LBNL Fault Detection and Diagnostics Data Sets: Chiller Plant

Jessica Granderson, Guanjing Lin, Yimin Chen, Armando Casillas

Lawrence Berkeley National Laboratory

Sen Huang, Draguna Vrabie

Pacific Northwest National Laboratory

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 chiller plant fault detection and diagnostics data set (LBNL FDD Data Sets_Chiller 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-chiller-plant/

1 - Building and system information

1.1 System type and diagram

The studied system is a chiller plant that provides chilled 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 has one cooling coil where chilled water, provided by the chiller plant, cools the air leaving the AHU.

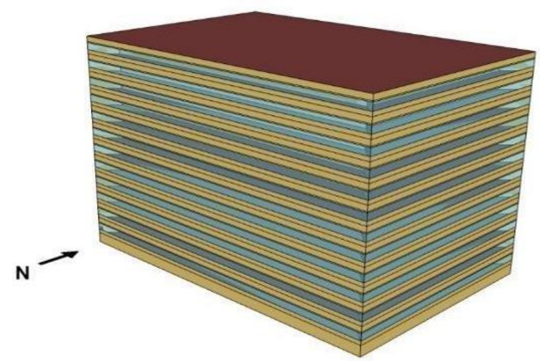


Figure 1 Studied large office building

Figure 2 illustrates the configuration of the chiller plant system. This system has three identical chillers. For each chiller, there is one dedicated primary chilled water pump and one dedicated condenser water pump. The three individual primary chilled water loops are combined and feed the secondary chilled water loop, which has two identical chilled water pumps that provide chilled water to the air-side system. A bypass line is used to balance the flow between the primary and secondary chilled water loops. On the condenser side of the chillers, the three individual condenser water loops are combined and feed three identical cooling towers. Flow through the cooling towers is controlled with one three-way valve that enables condenser water to bypass the cooling towers.

