LLBNL Fault Detection and Diagnostics Data Sets: Boiler Plant

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CONTACT INFORMATION

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

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This documentation describes the curated boiler plant fault detection and diagnostics data set (LBNL FDD Data Sets_Boiler Plant). 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-boiler-plant/

1 - Building and system information

1.1 System type and diagram

The studied system is a boiler plant that provides hot water to a typical large office, as illustrated in Figure 1. This office building consists of twelve floors with each floor served by one air handling unit (AHU). Each AHU serves five thermal zones, with individual zones having a dedicated VAV terminal unit with a reheat coil that uses hot water produced by the boiler plant.

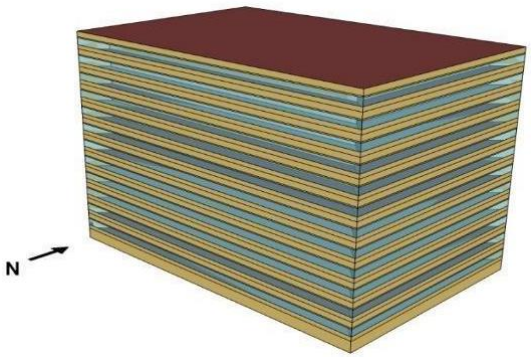

Figure 1 Studied large office building

Figure 2 illustrates the configuration of the boiler plant system. This system has two identical boilers and two hot water pumps and provides hot water to heating coils in the air-side system.

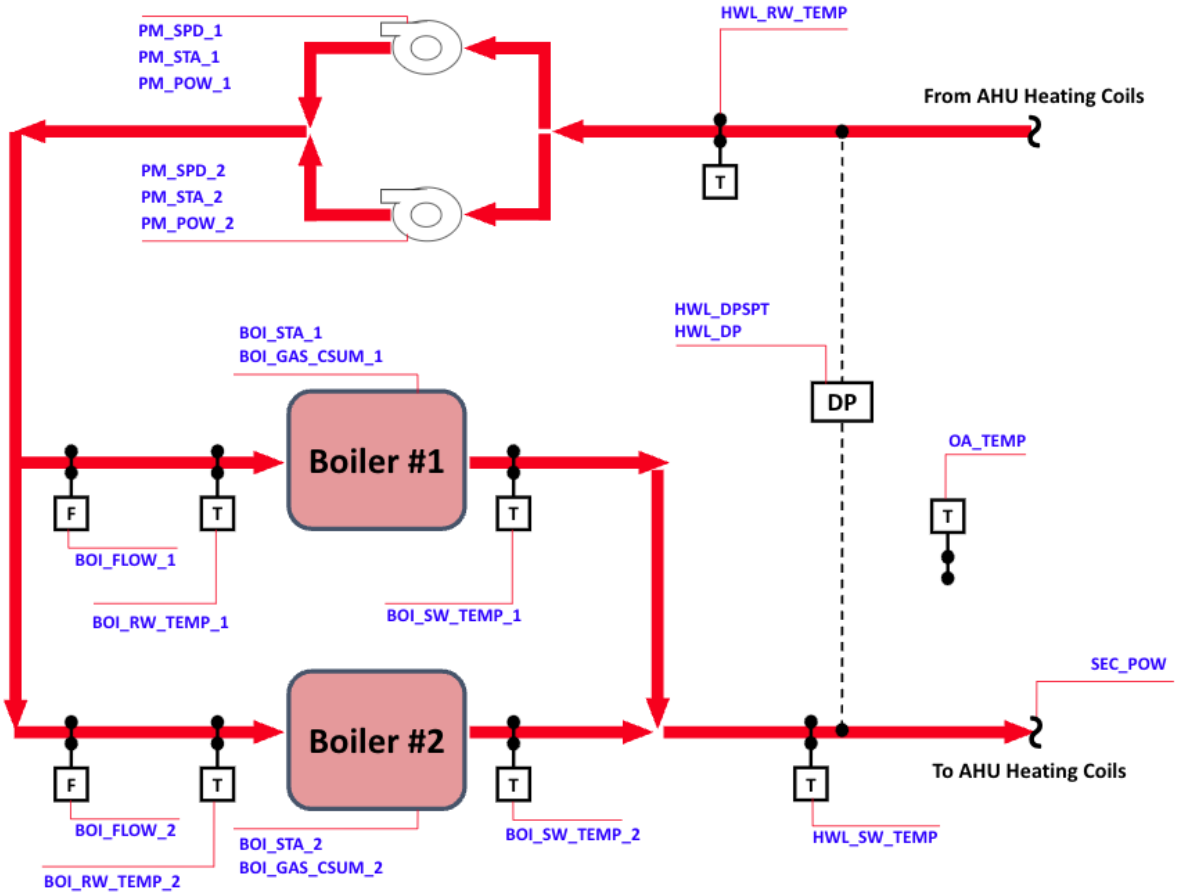

Figure 2 Schematic of the studied boiler plant system (the meaning of point abbreviations are summarized in Table 2)

