Validation and Uncertainty Characterization for Energy Simulation

Multi-Zone HVAC System using ORNL's Flexible Research Platform (FRP)

For: ASHRAE SSPC140

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Major National Lab Bldg Technology R&D Test Facilities

Environmental Energy Technologies Division

(DRAFT – Illustrative only)

Buildings Materials & Components → Systems, Controls, Tools & Energy Information for Buildings → Grid & EV Interactions with Buildings

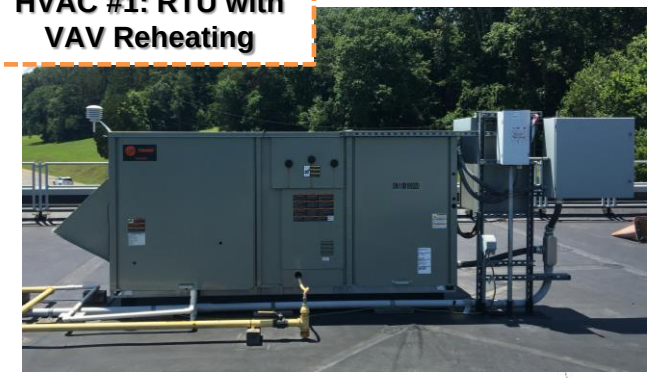
Designated User Facility

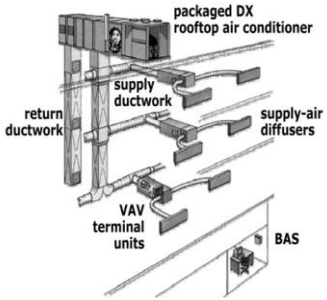
BTRIC					
Envelope Component Development & Testing	HVAC Sensors and Sequences, FDD	Whole Building Multi-zone HVAC Systems and Controls	Whole Building Mock Ups, Performance Testing		Grid & Distribution Equipment Testing
Whole Bldg Studies	Building Simulation Tool Validation	Envelope/ Multi-zone HVAC	Linking Building Operations to Grid Integration	TBD	Renewables & Generation Integration
Comparative Studies		Facades, Lighting, Zonal Systems/Perf		TBD	
Accelerated Emerging Technology Testing and Impacts Analysis	Zone Level Design & Performance of Integrated Systems	Integrated System and Component Controls Development & Testing	Linking Building Simulation & Energy Information to Operations & Performance		Energy Storage
FLEXLAB					ESIF

Flexible Research Platform

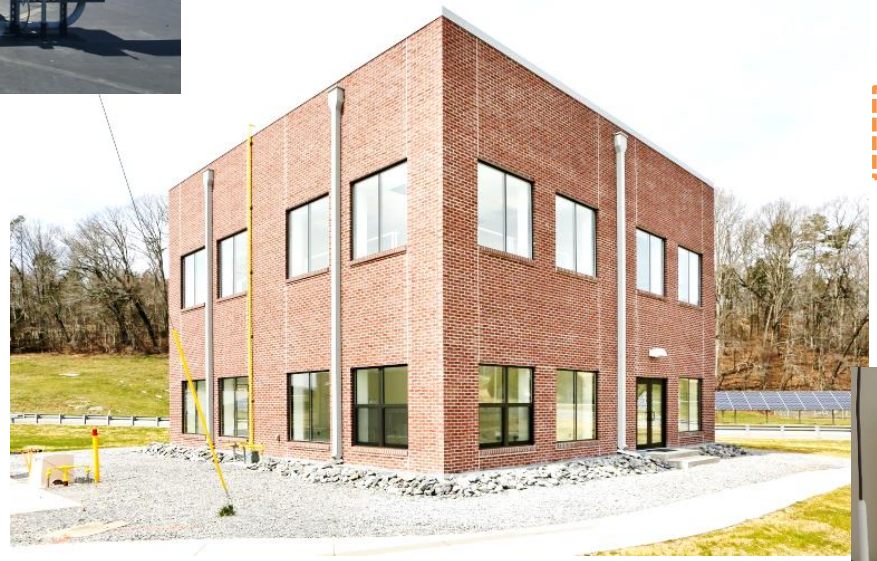
- HVAC System Performance Measurement, Modeling, Calibration and Validation