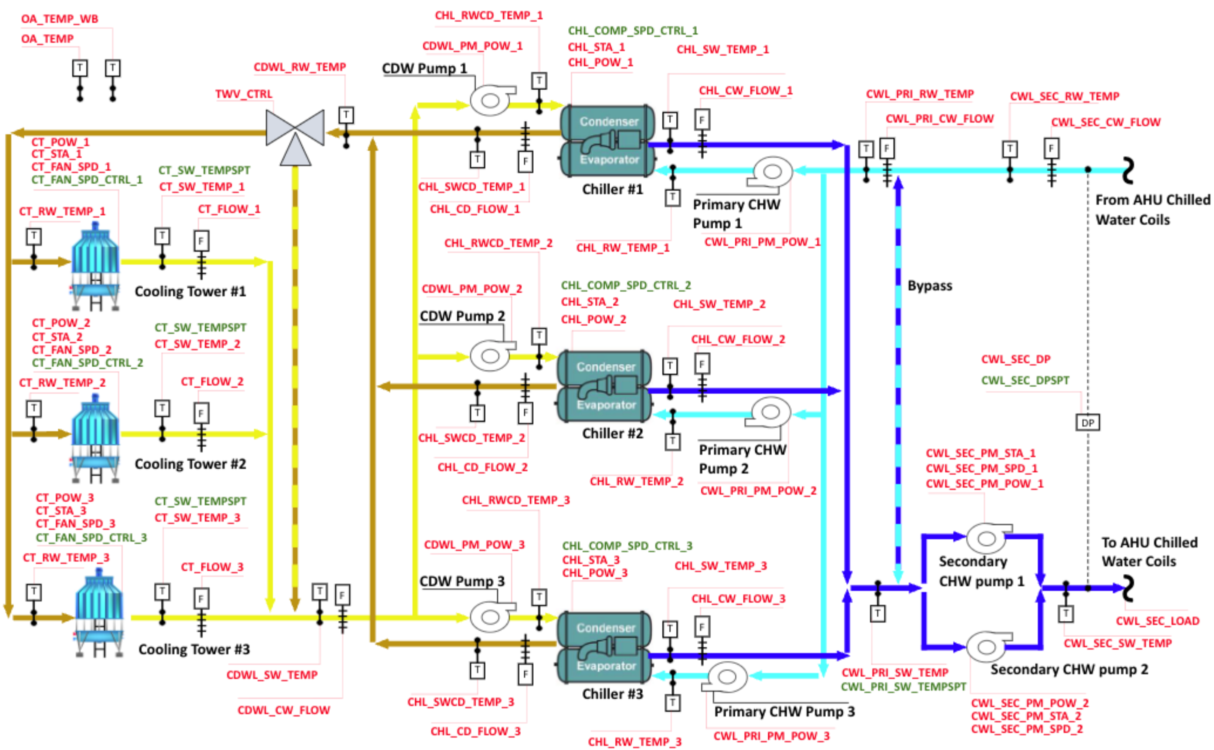


Figure 2 Schematic of the studied chiller plant system (the meaning of point abbreviations are summarized in Table 2)

1.2 Description of control sequence

The chiller plant system is controlled by four supervisory controllers and five local controllers. The supervisory controllers determine the number of operating chillers, secondary chilled water pumps, temperature of the chilled water leaving the chillers, and the temperature of the condenser water leaving the cooling towers, respectively. As shown in Figure 3, the number of operating chillers is determined based on the thermal load via a state machine, with the thermal load calculated using Equation (1):

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

where $\dot{Q}$ is the thermal load (positive values for cooling, negative values for heating), $\dot{v}_{chw}$ is the volumetric flow rate of the chilled water, ρ and C_p are the density and specific heat of water, respectively, T_{chw}^{ent} and T_{chw}^{lea} are the temperature of the chilled water entering and leaving the chiller plant system, respectively.

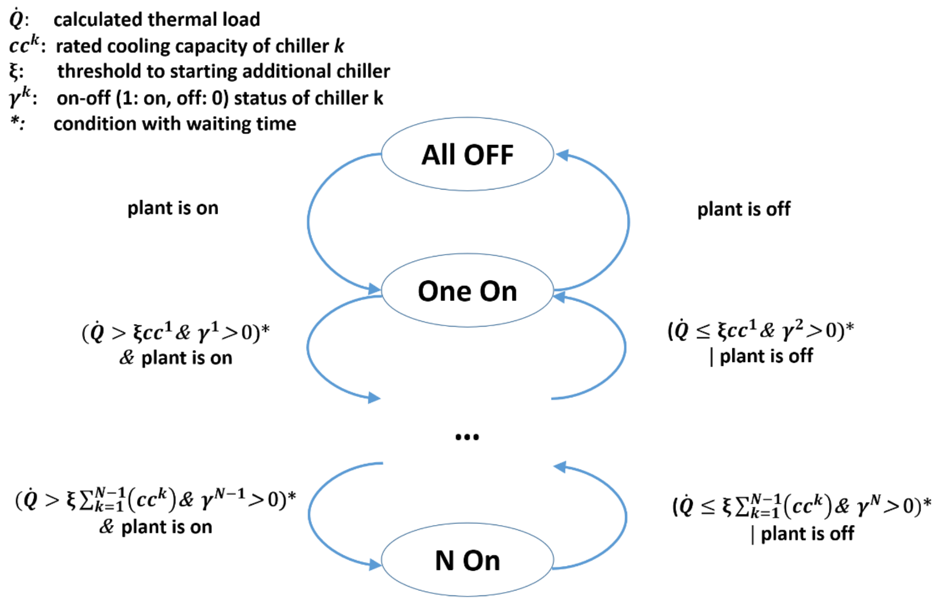


Figure 3 Staging control of chillers ($\xi = 0.95$ and waiting time: 30 min)

Likewise, the supervisory controller employs a state machine to determine the number of secondary chilled water pumps being used at any given time, as shown in Figure 4.

