LBNL Fault Detection and Diagnostics Data Sets: Roof Top Unit

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DISCLAIMER

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This documentation describes three curated rooftop unit (RTU) fault detection and diagnostics data sets (LBNL FDD Data Sets_RTU). In this documentation, the system information, data points specifications, and input scenarios for faulted and fault-free conditions represented in the data are detailed for each data set.

Experimental rooftop unit datasets

E1 - Building and system information

E1.1 System type and diagram

The experimental fault dataset for an RTU-VAV system was generated by Oak Ridge National Laboratory (ORNL) in ORNL's light-commercial flexible research platform (FRP). The two-story FRP is a 3,200 sq-ft facility designed to emulate a 1980s-era office building. The FRP is reserved for experiments and is not occupied, but internal loads are emulated. Figure E1 is a photo of the FRP facility and the RTU that serves it. Figure E2 is the floorplan of the facility. The FRP has three installed heating, ventilation, and air conditioning (HVAC) systems: 1) a single packaged RTU connected to a multi-zone VAV system; 2) a ground source heat pump (GSHP); and 3) a variable refrigerant flow (VRF) system. The RTU-VAV system was used to generate the fault datasets.

Figure E1 Two-story Flexible Research Platform (left) and RTU on the FRP (right) at Oak Ridge National Laboratory

Figure E2 FRP floorplans for the first floor (left) and second floor (right)

The RTU is a Trane® YCD150 12.5-ton unit with an energy efficiency rating (EER) of 9.6. The unit provided heating and cooling during the experiments. The connected VAV system serves a total of 10 zones (8 perimeter and 2 core). A schematic diagram of the system is shown in Figure E3. Each VAV box includes electric resistance reheat.

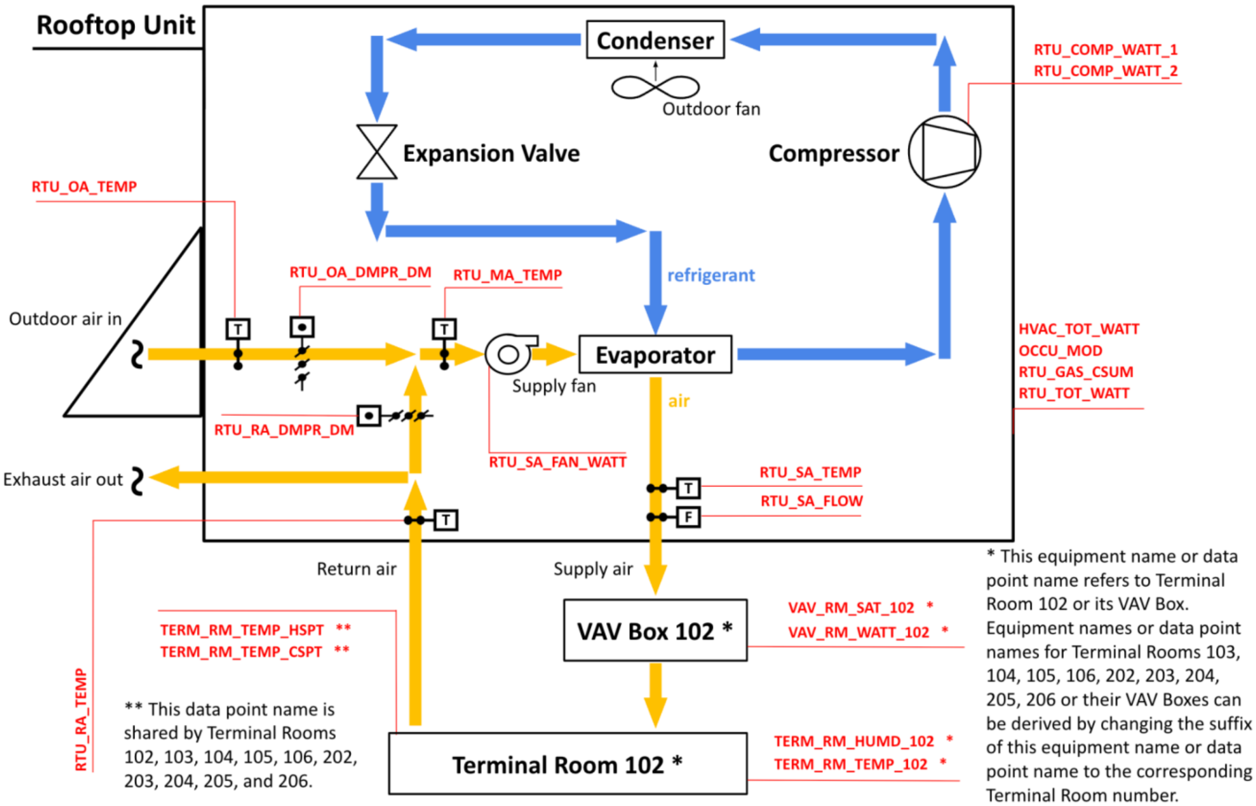

Figure E3 Schematic diagram of Experimental RTU with abbreviated data point names (summarized in Table E1)

E1.2 Description of control sequence

Control sequences used to generate the experimental RTU datasets are described below.

The AHU is scheduled for automatic operation on a time of day basis for occupied and unoccupied mode. The occupied mode starts at 7:00am and ends at 10:00pm.

Occupied mode

- Supply air temperature control: Two compressors and the gas furnace are sequenced on/off to maintain a constant supply air temperature (SAT) setpoint of 55°F year round.
- Space temperature control: The zone heating and cooling setpoints are 69.8°F and 75.2°F during the occupied period.
- Economizer control: The economizer has two dampers: outdoor air (OA) damper and return air (RA) damper. The positions of the two dampers are synchronized so that the sum of the opening percentages is always 100%. For example, if the OA damper position is 35%, then the RA damper position is 65%. The economizer is enabled when the OA temperature is lower than its setpoint

(set at 50 °F by default) and the mixed air (MA) temperature is higher than 45 °F. The minimum position of the OA damper is always 10% (even if the economizer is disabled).
- Static pressure control: The variable speed fan modulates its speed to maintain the static pressure in the main duct at its setpoint of 1 inWC.

Unoccupied mode
- Space temperature control: The zone heating and cooling setpoints are 60°F and 80°F during the unoccupied period.

E2 Data point summary

A total of 56 data points were included in the data sets. The data point descriptions are summarized in Table E1. 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 E1. Data point summary of the experimental RTU system

NO.	Data point name	Diagram Point Abbreviation	Description	Unit	Basic point?
1	RTU: Outdoor Air Damper Control Signal	RTU_OA_DMPR_DM	Control signal for RTU outdoor air damper; 0 – damper is fully closed, 1 – damper is fully open	0-1	Y
2	RTU: Return Air Damper Control Signal	RTU_RA_DMPR_DM	Control signal for RTU return air damper; 0 – damper is fully closed, 1 – damper is fully open	0-1	Y
3	RTU: Outside Air Temperature	RTU_OA_TEMP	Measured RTU outside air temperature	°F	Y
4	RTU: Mixed Air Temperature	RTU_MA_TEMP	Measured RTU mixed air temperature	°F	Y
5	RTU: Supply Air Temperature	RTU_SA_TEMP	RTU supply air temperature	°F	Y
6	RTU: Return Air Temperature	RTU_RA_TEMP	RTU return air temperature	°F	Y
7	RTU: Supply Air Volumetric Flow Rate	RTU_SA_FLOW	RTU volumetric air flow rate	ACFM	N
8	RTU: Electricity	RTU_TOT_WATT	RTU electricity consumption rate	W	N
9	RTU: Natural Gas	RTU_GAS_CSUM	RTU natural gas consumption rate	SCFM	N
10	Terminal: Room Air Temperature Heating Setpoint	TERM_RM_TEMP_HSPT	Heating temperature setpoint	°F	Y
11	Terminal: Room Air Temperature Cooling Setpoint	TERM_RM_TEMP_CSPT	Cooling temperature setpoint	°F	Y
12	Terminal: Room 102 Air Temperature	TERM_RM_TEMP_102	Room ambient temperature	°F	Y
13	Terminal: Room 103 Air Temperature	TERM_RM_TEMP_103			
14	Terminal: Room 104 Air Temperature	TERM_RM_TEMP_104			