1.2 Description of control sequence

The boiler plant system is controlled by two supervisory controllers and two local controllers (Table 1). One supervisory controller determines the number of the operating boilers using a state machine and the calculated heat load, as shown in Figure 3. The heating load is calculated from:

$$\dot{Q} = \dot{v}_{hw}\rho C_p(T_{hw}^{ent} - T_{hw}^{lea}), \quad (1)$$

where $\dot{v}_{hw}$ is the volumetric flow rate of the hot water, T_{hw}^{ent} and T_{hw}^{lea} are the temperature of the hot water entering and leaving the boiler plant system, respectively. The other supervisory controller determines the number of operating hot water pumps, as shown in Figure 4.

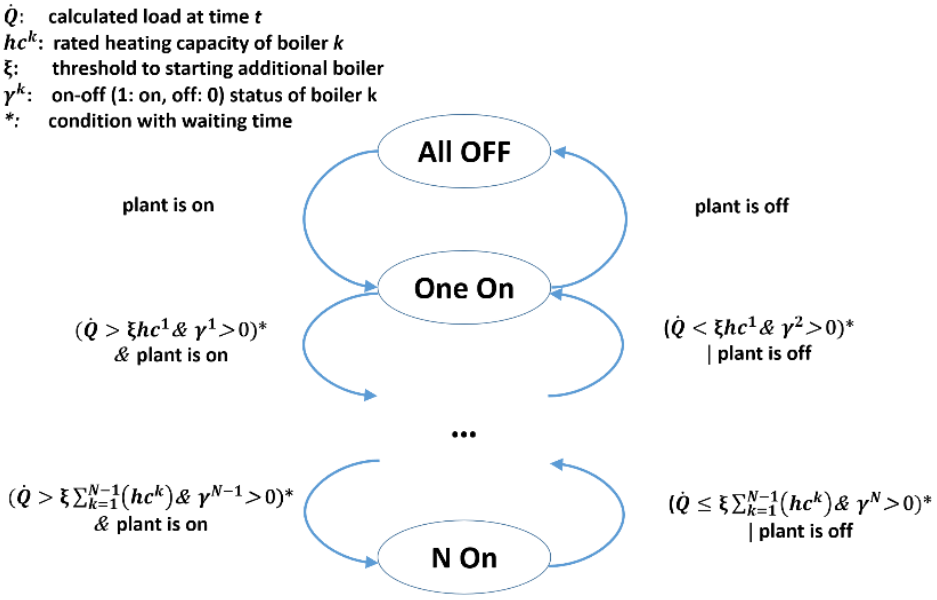

Figure 3 Staging control of boilers ($\xi = 0.95$ and waiting time: 30 min)

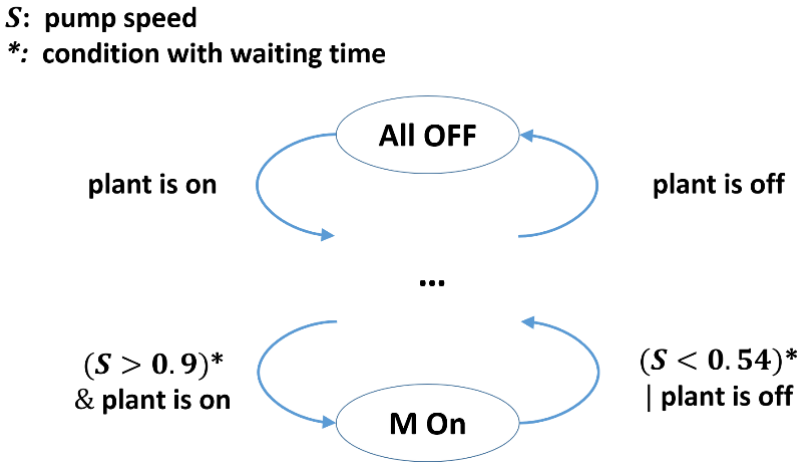

Figure 4 Staging control of hot water pumps in boiler plant system (waiting time: 30 min)

Table 1 Local controllers in the boiler plant system

No.	Controlled Variables	Description
1	Heating power of operating boilers	The heating power of each operating boiler is controlled by a feedback loop to maintain the temperature of the water leaving each boiler to be a predefined value (176°F).
2	Speeds of operating hot water pumps	Hot water pump speed is controlled by a feedback loop to maintain the pressure difference in the hot water loop to be 17.5 psi. If two hot water pumps are running, both pumps operate at the same speed.