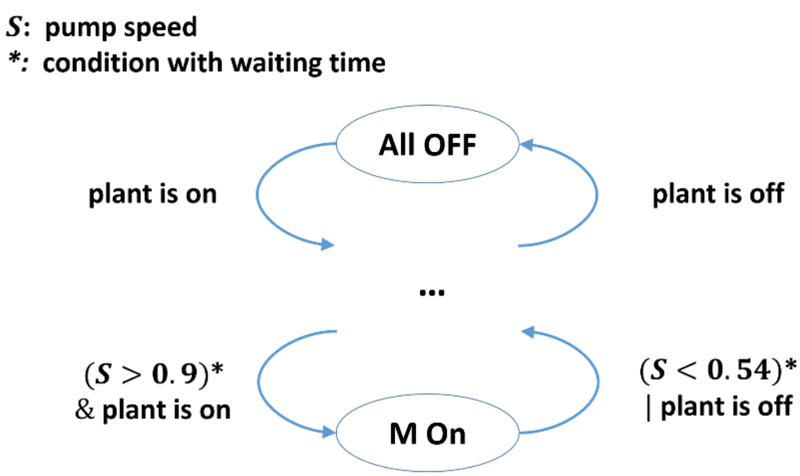


Figure 4 Staging control of secondary chilled water pumps (waiting time: 30 min)

The supervisory controller determines the temperature setpoint of the chilled water leaving the chillers based on the equation below:

$$T_{chw}^{set} = max\left(min\left(T_{chw}^{set,min} + \frac{T_{chw}^{set,max} - T_{chw}^{set,min}}{(T_o^{min} - T_o^{max})}(T_o - T_o^{max}), T_{chw}^{set,max}\right), T_{chw}^{set,min}\right), \quad (2)$$

where T_{chw}^{set} is the temperature setpoint of the chilled water leaving each chiller, $T_{chw}^{set,min}$ and $T_{chw}^{set,max}$ are the minimum and maximum value (42°F and 52 °F) of T_{chw}^{set}, T_o is the outdoor dry bulb temperature, T_o^{min} and T_o^{max} (60°F and 80 °F) are the minimum and maximum value of T_o for this reset.

Similarly, the supervisory controller determines the temperature setpoint of the condenser water leaving the cooling towers based on the equation below:

$$T_{cw}^{set} = max\left(T_{wb} + T_{app}, T_{cw}^{set,min}\right), \quad (3)$$

where T_{cw}^{set} is the temperature setpoint of the condenser water leaving each cooling tower, $T_{cw}^{set,min}$ is the minimum value (34 °F) of T_{cw}^{set}, T_{wb} is the outdoor wet bulb temperature, and $T_{app}$is a fixed approach temperature (8 °F).

The five local controllers are described in Table 1. In general, those local controllers determine the operating condition of each component based on the outputs from supervisory controllers.

Table 1 Local controllers in the chiller plant system

No.	Controlled Variables	Description
1	Number of the operating cooling towers, condenser water pumps, and primary chilled water pumps	The activation of one chiller also corresponds to the activation of one cooling tower, one condenser water pump (constant speed), and one primary chilled water pump (constant speed).
2	Speeds of the operating cooling towers	All the operating cooling towers operate at the same speed and the speed is controlled by a feedback loop to maintain the temperature of the condenser water leaving the cooling towers to be 8°F higher than the outdoor wet bulb temperature. The temperature of the condenser water leaving cooling towers is constrained to be greater than 60 °F.
3	Position of the three-way valve	The position of the three-way valve is controlled by a feedback loop to maintain the temperature of the condenser water leaving the condenser water loop to be greater than 60 °F.
4	Cooling power of operating chillers	The cooling power of each operating chiller is controlled by a feedback loop to maintain the temperature of the chilled water leaving each chiller at the setpoint determined by equation 2 (updated every hour).
5	Speeds of the operating secondary chilled water pumps	Secondary chilled water pump speed is controlled by a feedback loop to maintain the pressure difference in the secondary chilled water loop at 35 psi. If two secondary pumps are running, both pumps operate at the same speed.