15	Terminal: Room 105 Air Temperature	TERM_RM_TEMP_105			
16	Terminal: Room 106 Air Temperature	TERM_RM_TEMP_106			
17	Terminal: Room 202 Air Temperature	TERM_RM_TEMP_202			
18	Terminal: Room 203 Air Temperature	TERM_RM_TEMP_203			
19	Terminal: Room 204 Air Temperature	TERM_RM_TEMP_204			
20	Terminal: Room 205 Air Temperature	TERM_RM_TEMP_205			
21	Terminal: Room 206 Air Temperature	TERM_RM_TEMP_206			
22	Terminal: Room 102 Air Humidity	TERM_RM_HUMD_102	Room ambient relative humidity	%	N
23	Terminal: Room 103 Air Humidity	TERM_RM_HUMD_103			
24	Terminal: Room 104 Air Humidity	TERM_RM_HUMD_104			
25	Terminal: Room 105 Air Humidity	TERM_RM_HUMD_105			
26	Terminal: Room 106 Air Humidity	TERM_RM_HUMD_106			
27	Terminal: Room 202 Air Humidity	TERM_RM_HUMD_202			
28	Terminal: Room 203 Air Humidity	TERM_RM_HUMD_203			
29	Terminal: Room 204 Air Humidity	TERM_RM_HUMD_204			
30	Terminal: Room 205 Air Humidity	TERM_RM_HUMD_205			
31	Terminal: Room 206 Air Humidity	TERM_RM_HUMD_206			
32	HVAC System: Electricity	HVAC_TOT_WATT	Total electricity consumption rate of HVAC system including RTUs and VAV terminal reheat	W	N
33	Occupancy Mode Indicator	OCCU_MOD	Indicator if the system operates in occupied mode; 1-occupied mode, 0-unoccupied mode	--	Y
34	RTU: Compressor 1 consumption	RTU_COMP_WATT_1	RTU compressor electricity consumption rate	W	N
35	RTU: Compressor 2 consumption	RTU_COMP_WATT_2			

36	RTU: Fan Electricity	RTU_SA_FAN_WATT	RTU supply air fan electricity consumption rate	W	N
37	VAV Box: Room 102 power consumption	VAV_RM_WATT_102	Room VAV box power consumption rate	W	N
38	VAV Box: Room 103 power consumption	VAV_RM_WATT_103			
39	VAV Box: Room 104 power consumption	VAV_RM_WATT_104			
40	VAV Box: Room 105 power consumption	VAV_RM_WATT_105			
41	VAV Box: Room 106 power consumption	VAV_RM_WATT_106			
42	VAV Box: Room 202 power consumption	VAV_RM_WATT_202			
43	VAV Box: Room 203 power consumption	VAV_RM_WATT_203			
44	VAV Box: Room 204 power consumption	VAV_RM_WATT_204			
45	VAV Box: Room 205 power consumption	VAV_RM_WATT_205			
46	VAV Box: Room 206 power consumption	VAV_RM_WATT_206			
47	VAV Box: Room 102 Air Temperature	VAV_RM_SAT_102	Room VAV box supply air temperature	°F	N
48	VAV Box: Room 103 Air Temperature	VAV_RM_SAT_103			
49	VAV Box: Room 104 Air Temperature	VAV_RM_SAT_104			
50	VAV Box: Room 105 Air Temperature	VAV_RM_SAT_105			
51	VAV Box: Room 106 Air Temperature	VAV_RM_SAT_106			
52	VAV Box: Room 202 Air Temperature	VAV_RM_SAT_202			
53	VAV Box: Room 203 Air Temperature	VAV_RM_SAT_203			
54	VAV Box: Room 204 Air Temperature	VAV_RM_SAT_204			
55	VAV Box: Room 205 Air Temperature	VAV_RM_SAT_205			
56	VAV Box: Room 206 Air Temperature	VAV_RM_SAT_206			

It is noted that, for the biased supply air temperature sensor, the supply air temperature in the dataset is the faulty value.

A LBNL_FDD_Data_Sets_RTU_Exp.ttl file was also developed to present the data points and their relationships according to the Brick Schema[1](version 1.2). Figure E4 shows the RTU data point relations created under the Brick schema model.

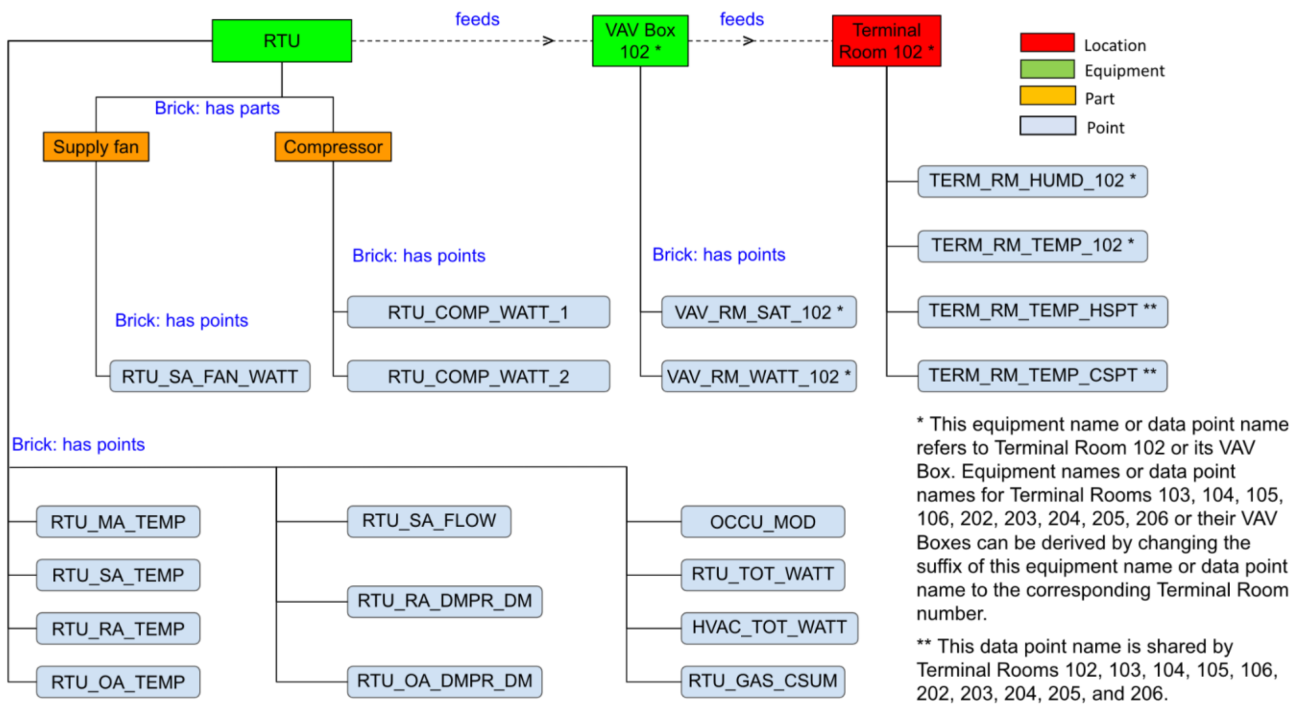

Figure E4 The schematic diagram of the Experimental RTU Brick model

E3 Faulty and fault-free scenarios

The team creates faulted and unfaulted scenarios at FRP, Oak Ridge, TN, located in ASHRAE climate zone 4A (mixed – humid). Table E2 shows the input scenarios for the experiments that have been conducted including unfaulted test cases, as well as OA damper stuck, incorrect economizer setpoint, and biased supply air temperature sensor fault test cases. Each unfaulted test case operated the building for a day immediately prior to the related fault. Each fault test was to impose a single fault at a single intensity at 12am and last for a day, after which the facility will be restored to normal operation. There are a total of 48 faulted cases and 4 fault-free cases.