HVAC #1: RTU with VAV Reheating



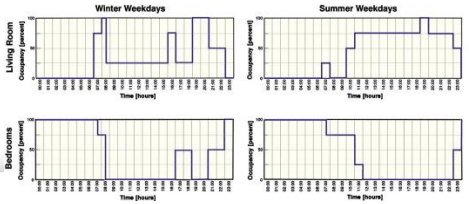


Weather Station



Sensors & Data Acquisition

Simulated Occupancy

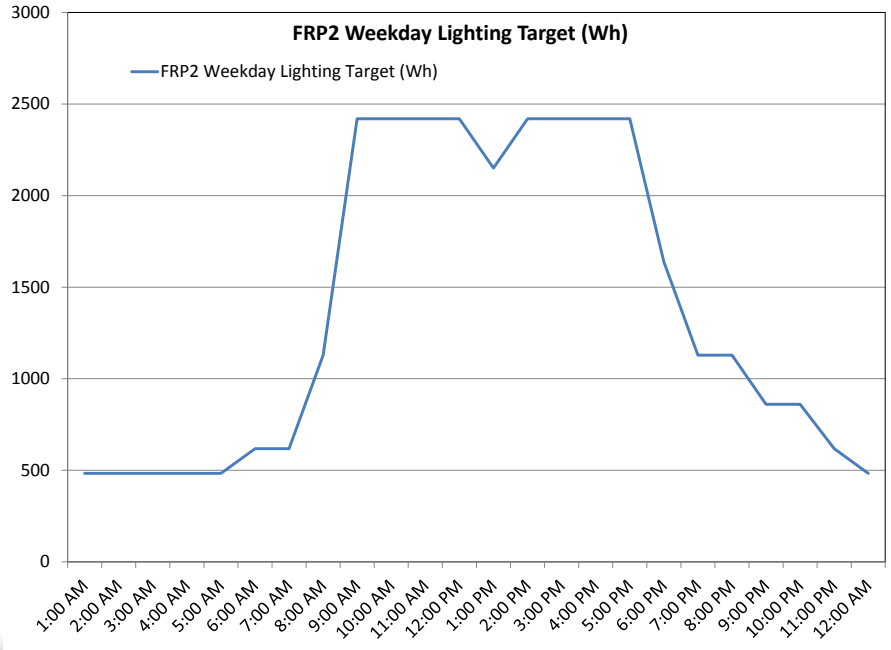


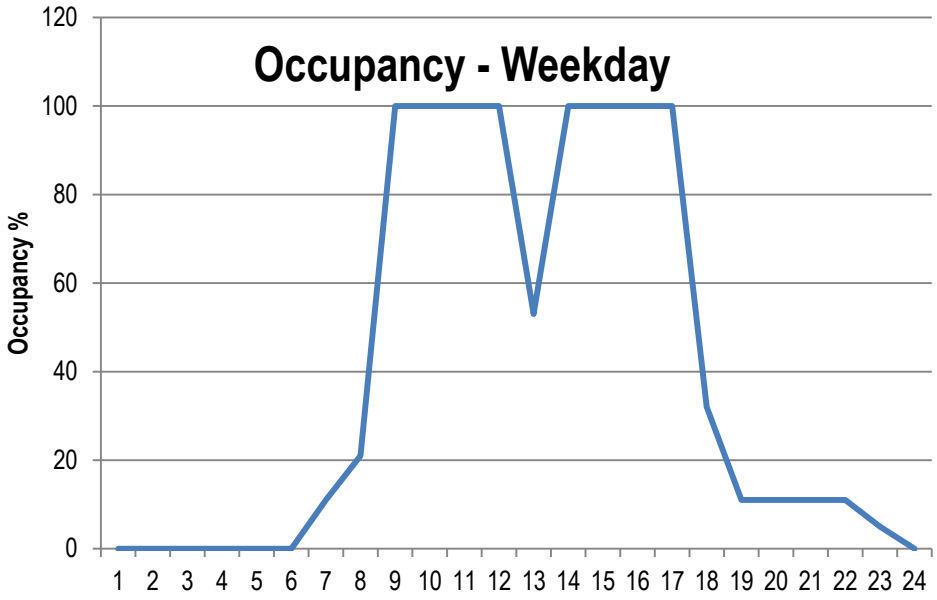
2 Story FRP Characteristics w/ Baseline RTU VAV Reheat