2 Data point summary

A total of 77 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 chiller plant system

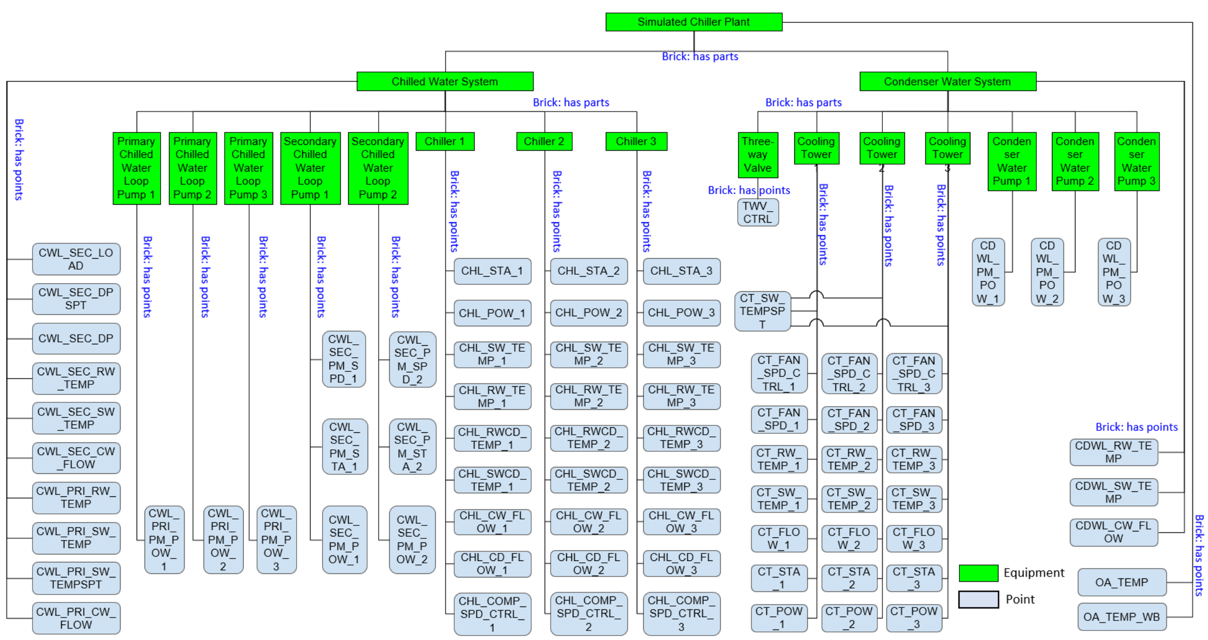
NO.	Data point name	Diagram Point Abbreviation	Description	Unit	Basic point?
1	Secondary Loop Cooling Load Calc	CWL_SEC_LOAD	Calculated cooling load from secondary loop, product of secondary loop flow and supply/return temperature difference	W	N
2	Secondary Chilled Water Loop: Return Water Temperature	CWL_SEC_RW_TEMP	Temperature of the water entering the secondary chilled water loop	°F	Y
3	Secondary Chilled Water Loop: Supply Water Temperature	CWL_SEC_SW_TEMP	Temperature of the water leaving the secondary chilled water loop	°F	Y
4	Secondary Chilled Water Loop: Chilled Water Flow Rate	CWL_SEC_CW_FLOW	Flow rate of the secondary chilled water loop	GPM	N
5	Three-way Valve: Control Signal	TWV_CTRL	Control signal of condenser water loop 3-way mixing valve	0-1	Y
6	Cooling Tower Supply Water Temperature Setpoint	CT_SW_TEMPSPT	Set point of temperature of the condenser water leaving cooling tower	°F	Y
7	Condenser Water Loop: Supply Water Temperature	CDWL_SW_TEMP	Temperature of the water leaving the condenser water loop	°F	Y
8	Condenser Water Loop: Return Water Temperature	CDWL_RW_TEMP	Temperature of the water entering the condenser water loop	°F	Y
9	Condenser Water Loop: Chilled Water Flow Rate	CDWL_CW_FLOW	Flow rate of the condenser water loop	GPM	N
10	Primary Chilled Water Loop: Return Chilled Water Temperature	CWL_PRI_RW_TEMP	Temperature of the water entering the primary chilled water loop	°F	Y
11	Primary Chilled Water Loop: Supply Water Temperature	CWL_PRI_SW_TEMP	Temperature of the water leaving the primary chilled water loop	°F	Y
12	Primary Chilled Water Loop: Chilled Water Flow Rate	CWL_PRI_CW_FLOW	Flow rate of the primary chilled water loop	GPM	N
13	Primary Loop Chilled Water Supply Temperature Setpoint	CWL_PRI_SW_TEMPSPT	Setpoint for temperature of the water leaving the primary chilled water loop	°F	Y
14	Outdoor Air: Dry Bulb Temperature	OA_TEMP	Dry bulb temperature of outdoor air	°F	Y
15	Outdoor Air: Wet Bulb Temperature	OA_TEMP_WB	Wet bulb temperature of outdoor air	°F	Y