Table E2. Input scenarios of the experiments included in the dataset for RTU

Input Scenarios	Method of fault	Fault occurred time

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

Fault type	Fault intensity	imposition	
OA damper stuck	Half of minimum position (OA damper position 5%, RA damper position 95%)	Modify the control programming for control signal	Fall 2020, Spring 2021, Summer 2021, and Winter 2022
	Minimum position (10%) (OA damper position 10%, RA damper position 90%)		
	50% open (OA damper position 50%, RA damper position 50%)		
	Fully open (OA damper position 100%, RA damper position 0%)		
Incorrect economizer setpoint*	12 °C	Modify the economizer setpoint in control programming	
	14 °C		
	8 °C		
	6 °C		
Biased supply air temperature sensor	Bias = 2°C	Modify the supply air temperature setpoint in control programming	
	Bias = 4°C		
	Bias = -2°C		
	Bias = -4°C		
Unfaulted			

*The correct economizer setpoint is 10°C (50°F).

The data set is provided in a set of the csv files. For the faulted cases, each .csv file represents one-day data of a fault with a specific fault intensity within a single season. For the fault-free cases, each .csv file represents multiple days of data within a single season. 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 E3 lists the csv file description for each faulty case and fault-free case. Note that during the unoccupied mode (before 7:00am and after 10:00pm), several temperature sensors and 1 flow sensor did not output data or did output data intermittently. The temperature and flow data point entries without output data are indicated with the string “NAN”.

Table E3. File inventory

No	File Name	Fault Name	Fault Intensity
For **Fall 2020, Spring 2021, Summer 2021, and Winter 2022** test periods**,** the name of all datasets below (before “.csv”) contains suffix **_Fall_2020**, **_Spring_2021**, **_Summer_2021**, and **_Winter_2022**, respectively			
1	SA_temp_bias_4.csv	Supply air temperature sensor bias	4°C
2	SA_temp_bias_2.csv	Supply air temperature sensor bias	2°C
3	SA_temp_bias_-4.csv	Supply air temperature sensor bias	-4°C
4	SA_temp_bias_-2.csv	Supply air temperature sensor bias	-2°C
5	Inc_Eco_SP_4.csv	Incorrect economizer setpoint	4°C
6	Inc_Eco_SP_2.csv	Incorrect economizer setpoint	2°C
7	Inc_Eco_SP_-4.csv	Incorrect economizer setpoint	-4°C
8	Inc_Eco_SP_-2.csv	Incorrect economizer setpoint	-2°C
9	OA_damper_stuck_005.csv	OA damper stuck	5%
10	OA_damper_stuck_010.csv	OA damper stuck	10%
11	OA_damper_stuck_050.csv	OA damper stuck	50%
12	OA_damper_stuck_100.csv	OA damper stuck	100%
13	ERTU.csv	Fault-free case (multiple days)	-

Field measured rooftop unit data set

F1 - Building and system information

F1.1 System type and diagram

This section describes field datasets for three rooftop units (RTUs) monitored as part of a DOE-funded project titled “Bringing Fault Detection and Diagnosis Tools into the Mainstream: Retro-Commissioning and Continuous Commissioning of HVAC and Refrigeration Systems[2].” The dataset generated by Professor Ravi Gorthala’s research team at University of Connecticut. Table F1 summarizes the two sites from which data were collected. Included are the building location, type, and size, as well as the RTU capacity and efficiency, the FDD tool used to monitor the RTU and its date of installation.

Table F1. Summary of field test sites and RTU characteristics

	Building			RTU		FDD Tool	
Site #	**Location**	**Space Type**	**Floor Area (ft^2)**	**Capacity (Tons)**	**EER**	**Manufacturer**	**Installation Date**
1	Milford, CT	Restaurant	5,168	7.5	9	ClimaCheck	4/3/19
2	Colchester, CT	Distribution Center	207,635	10	10.4	Enerfit	7/30/19

An illustration of a typical RTU with sensor locations used in this study is shown Figure F1. Refrigerant temperature and pressure as well as air temperature and relative humidity are measured at various points in the system in order to characterize operation and identify faults.

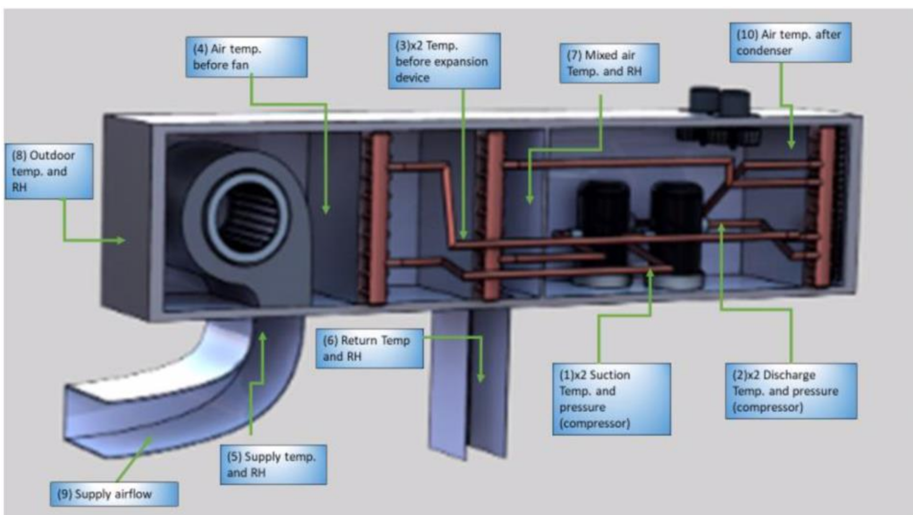

Figure F1 Illustration of a typical RTU with sensor locations used in this study

Table F2 provides further details for the sensors used in this study. Included is the sensor location (cross referenced with Figure F1), model information, and performance specifications.

Table F2. Sensors used to monitor the field RTUs

Sensor/ Variable	**Location** (see Fig.F1)	**Model**	**Specification**	**Quantity**
Power meter (main, compressor, fans)		EP Pro Scout 100 460	3 channels (.53 VAC max, 333mV CTs, 0-4 00A), .2% accuracy. 600V phase to phase, 80- 600VAC CAT III 50/60 Hz, 70mA max	3

[2] Albayati, Mohammed, Ravi Gorthala, Amy Thompson, Prathamesh Patil, and Annika Hacker. “Bringing Automated Fault Detection and Diagnostics Tools for HVAC&R Into the Mainstream.” ASME Journal of Engineering for Sustainable Buildings and Cities 1, no. 3 (August 19, 2020). https://doi.org/10.1115/1.4047958.