2 Data point summary

A total of 22 data points were 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 boiler plant system

NO.	Data point name	Diagram Point Abbreviation	Description	Unit	Basic point?
1	Outdoor Air: Dry Bulb Temperature	OA_TEMP	Dry bulb temperature of outdoor air	°F	Y
2	Secondary Loop Load	SEC_POW	Calculated heating load from hot water loop, product of hot water loop flow and supply/return temperature difference	kW	N
3	Hot Water Loop: Differential Pressure	HWL_DP	Pressure differential of the hot water loop	In H2O	Y
4	Hot Water Loop: Supply Water Temperature	HWL_SW_TEMP	Temperature of the water leaving the hot water loop	°F	Y
5	Hot Water Loop: Return Water Temperature	HWL_RW_TEMP	Temperature of the water entering the hot water loop	°F	Y
6	Hot Water Loop Supply Water Temperature Setpoint	HWL_DPSPT	Setpoint for temperature of the water leaving the hot water loop	°F	Y
For **boiler 1 and 2** (the name of data points is followed by 1, 2, respectively):					
7	Boiler: Status	BOI_STA	On-off status of a boiler	0-Off;1-On	Y
8	Boiler: Supply Water Temperature	BOI_SW_TEMP	Temperature of the water leaving a boiler	°F	Y
9	Boiler: Return Water Temperature	BOI_RW_TEMP	Temperature of the water entering a boiler	°F	Y
10	Boiler: Water Flow Rate	BOI_FLOW	Flow rate of the hot water leaving a boiler	GPM	N
11	Boiler: Gas Consumption	BOI_GAS_CSUM	Gas consumption of a boiler	kW	N
For each hot water pump (pump variables are followed by 1, 2, respectively):					
12	Hot Water Loop Pump: Speed Ratio	PM_SPD	Speed of a pump	0-1	Y
13	Pump: Status	PM_STA	On-off status of a pump	0-Off;1-On	Y
14	Pump: Power Consumption	PM_POW	Power consumption of pump	kW	N

It is noted that, when sensor related faults are imposed, the value of the sensor logged is the faulty value.

A LBNL FDD Data Sets_Boiler Plant.ttl file was also developed to present the data points and their relationships according to the Brick Schema[1](version 1.2). Figure 5 shows the data point relations created under the Brick schema model.