Building component	Value
Location	Oak Ridge, Tennessee
Building width	40 ft
Building length	40 ft
Story height (floor to floor)	14 ft
Number of floors	2
Number of thermal zones	10 (8 perimeter and 2 core)
Wall structure	Concrete masonry unit (CMU) with face brick
Wall insulation	Fiberglass R-11
Floor	Slab on grade
Roof structure	Metal deck with polyiso and EPDM
Roof insultaion	Polyiso R-18
Windows	Double clear glazing
Window-to-wall ratio	28%
Lighting power density	0.85 W/ft^2
Equipment power density	1.3 W/ft^2
Baseline RTU capacity	12.5 ton
EER	9.7
Reheat	VAV box with electric reheat

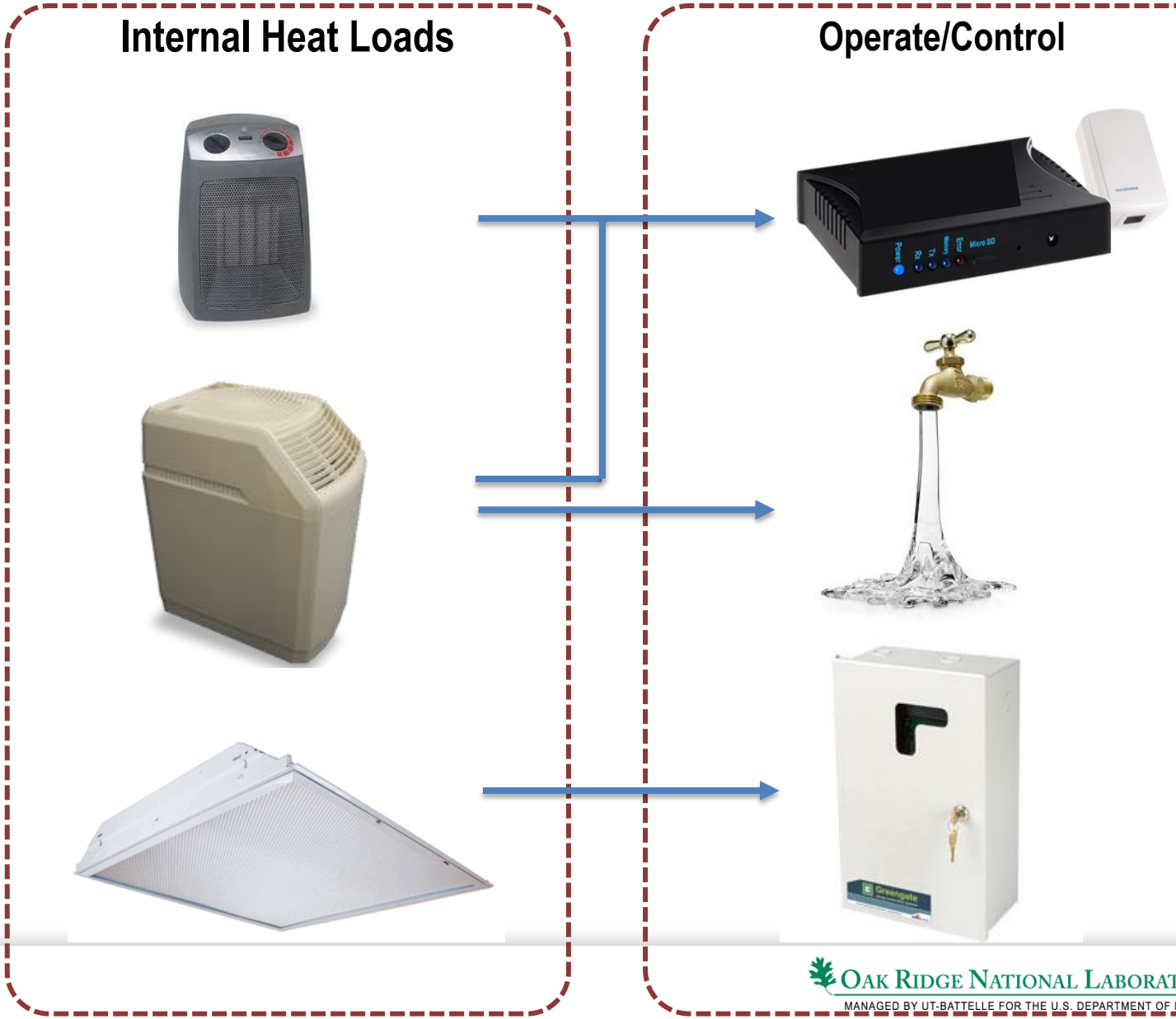
Occupancy Simulation

- Various sources to define the schedules & power density
  - ASHRAE 90.1-1989
  - Huang et al. (1990) 481 PROTOTYPICAL COMMERCIAL BUILDINGS FOR 20 URBAN MARKET AREAS, LBL-29798
  - Huang and Franconi (1999) COMMERCIAL HEATING AND COOLING LOADS COMPONENT ANALYSIS
  - PNNL report (1990) ARCHITECT'S AND ENGINEER'S GUIDE TO ENERGY CONSERVATION IN EXISTING BUILDINGS: Volume 1 - Energy Use Assessment and Simulation Methods