Supply Duct Avg Temp	5	Kele ST-FZR21-18-XN3	±0.36°F (±0.2°C) accuracy, (XN3 NIST certificate, three reference points 32°F/77°F/158°F(0°C/25°C/70°C)	1
Return Duct Average	6	Kele ST-FZR21-18-XN3	±0.36°F (±0.2°C) accuracy, (XN3 NIST certificate, three reference points 32°F/77°F/158°F(0°C/25°C/70°C)	1
Refrigerant Temp (suction, discharge, before expansion device)	1,2,3	PT1000 DIN class A	+/-1.32 Ohms/+.35˚C (resistivity of cable), '+/- .15+.002*t˚C/K and 2% RH (temp), temp range -50 to 150˚C	6
Air Temp before fan	4	PT1000 DIN class A	test plug and sensors, '+/-1.32 Ohms/+.35˚C (resistivity of cable), '+/- .15+.002*t˚C/K and 2% RH (temp), temp range -50 to 150˚C	1
Air temp after condenser	10			1
Duct Airflow	9	Flow Measurement Technology NL 1x3	±2% of reading, 3 nodes, single strut,NIST, Thermal Dispersion Airflow	1
Return Temp/RH	6	KLH 100	Humidity and temp Transmitter, 0-100% RH, 0-50 Temp, +/-2%RH, +/-.5°C. 24Vac/dc, supply, 0-10Vdc output	1
Supply Temp/RH	5	SRH1-3P-D-11-T3-N	Duct Temp/RH with 3% accuracy, 4 to 20mA @ 24VDC, -58 to 140°F (-50 to 60°C), (SRH1-2P- D-11-T3-N-C is $399 with NIST Calibration Certificate)	1
Mixed Temp/RH	7	KLK 100	Humidity and temp Transmitter, 0-100% RH, 0-50 Temp, +/-2%RH, +/-.5°C. 24Vac/dc, supply, 0-10Vdc output	1
Outdoor Temp/RH	8	KLU 100	Humidity and temp Transmitter, 0-100% RH, - 50-+50 Temp, +/-2%RH, +/-.5°C. 24Vac/dc 9less than 50mA) supply, 4-20mA output	1
Indoor temp and RH	inside	SRH1-3P-W-11-T3	Indoor temp and RH with 3% accuracy, 0-99% 4 to 20mA @ 24VDC, -58 to 140°F (-50 to 60°C)	1
Refrigerant Pressure Transmitters	200 140	-7 to 5 bar	1% full scale	4
	201 141	10bar		
	202 142	35bar		
	203 143	50bar		
	204 144	150 bar		

F2 - Data point summary

Table F3. Data point summary of the field measured RTU systems

NO.	Data point name	Diagram Point Abbreviation	Description	Unit	Basic point?
1	RTU: Return Air Temperature	RTU_RA_TEMP	Return air temperature	°C	Y
2	RTU: Fan Power	RTU_SA_FAN_WATT	Fan power	W	N
3	RTU: Compressor Power	RTU_COMP_WATT	Stage 1 (circuit 1) compressor power	W	N
4	RTU: Total Power	RTU_TOT_WATT	Total power	W	N
5	RTU: Supply Air Volumetric Flow Rate	RTU_SA_FLOW	Supply fan airflow rate	CFM	N
6	RTU: Mixed Air Humidity	RTU_MA_HUM	Mixed air relative humidity	%RH	N
7	RTU: Outdoor Air Humidity	RTU_OA_HUM	Outdoor air relative humidity	%RH	N
8	Zone: Air Humidity	ZA_HUM	Indoor air relative humidity	%RH	N
9	RTU: Return Air Humidity	RTU_RA_HUM	Return air relative humidity	%RH	N
10	RTU: Supply Air Humidity	RTU_SA_HUM	Supply air relative humidity	%RH	N
11	RTU: Supply Air Temperature	RTU_SA_TEMP	Supply air temperature	°C	Y
12	RTU: Mixed Air Temperature	RTU_MA_TEMP	Mixed air temperature	°C	Y
13	RTU: Outdoor Air Temperature	RTU_OA_TEMP	Outdoor air temperature	°C	Y
14	Zone: Air Temperature	ZA_TEMP	Indoor (room) air temperature	°C	Y
15	RTU: Discharge Pressure 1	RTU_REFG_DISC_PRES_1	Discharge pressure for stage 1 (leaving the compressor)	bar	N
16	RTU: Discharge Pressure 2	RTU_REFG_DISC_PRES_2	Discharge pressure for stage 2 (leaving the compressor)	bar	N
17	RTU: Suction Pressure 1	RTU_REFG_SUCT_PRES_1	Suction pressure for stage 1 (leaving the evaporator)	bar	N
18	RTU: Suction Pressure 2	RTU_REFG_SUCT_PRES_2	Suction pressure for stage 2 (leaving the evaporator)	bar	N
19	RTU: Condenser Discharge Air Temperature	RTU_LA_COND_TEMP	Air temperature leaving condenser	°C	N
20	RTU: Condenser Outlet Temperature 1	RTU_REFG_COND_TEMP_1	Liquid line surface temperature for stage 1 (circuit 1) (leaving the condenser)	°C	N
21	RTU: Condenser Outlet Temperature 2	RTU_REFG_COND_TEMP_2	Liquid line surface temperature for stage 2 (circuit 2) (leaving the condenser)	°C	N

22	RTU: Suction Temperature 1	RTU_REFG_SUCT_TEMP_1	Suction line surface temperature for stage 1 (circuit 1) (leaving the evaporator)	°C	N
23	RTU: Suction Temperature 2	RTU_REFG_SUCT_TEMP_2	Suction line surface temperature for stage 2 (circuit 2) (leaving the evaporator)	°C	N
24	RTU: Discharge Temperature 1	RTU_REFG_DISC_TEMP_1	Discharge line temperature for stage 1 (leaving the compressor)	°C	N
25	RTU: Discharge Temperature 2	RTU_REFG_DISC_TEMP_2	Discharge line temperature for stage 2 (leaving the compressor)	°C	N

F3 Faulty and fault-free scenarios

The field measured dataset presents one fault case for each site. Site 1 provides about 2 months of fault data for a compressor control fault along with approximately 1 month of baseline, fault free data. Site 2 provides 1 month of fault data for an undercharged system paired with about 5 months of baseline, fault free data. Table F2 summarizes the available fault cases.

Table F2. Input scenarios of the experiments included in the dataset for RTU

Site	Fault Type	Description	Time Period
Milford, CT	Staging Fault	Compressor Controls Fault, Stage 2 will not engage	June 9, 2021 - August 8 2021
Milford, CT	Unfaulted	N/A	Aug 10, 2021 - Sep 29, 2021
Colchester, CT	Undercharged (40%)	Low Charge On Circuit B	June 1, 2020 - June 29, 2020
Colchester, CT	Unfaulted	N/A	July 31 2020 - Sep 30, 2020 & June 1, 2021 - Sep 30, 2021

The data set is provided in a set of the csv files. Each .csv file represents data of a fault or 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 F3 lists the csv file description for each faulty case and fault-free case.

Table F3. File inventory

No	File Name	Fault Name	Fault Intensity
1	Site1_Staging_Fault.csv	Compressor controls fault: Stage 2 will not engage	Faulted
2	Site1_Unfaulted.csv	Fault-free case at Site 1	-
3	Site2_Undercharged40.csv	Percent undercharge on Circuit B	40%
4	Site2_Unfaulted.csv	Fault-free case at Site 2	-

Simulated rooftop unit data set

S1 - Building and system information

S1.1 System type and diagram

This section describes the simulation fault dataset for a rooftop unit (RTU) that was generated by the National Renewable Energy Laboratory (NREL). The configuration of the simulated RTU is based on an RTU installed at the Thermal Test Facility (TTF) at NREL, for which a detailed performance map has been created through experimentation.

A Modelica-Spawn of EnergyPlus co-simulation framework is used to integrate a Modelica RTU model with an EnergyPlus envelope model. The EnergyPlus envelope model is a single floor, single-zone model based on the Small Office DOE Prototype Building for ASHRAE Climate Zone 3C; the construction, loads, and schedules match those for the prototype building,while the geometry has been scaled down to achieve a floor area of 5,500 square feet. The climate data is TMY3 San Francisco International Airport (TMY3_724940).