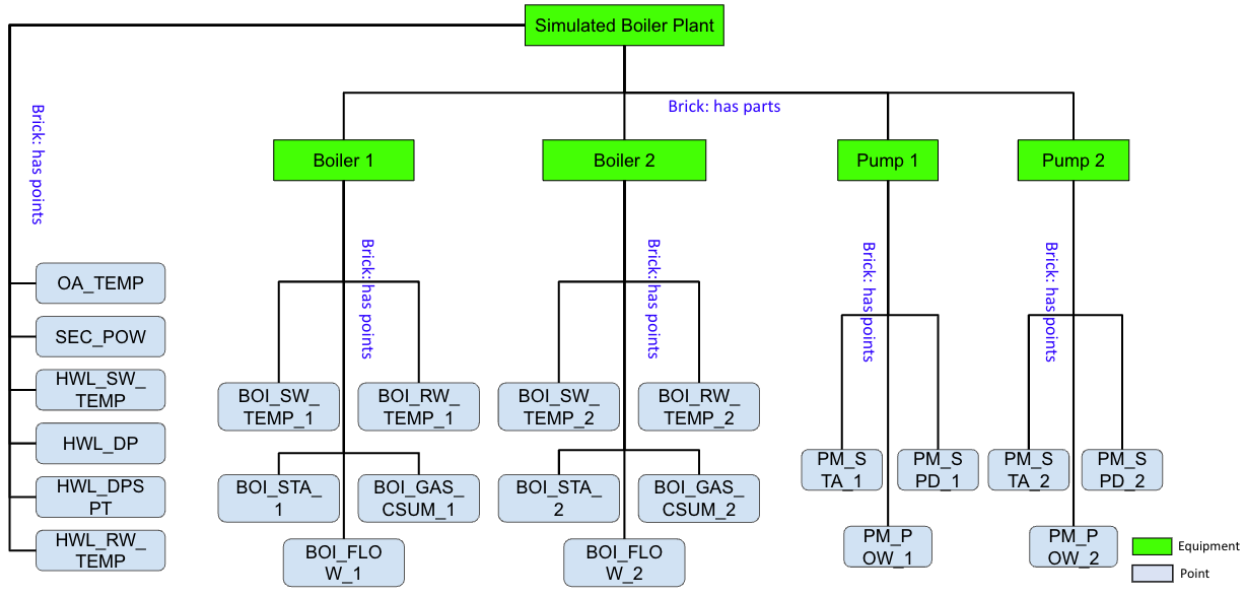

Figure 5 The schematic diagram of boiler plant Brick model

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 16 faulted cases and 1 fault-free case. Each faulted case lasts for one year. The TMY weather data for Chicago, IL is used as the weather inputs.

Table 3 Simulated input scenarios included in the dataset for boiler plant

Input Scenarios			**Method of Fault Imposition**
Fault type		**Fault intensity**	
The hot water leaving temperature sensor of boiler 1	Sensor bias	-4°C, -2°C, 2°C, 4°C	Add bias to sensor output
The hot water leaving temperature sensor of the hot water loop		-4°C, -2°C, 2°C, 4°C	
The differential pressure sensor in the hot water loop		-20%, -10%, 10%, 20%	
Boiler 1 heat exchanger	Fouling	95%, 80%, 65%	Multiply intensity value by heat transfer coefficient

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

Controller PI for boiler supply temperature setpoint	Inappropriate tuning	Faulted	Modify gain value of controllers
Fault free			NA

It is noted that, for sensor bias faults, the value of the faulty sensor logged is the faulty value.

The data set is provided in a set of the csv files. Each .csv file represents either one-year of data for a fault with a specific fault intensity or a fault-free case. Note that the first hour of data in each data file has been removed to eliminate transient behavior associated with the startup of the simulation. 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.	Fault file name	Fault type	Fault Intensity
1	BoilerPlant_boiler_bias_-2.csv	The hot water leaving temperature sensor bias of boiler 1	-2°C
2	BoilerPlant_boiler_bias_-4.csv	The hot water leaving temperature sensor bias of boiler 1	-4°C
3	BoilerPlant_boiler_bias_2.csv	The hot water leaving temperature sensor bias of boiler 1	+2°C
4	BoilerPlant_boiler_bias_4.csv	The hot water leaving temperature sensor bias of boiler 1	+4°C
5	BoilerPlant_hot_water_temp_bias_-2.csv *	The hot water leaving temperature sensor of the hot water loop sensor bias	-2°C
6	BoilerPlant_hot_water_temp_bias_-4.csv *	The hot water leaving temperature sensor of the hot water loop sensor bias	-4°C
7	BoilerPlant_hot_water_temp_bias_2.csv *	The hot water leaving temperature sensor of the hot water loop sensor bias	+2°C
8	BoilerPlant_hot_water_temp_bias_4.csv *	The hot water leaving temperature sensor of the hot water loop sensor bias	+4°C
9	BoilerPlant_hot_water_pressure_bias_-10.csv	The differential pressure sensor in the hot water loop sensor bias	-10%
10	BoilerPlant_hot_water_pressure_bias_-20.csv	The differential pressure sensor in the hot water loop sensor bias	-20%
11	BoilerPlant_hot_water_pressure_bias_10.csv	The differential pressure sensor in the hot water loop sensor bias	10%
12	BoilerPlant_hot_water_pressure_bias_20.csv	The differential pressure sensor in the hot water loop sensor bias	20%
13	BoilerPlant_boiler_foul_065.csv *	Boiler 1 heat exchanger fouling	65%
14	BoilerPlant_boiler_foul_080.csv *	Boiler 1 heat exchanger fouling	80%
15	BoilerPlant_boiler_foul_095.csv *	Boiler 1 heat exchanger fouling	95%
16	BoilerPlant_boiler_PI.csv *	Controller PI for boiler supply temperature setpoint Inappropriate tuning	NA

17	BoilerPlant.csv	Fault free	NA

* These fault cases did not output values for the “Pump: Power Consumption” data points, which include “PM_POW_1” and “PM_POW_2,” to the data files. The “PM_POW_1” and “PM_POW_2” data point entries have been marked with “NAN.”