16	Secondary Loop Differential Pressure Setpoint	CWL_SEC_DPSPTS	Setpoint of Secondary loop differential pressure	inH2O	Y
17	Secondary Chilled Water Loop: Pressure Differential	CWL_SEC_DP	Pressure differential of the secondary chilled water loop	inH2O	Y
For **cooling tower 1, 2, 3 ,** the name of data points is followed by 1, 2, 3, respectively					
18	Cooling Tower: Status	CT_STA	On-off status of a cooling tower	0-Off;1-On	Y
19	Cooling Tower: Water Flow Rate	CT_FLOW	Flow rate of a cooling tower	GPM	N
20	Cooling Tower: Return Water Temperature	CT_RW_TEMP	Temperature of the water entering a cooling tower	°F	Y
21	Cooling Tower: Supply Water Temperature	CT_SW_TEMP	Temperature of the water leaving a cooling tower	°F	Y
22	Cooling Tower: Speed	CT_FAN_SPD	Speed of a cooling tower fan	0-1	Y
23	Cooling Tower: Speed Control Signal	CT_FAN_SPD_CTRL	Control signal for cooling tower fan speed	0-1	Y
24	Cooling Tower: Power Consumption	CT_POW	Power consumption of a cooling tower	kW	N
For **chiller 1, 2, 3,** the name of data points is followed by 1, 2, 3, respectively:					
25	Chiller: Status	CHL_STA	On-off status of a chiller	0-Off;1-On	Y
26	Chiller: Control Signal	CHL_COMP_SPD_CTRL	Control signal for chiller compressor speed	0-1	N
27	Chiller: Chilled Water Flow Rate	CHL_CW_FLOW	Flow rate of the chilled water leaving a chiller	GPM	N
28	Chiller: Condenser Water Flow Rate	CHL_CD_FLOW	Flow rate of the condenser water leaving a chiller	GPM	N
29	Chiller: Return Chilled Water Temperature	CHL_RW_TEMP	Temperature of the chilled water entering a chiller	°F	Y
30	Chiller: Supply Chilled Water Temperature	CHL_SW_TEMP	Temperature of the chilled water leaving a chiller	°F	Y
31	Chiller: Supply Condenser Water Temperature	CHL_SWCD_TEMP	Temperature of the condenser water leaving a chiller	°F	Y
32	Chiller: Return Condenser Water Temperature	CHL_RWCD_TEMP	Temperature of the condenser water entering a chiller	°F	Y
33	Chiller: Power Consumption	CHL_POW	Power consumption of a chiller	kW	N

For **condenser water loop pump 1, 2, 3**, the name of data points is followed by 1, 2, 3, respectively:					
34	Condenser Water Loop Pump: Power consumption	CDWL_PM_POW	Power consumption of a condenser water loop pump	kW	N
For **primary chilled water loop pump 1, 2, 3,** the name of data points is followed by 1, 2, 3, respectively:					
35	Primary Chilled Water Loop Pump: Power Consumption	CWL_PRI_PM_POW	Power consumption of a primary chilled water loop pump	kW	N
For **secondary chilled water loop pump 1, 2,** the name of data points is followed by 1, 2, respectively:					
36	Secondary Chilled Water Loop Pump: Power Consumption	CWL_SEC_PM_POW	Power consumption of a secondary chilled water loop pump	kW	N
37	Secondary Chilled Water Loop Pump: Speed	CWL_SEC_PM_SPD	Speed of a secondary chilled water loop pump	0-1	Y
38	Secondary Chilled Water Loop Pump: Status	CWL_SEC_PM_STA	On-off status of a secondary chilled water loop pump	0-Off;1-On	Y

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_chiller_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 chiller plant data point relations created under the Brick schema model.