The combined Modelica-EnergyPlus system diagram is shown in Figure S1.

At each time step during co-simulation, EnergyPlus provides input data to the Modelica RTU model consisting of:

1. Return air conditions (temperature, humidity, and flow); and
2. Heat flow within the thermal zone.

The Modelica model then determines the appropriate system operating mode based on zone temperature, zone temperature setpoint, and other control requirements (details of the control sequences used in this study are provided in the next section). Finally, the Modelica model passes the conditions (temperature, humidity, and air flow) of the supply airstream back to the EnergyPlus model. Since Spawn of EnergyPlus and Modelica native models are coupled in a manner of co-simulation, it is important to check the time step in the original IDF files. It is recommended that the time step should not be less than 6, i.e., 10 minutes. A less than 6 setting will sometimes lead to space air temperature and humidity fluctuating to an unrealistic level, eventually crashing the simulation.

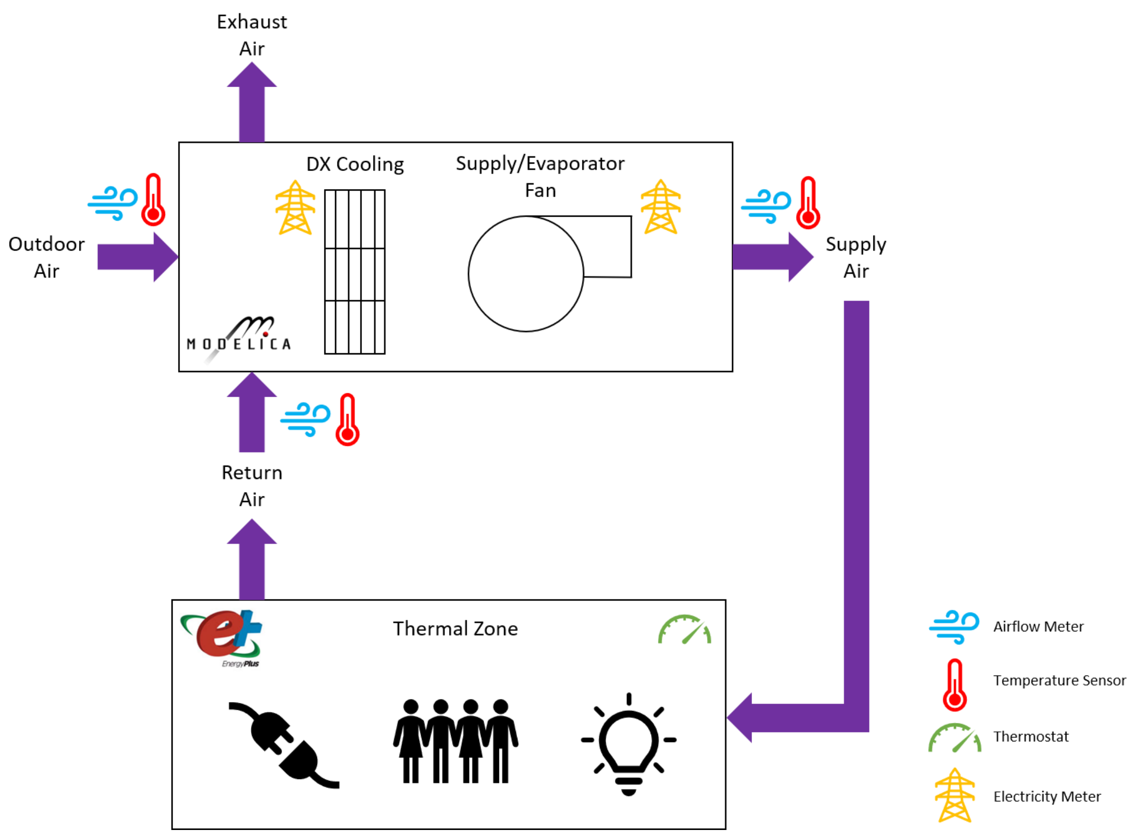

Figure S1 Combined Modelica-EnergyPlus system diagram

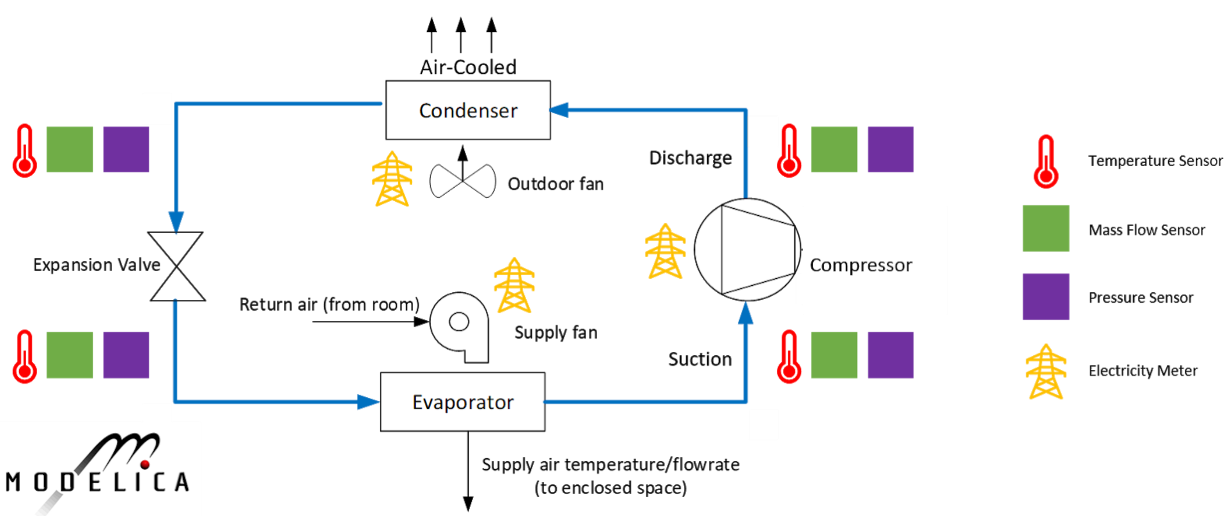

Figure S2 Detailed diagram of the Modelica RTU model

Figure S2 shows a detailed diagram of the RTU vapor-compression cycle implemented in Modelica. The Modelica model represents an RTU with multi-speed fan operation and a single two-stage compressor.

Rooftop Unit Model

The rooftop unit model is based on a four-component vapor compression cycle. Additional suction line pipe and liquid line pipe were added to enable pipe blockage fault simulations. The unit model was set up based on Table S1 and since the component models require more inputs than available in the table, some parameters have to be estimated. An illustration of the unit and a schematic diagram of the modeled system are shown in Figures S3 and S4.

