPU_VAVDMPRStuck_100%.csv	VAV damper stuck	Stuck at 100%
29	PFPU_VAVDMPRUnstable.csv	Room VAV damper control (PI2)	NA
30	PFPU_VAVFanRestrictFlow.csv	VAV box fan restricted flow	NA
31	PFPU_FaultFree.csv	Fault free	NA

Table 4 SFPU data file inventory

No.	Fault file name	Fault type	Fault intensity
1	SFPU_ReheatCoilFouling_Airside_Minor.csv	Hydronic reheat coil fouling air-side	Minor
2	SFPU_ReheatCoilFouling_Airside_Moderate.csv	Hydronic reheat coil fouling air-side	Moderate
3	SFPU_ReheatCoilFouling_Airside_Severe.csv	Hydronic reheat coil fouling air-side	Severe
4	SFPU_ReheatCoilFouling_Waterside_Minor.csv	Hydronic reheat coil fouling water-side	Minor
5	SFPU_ReheatCoilFouling_Waterside_Moderate.csv	Hydronic reheat coil fouling water-side	Moderate
6	SFPU_ReheatCoilFouling_Waterside_Severe.csv	Hydronic reheat coil fouling water-side	Severe
7	SFPU_ReheatVLVLeak_20%MaxFlow.csv	Reheat valve leaking	Leakage at 20%
8	SFPU_ReheatVLVLeak_50%MaxFlow.csv	Reheat valve leaking	Leakage at 50%
9	SFPU_ReheatVLVLeak_80%MaxFlow.csv	Reheat valve leaking	Leakage at 80%
10	SFPU_ReheatVLVStuck_0%.csv	Reheat valve stuck	Stuck at 0%
11	SFPU_ReheatVLVStuck_20%.csv	Reheat valve stuck	Stuck at 20%
12	SFPU_ReheatVLVStuck_50%.csv	Reheat valve stuck	Stuck at 50%
13	SFPU_ReheatVLVStuck_80%.csv	Reheat valve stuck	Stuck at 80%
14	SFPU_ReheatVLVStuck_100%.csv	Reheat valve stuck	Stuck at 100%
15	SFPU_RMTEMPUnstable.csv	Room air temperature control sequence unstable (PI1)	NA
16	SFPU_SensorBias_RMTEMP_-2C.csv	Room temperature sensor bias	-2°C
17	SFPU_SensorBias_RMTEMP_-4C.csv	Room temperature sensor bias	-4°C
18	SFPU_SensorBias_RMTEMP_+2C.csv	Room temperature sensor bias	+2°C
19	SFPU_SensorBias_RMTEMP_+4C.csv	Room temperature sensor bias	+4°C
20	SFPU_SensorBias_VAVAirflow_-200CFM.csv	VAV airflow sensor bias	-200CFM
21	SFPU_SensorBias_VAVAirflow_-400CFM.csv	VAV airflow sensor bias	-400CFM
22	SFPU_SensorBias_VAVAirflow_+200CFM.csv	VAV airflow sensor bias	+200CFM

23	SFPU_SensorBias_VAVAirflow_+400CFM.csv	VAV airflow sensor bias	+400CFM
24	SFPU_VAVDMPRStuck_0%.csv	VAV damper stuck	Stuck at 0%
25	SFPU_VAVDMPRStuck_20%.csv	VAV damper stuck	Stuck at 20%
26	SFPU_VAVDMPRStuck_50%.csv	VAV damper stuck	Stuck at 50%
27	SFPU_VAVDMPRStuck_80%.csv	VAV damper stuck	Stuck at 80%
28	SFPU_VAVDMPRStuck_100%.csv	VAV damper stuck	Stuck at 100%
29	SFPU_VAVDMPRUnstable.csv	Room VAV damper control (PI2)	NA
30	SFPU_VAVFanRestrictFlow.csv	VAV box fan restricted flow	NA
31	SFPU_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

[2] K. Nae-Hyun and R. L. Webb, "Particulate fouling of water in tubes having a two-dimensional roughness geometry," *International journal of heat and mass transfer,* vol. 34, no. 11, pp. 2727-2738, 1991

[3] B. C. Pak, E. A. Groll, and J. E. Braun, "Impact of Fouling and Cleaning on Plate Fin and Spine Fin Heat Exchanger Performance," *ASHRAE Transactions,* vol. 111, no. 1, 2005.

[4] I. H. Bell and E. A. Groll, "Air-side particulate fouling of microchannel heat exchangers: experimental comparison of air-side pressure drop and heat transfer with plate-fin heat exchanger," *Applied Thermal Engineering,* vol. 31, no. 5, pp. 742-749, 2011.