---

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

Figure 5 The schematic diagram of the chiller plant system 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 21 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 Input scenarios of simulated chiller plant

Input Scenarios			Method of Fault Imposition
Fault type		Fault intensity	
The chilled water leaving temperature sensor of Chiller 1	Sensor bias	-2°C, -1°C, 1°C, 2°C	Add bias to sensor output
The condenser water leaving temperature sensor of Cooling tower 1			
The differential pressure sensor in the secondary chilled water loop		-20%, -10%, 10%, 20%	
The condenser water leaving the three-way valve	Leakage	25%, 50%, 75%	Increase the default minimum position setting
The condenser water leaving the three-way valve	Stuck	50%, 75%	Assign a fixed simulated controlled device position
Cooling tower 1 heat exchanger	Fouling	95%, 80%, 65%	Multiply intensity value by heat transfer coefficient
Controller PI for condenser loop supply temperature setpoint	Inappropriate tuning	Faulted	Modify gain value of controllers
Unfaulted			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	ChillerPlant_coolingtower_bias_-1.csv	Condenser water leaving temperature sensor bias of Cooling tower 1	-1°C
2	ChillerPlant_coolingtower_bias_-2.csv	Condenser water leaving temperature sensor bias of cooling tower 1	-2°C
3	ChillerPlant_coolingtower_bias_1.csv	Condenser water leaving temperature sensor bias of cooling tower 1	+1°C
4	ChillerPlant_coolingtower_bias_2.csv	Condenser water leaving temperature sensor	+2°C

		bias) of cooling tower 1	
5	ChillerPlant_chiller_bias_-1.csv	Chilled water leaving temperature sensor bias of chiller 1	-1°C
6	ChillerPlant_chiller_bias_-2.csv	Chilled water leaving temperature sensor bias of chiller 1	-2°C
7	ChillerPlant_chiller_bias_1.csv	Chilled water leaving temperature sensor bias of chiller 1	+1°C
8	ChillerPlant_chiller_bias_2.csv	Chilled water leaving temperature sensor bias of chiller 1	+2°C
9	ChillerPlant_secondary_chilled_water_pressure_bias_-010.csv	Differential pressure sensor bias in the secondary chilled water loop	-10%
10	ChillerPlant_secondary_chilled_water_pressure_bias_-020.csv	Differential pressure sensor bias in the secondary chilled water loop	-20%
11	ChillerPlant_secondary_chilled_water_pressure_bias_010.csv	Differential pressure sensor bias in the secondary chilled water loop	10%
12	ChillerPlant_secondary_chilled_water_pressure_bias_020.csv	Differential pressure sensor bias in the secondary chilled water loop	20%
13	ChillerPlant_bypass_leakage_025.csv	Leakage of the condenser water leaving the three-way valve	25%
14	ChillerPlant_bypass_leakage_050.csv	Leakage of the condenser water leaving the three-way valve	50%
15	ChillerPlant_bypass_leakage_075.csv	Leakage of the condenser water leaving the three-way valve	75%
16	ChillerPlant_bypass_stuck_050.csv	Stuck three-way valve of condenser loop	50%
17	ChillerPlant_bypass_stuck_075.csv	Stuck three-way valve of condenser loop	75%
18	ChillerPlant_coolingtower_fouling_065.csv	Fouling of cooling tower heat exchanger	65%
19	ChillerPlant_coolingtower_fouling_080.csv	Fouling of cooling tower heat exchanger	80%
20	ChillerPlant_coolingtower_fouling_095.csv	Fouling of cooling tower heat exchanger	95%
21	ChillerPlant_coolingtower_PI.csv	Inappropriate tuning of PID loop for condenser water supply temperature control	Faulted
22	ChillerPlant.csv	Fault free	NA