Table S1. RTU Equipment Specifications

Items	Unit	Value
Cooling Performance		
Nominal Cooling Capacity	Btu/hr	60000
EER/SEER	Btu/W/hr	13/17
AHRI Cooling Capacity (High Stage)	Btu/hr	58500
Nominal CFM (High Stage)	CFM	2000
Nominal CFM (Low Stage)	CFM	1400
Nominal CFM (No Cooling / Ventilation Only)	CFM	1000
System Power (High Stage)	kW	4.57
Nominal COP	-	3.81
Compressor		
Compressor Type	-	Scroll (Two-Stage)
Refrigerant		
Refrigerant	-	R410A
Mass	lbs	12.5
Outdoor Coil		
type	-	Lanced
Tube Size	inch	0.3125
Face Area	sqft	17
Rows	-	3
Fins per inch	-	16
Indoor Coil		
type	-	Lanced
Tube Size (Diameter)	inch	0.3125
Face Area	sqft	9.89
Rows	-	4
Fins per inch	-	16
Refrigerant Control	-	Thermal Expansion Valve

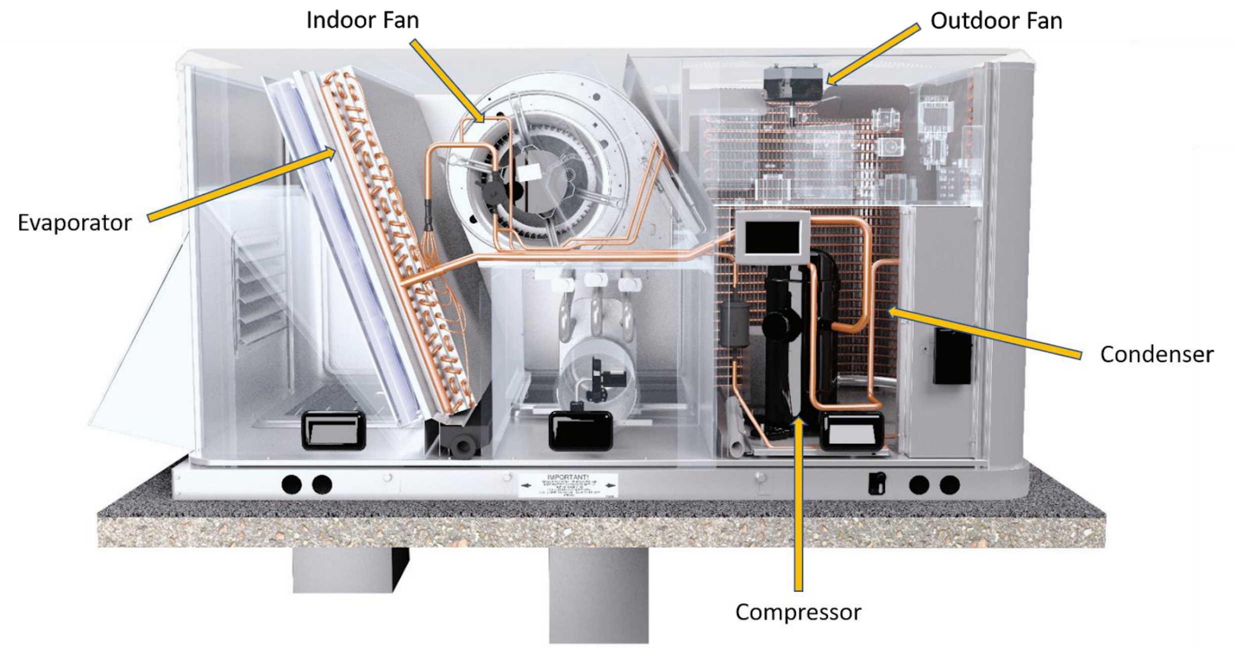

Figure S3 Trane RTU Layout (Credit: Trane)

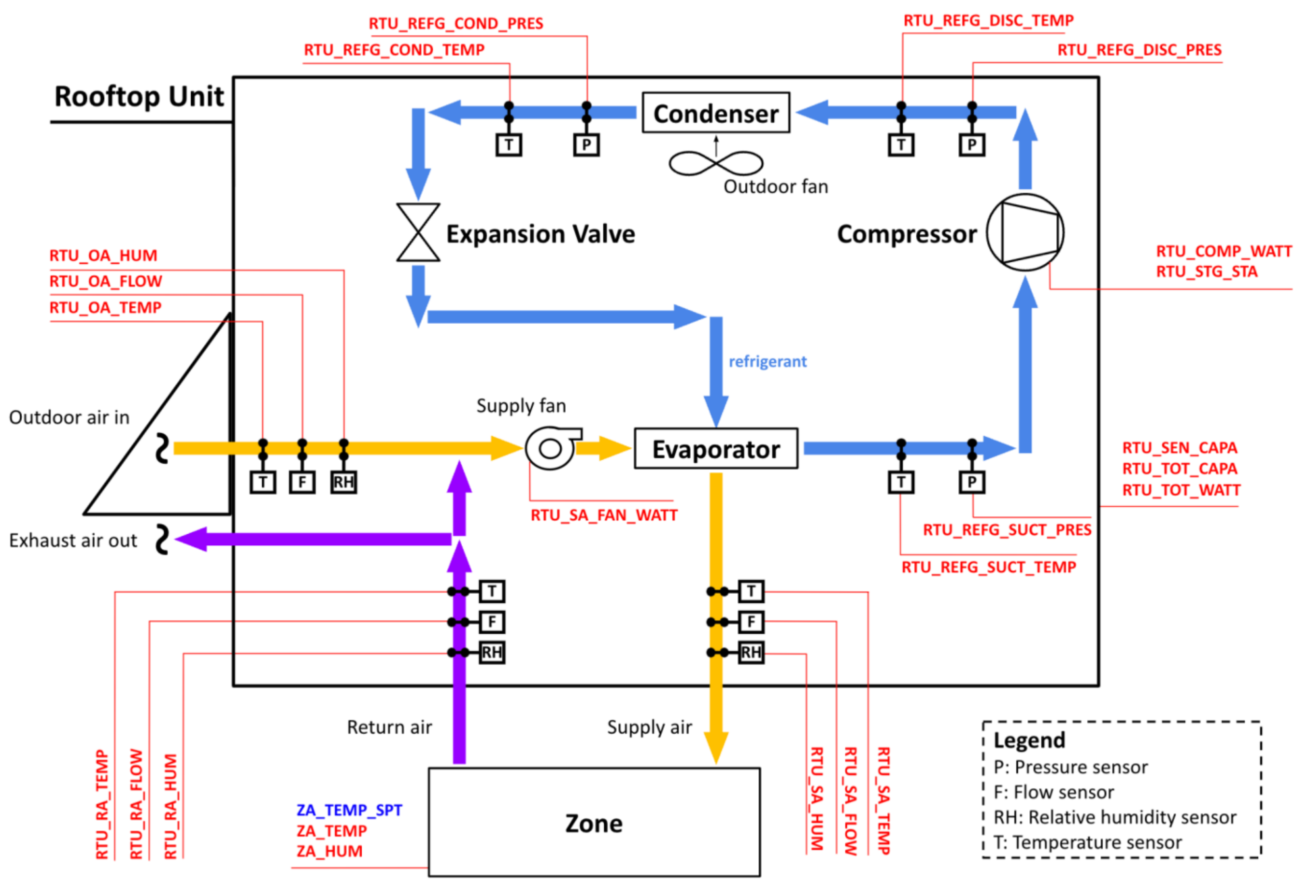

Figure S4 Schematic diagram of Simulated RTU with abbreviated data point names (summarized in Table S3)

S1.2 Description of control sequence

The RTU has the same operational behavior regardless of time and day of week. The zone cooling setpoint is fixed at 23°C at all times (no reset during unoccupied periods).

Compressor, staging control

The RTU compressor is controlled to maintain the thermal zone temperature according to the setpoint value. In order to avoid compressor cycling, a dead band value of 0.5 degC was implemented. A state machine (Figure S5) was used to stage the compressor between off, stage-1 and stage-2 based on the measured thermal zone temperature. The input signal is the measured thermal zone air temperature. The output signal is a value between 0 and 1, indicating the fractional operating capacity of the compressor, where a value of 0 indicates the compressor is off and a value of 1 indicates it is operating at its maximum capacity. During simulation of the Modelica RTU model, specified compressor capacities at or near zero resulted in reverse refrigerant flow, causing the solver to stall. Accordingly, we set the minimum compressor capacity fraction to 0.1 (corresponding to an 'off' condition) and removed the corresponding power consumption during postprocessing. Note that the compressor had no impact on the EnergyPlus thermal zone when operating in its 'off' state. For stage-1 operation, the state machine outputs a value of 0.67 (corresponding to the compressor operating at 67% of its capacity); and for stage-2 operation, the state machine outputs a value of 1 (100% capacity).

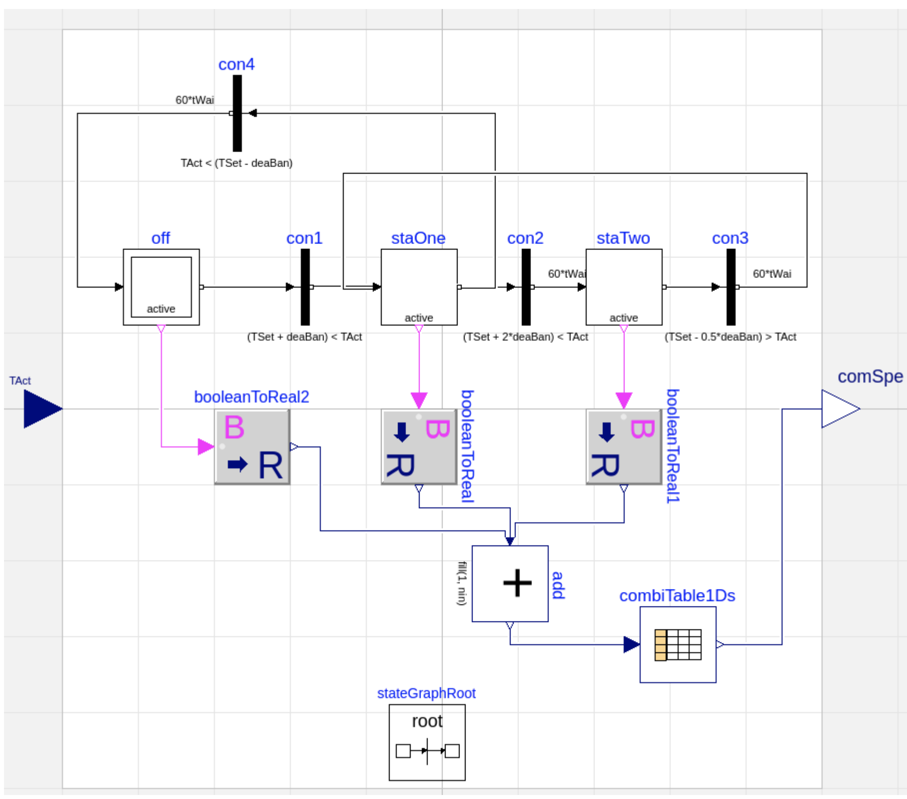

Figure S5 Modelica state Machine

Table S2 provides the details of the compressor sequence of operation, where the key constraints are the temperature setpoint and the value of the deadband parameter.

Table S2. Compressor sequence of operation

Constraints	Compressor status	Zone measured temperature (degC)	Waiting time (minutes)
Tset = 23 degC deadBan = 0.5 degC	off	< Tset-deadBan	--
	off to stage-1	>Tset+deadBan	0
	stage-1 to stage-2	>Tset+2*deadBan	10
	stage-2 to stage-1	<Tset-0.5*deadBan	10
	stage-1 to off	<Tset-deadBan	10

Thermal expansion valve controller

A simplified thermal expansion model was used to maintain a refrigerant superheating temperature of 5 Kelvin. A limited PI controller sets the flow coefficient Kv, which represents the mechanical components in the TXV and their reaction to an experienced superheating of the refrigerant at the evaporator outlet. The valve requires minimum and maximum Kv values (yMin = 0.002 m3/h in the model, yMax = 1 m3/h) as parameter input as well as the SuperHeatSetPoint. A time constant Ti (20s in the model) specifies the integrating behavior of the bulb expansion. The measured superheat temperature is required as input signal at port Delta_SH and can be obtained by using the SuperHeatSensor.

Supply (evaporator) air flow rate control

- Supply (evaporator) fan flow rate is determined by the compressor operating mode and the occupancy mode:
  - if the compressor RPM is off, the supply air flow rate operates at a flow rate of 1000 cfm
  - If the compressor operates in Low Stage, the supply fan operates at a flow rate of 1400 cfm
  - If the compressor operates in High Stage, the supply fan operates at a flow rate of 2000 cfm

Ventilation control

Outdoor air level determination is provided based on ASHRAE standard 62 minimum ventilation requirement: ventilation = $a * spacearea\ +\ b * n_{occ}$, where a = 5 cfm/per person and b = 0.06 cfm/sqft. The occupant number, n_{occ}, is estimated based on one person every 200 sq ft. The ventilation rate is constant throughout the simulation and specified at approximately 180 cfm.

S2 Data point summary

A total of 24 data points were included in the data sets. The data point descriptions are summarized in Table S2. 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 S3. Data point summary of the simulated RTU system

NO.	Points	Diagram Point Abbreviation	Description	Unit	Basic Point?
1	RTU: Supply Air Temperature	RTU_SA_TEMP	Simulated RTU supply air temperature	°F	Y
2	RTU: Supply Air Volumetric Flow Rate	RTU_SA_FLOW	Simulated RTU supply air volumetric air flow rate	cfm	N
3	RTU: Supply Air Humidity	RTU_SA_HUM	Simulated RTU supply air relative humidity	1-100	N
4	RTU: Return Air Temperature	RTU_RA_TEMP	Simulated RTU return air temperature	°F	Y
5	RTU: Return Air Volumetric Flow Rate	RTU_RA_FLOW	Simulated RTU return air volumetric air flow rate	cfm	N
6	RTU: Return Air Humidity	RTU_RA_HUM	Simulated RTU return air relative humidity	1-100	N
7	RTU: Outdoor Air Temperature	RTU_OA_TEMP	Simulated RTU outdoor air temperature	°F	Y
8	RTU: Outdoor Air Volumetric Flow Rate	RTU_OA_FLOW	Simulated RTU outdoor air volumetric air flow rate	cfm	N
9	RTU: Outdoor Air Humidity	RTU_OA_HUM	Simulated RTU outdoor air relative humidity	1-100	N
10	RTU: Compressor Stage Control	RTU_STG_STA	RTU compressor status; 0 – off, 0.67 - Stage 1 On, 1- Stage 2 On	0-1	Y
11	RTU: Discharge Temperature	RTU_REFG_DISC_TEMP	Array of refrigerant temperature on the RTU	°F	N
12	RTU: Condenser Outlet Temperature	RTU_REFG_COND_TEMP			N
13	RTU: Suction Temperature	RTU_REFG_SUCT_TEMP			N
14	RTU: Discharge Pressure	RTU_REFG_DISC_PRES	Array of refrigerant pressure on the RTU	Pa	N
15	RTU: Condenser Outlet Pressure	RTU_REFG_COND_PRES			N
16	RTU: Suction Pressure	RTU_REFG_SUCT_PRES			N

17	RTU: Total Power	RTU_TOT_WATT	RTU total electricity consumption	W	N
18	RTU: Compressor Power	RTU_COMP_WATT	Power of compressor	W	N
19	RTU: Fan Power	RTU_SA_FAN_WATT	RTU supply air fan power	W	N
20	RTU: Sensible Cooling Capacity	RTU_SEN_CAPA	RTU Sensible Cooling Capacity	W	N
21	RTU: Total Cooling Capacity	RTU_TOT_CAPA	RTU total cooling capacity	W	N
22	Zone: Air Temperature	ZA_TEMP	Room measured ambient temperature	°F	Y
23	Zone: Air Humidity	ZA_HUM	Room measured ambient relative humidity	1-100	N
24	Zone: Air Temperature Setpoint	ZA_TEMP_SPT	Room measured ambient temperature setpoint	°F	Y

A LBNL_FDD_Data_Sets_RTU_Sim.ttl file was also developed to present the data points and their relationships according to the Brick Schema[3](version 1.2). Figure S6 shows the RTU data point relations created under the Brick schema model.

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

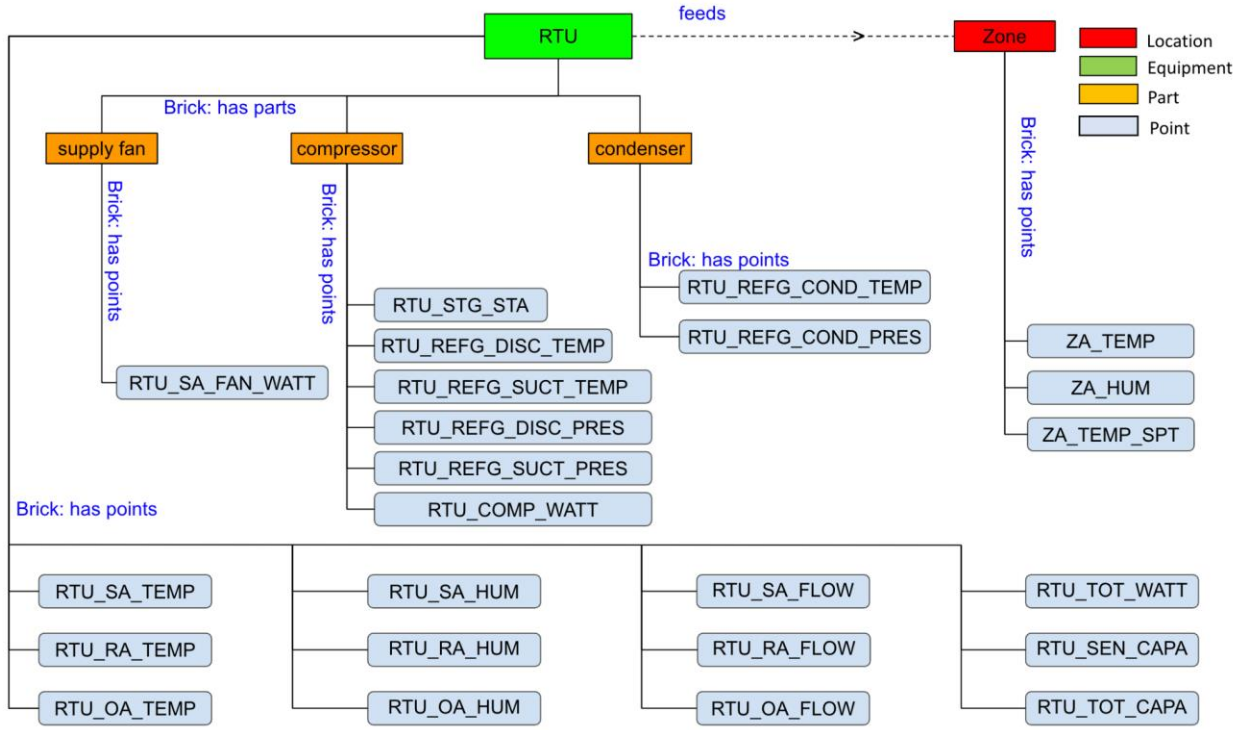

Figure S6 The schematic diagram of the Simulated RTU Brick model

S3 Faulty and fault-free scenarios

Simulations of six RTU fault types at different intensity levels were conducted to produce 24 files with faulted data for the simulated RTU. For each simulation, data were collected for a 100-day period (July 20 -October 28) using TMY3 weather data for San Francisco, located in ASHRAE Climate Zone 3C (marine). An unfaulted baseline case was also simulated to provide a reference for fault impact measurement. Table S4 describes the input scenarios that define the scope for data collection; for each faulted scenario, a fault with fixed intensity was applied continuously throughout the simulation period. Table S5 lists the csv file description for each faulty case and fault-free case.

Table S4. Input scenarios included in the dataset for the simulated RTU

Input Scenario		**Method of Fault Imposition**
Fault Type	**Fault Intensity**	
Refrigerant Overcharging	10%,15%,20%	Lowering refrigerant enthalpy. Less enthalpy results in higher charge because liquid has lower enthalpy, high density.
Refrigerant Undercharging	10%,15%,20%	Increasing refrigerant enthalpy. More enthalpy results in lower charge because liquid has higher enthalpy, low density.

Condenser fouling	Reduction of airflow through the condenser (10%,20%,30%,40%,50%)	Reducing condenser fan mass flow rate.
Evaporator fouling	Reduction of airflow through the evaporator (10%,20%,30%,40%,50%)	Reducing evaporator fan mass flow rate.
Refrigerant liquid-line restriction	Pressure drop due to liquid-line restriction: (1 bar, 4 bar, 8 bar, 10 bar)	Increasing the pressure drop just after the condenser outlet (cold liquid refrigerant)
Refrigerant suction-line restriction	Pressure drop due to suction-line restriction: (1 bar, 3 bar, 6 bar, 9 bar)	Increasing the pressure drop just after the evaporator outlet (hot gas refrigerant)
Unfaulted		NA

Table S5. File inventory

No	File Name	Fault Name	Fault Intensity
1	RTU_sim_condfouling10.csv	Percent reduction of airflow through the condenser	10%
2	RTU_sim_condfouling20.csv	Percent reduction of airflow through the condenser	20%
3	RTU_sim_condfouling30.csv	Percent reduction of airflow through the condenser	30%
4	RTU_sim_condfouling40.csv	Percent reduction of airflow through the condenser	40%
5	RTU_sim_condfouling50.csv	Percent reduction of airflow through the condenser	50%
6	RTU_sim_baseline.csv	Fault-free case	-
7	RTU_sim_evapfouling10.csv	Percent reduction of airflow through the evaporator	10%
8	RTU_sim_evapfouling20.csv	Percent reduction of airflow through the evaporator	20%
9	RTU_sim_evapfouling30.csv	Percent reduction of airflow through the evaporator	30%
10	RTU_sim_evapfouling40.csv	Percent reduction of airflow through the evaporator	40%
11	RTU_sim_evapfouling50.csv	Percent reduction of airflow through the evaporator	50%

12	RTU_sim_liquidpipe01bar.csv	Pressure drop due to liquid-line restriction	1 bar
13	RTU_sim_liquidpipe04bar.csv	Pressure drop due to liquid-line restriction	4 bar
14	RTU_sim_liquidpipe08bar.csv	Pressure drop due to liquid-line restriction	8 bar
15	RTU_sim_liquidpipe10bar.csv	Pressure drop due to liquid-line restriction	10 bar
16	RTU_sim_overcharge10.csv	Percent overcharge of refrigerant	10%
17	RTU_sim_overcharge15.csv	Percent overcharge of refrigerant	15%
18	RTU_sim_overcharge20.csv	Percent overcharge of refrigerant	20%
19	RTU_sim_suctionpipe01bar.csv	Pressure drop due to suction-line restriction	1 bar
20	RTU_sim_suctionpipe03bar.csv	Pressure drop due to suction-line restriction	3 bar
21	RTU_sim_suctionpipe06bar.csv	Pressure drop due to suction-line restriction	6 bar
22	RTU_sim_suctionpipe09bar.csv	Pressure drop due to suction-line restriction	9 bar
23	RTU_sim_undercharge10.csv	Percent undercharge of refrigerant	10%
24	RTU_sim_undercharge15.csv	Percent undercharge of refrigerant	15%
25	RTU_sim_undercharge20.csv	Percent undercharge of refrigerant	20%