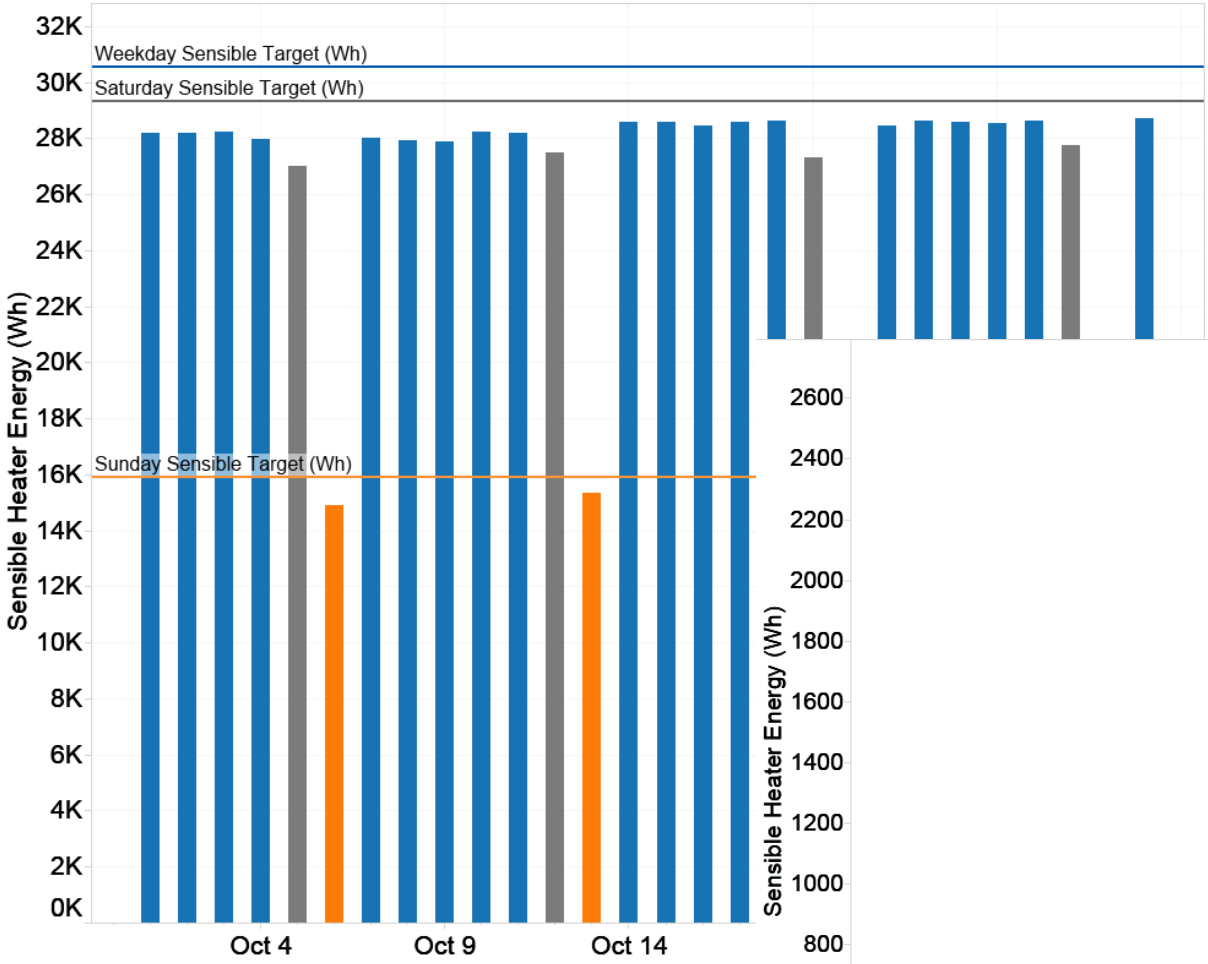




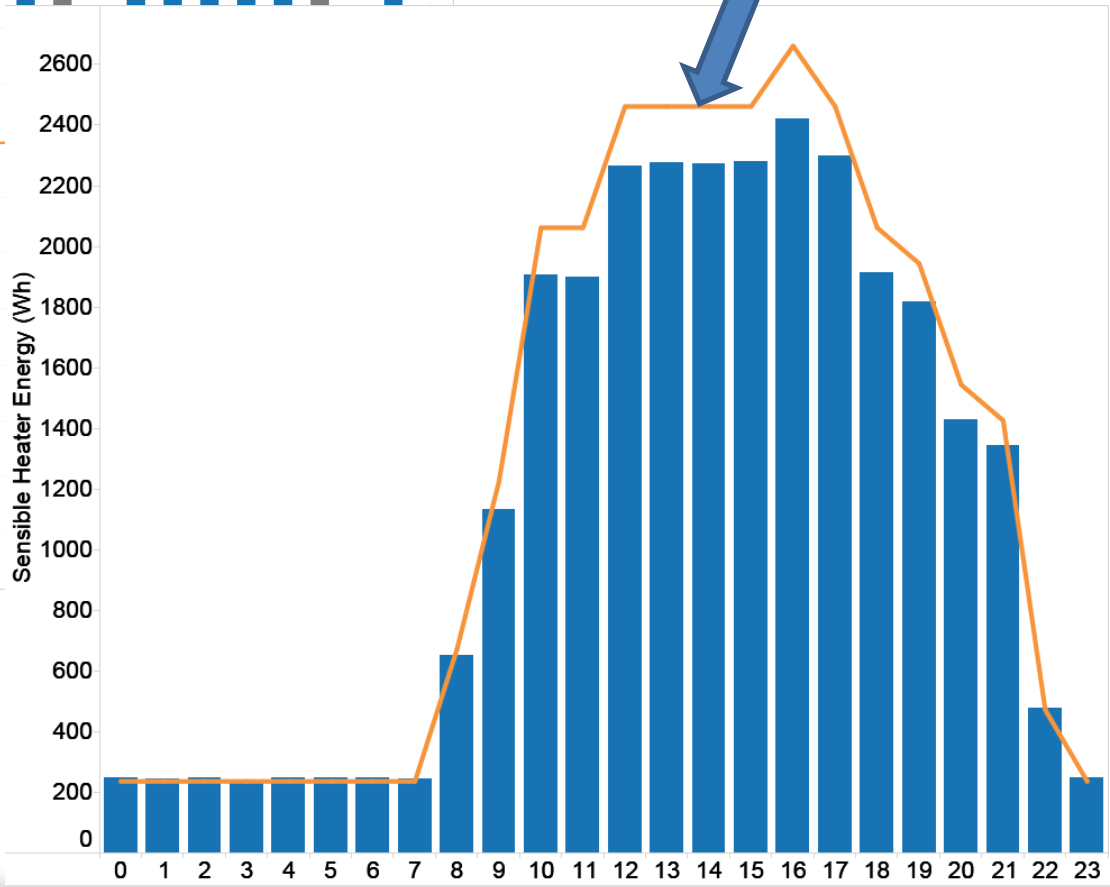
Add latent, sensible, and lighting load to space according to occupancy schedule



Validation Example – FRP1 Sensible



Hourly targets



FRP2 DAQ Hardware

- 1 Master Cabinet
- 4 Peripheral Cabinets
- 256 Thermistor Channels
- 256 Single Ended Voltage Channels
- 100 Thermocouple Channels
- 64 Frequency input or 5V control Channels

FRP2 Installed Sensors

- 35 Temp/RH Probes
- 6 Refrigerant Side Immersion Thermistors
- 6 Refrigerant Side Pressure Transducers
- 2 Refrigerant Mass Flow Sensors
- 1 Natural Gas Mass Flowmeters
- 2 Airflow Measurement Stations
- 16 HVAC Power Measurements (Wattnode and CTs)
- 21 General Building Power Measurements (Wattnode and CTs)

FRP 2 Sensors

Refrigerant mass flow

Natural gas flow

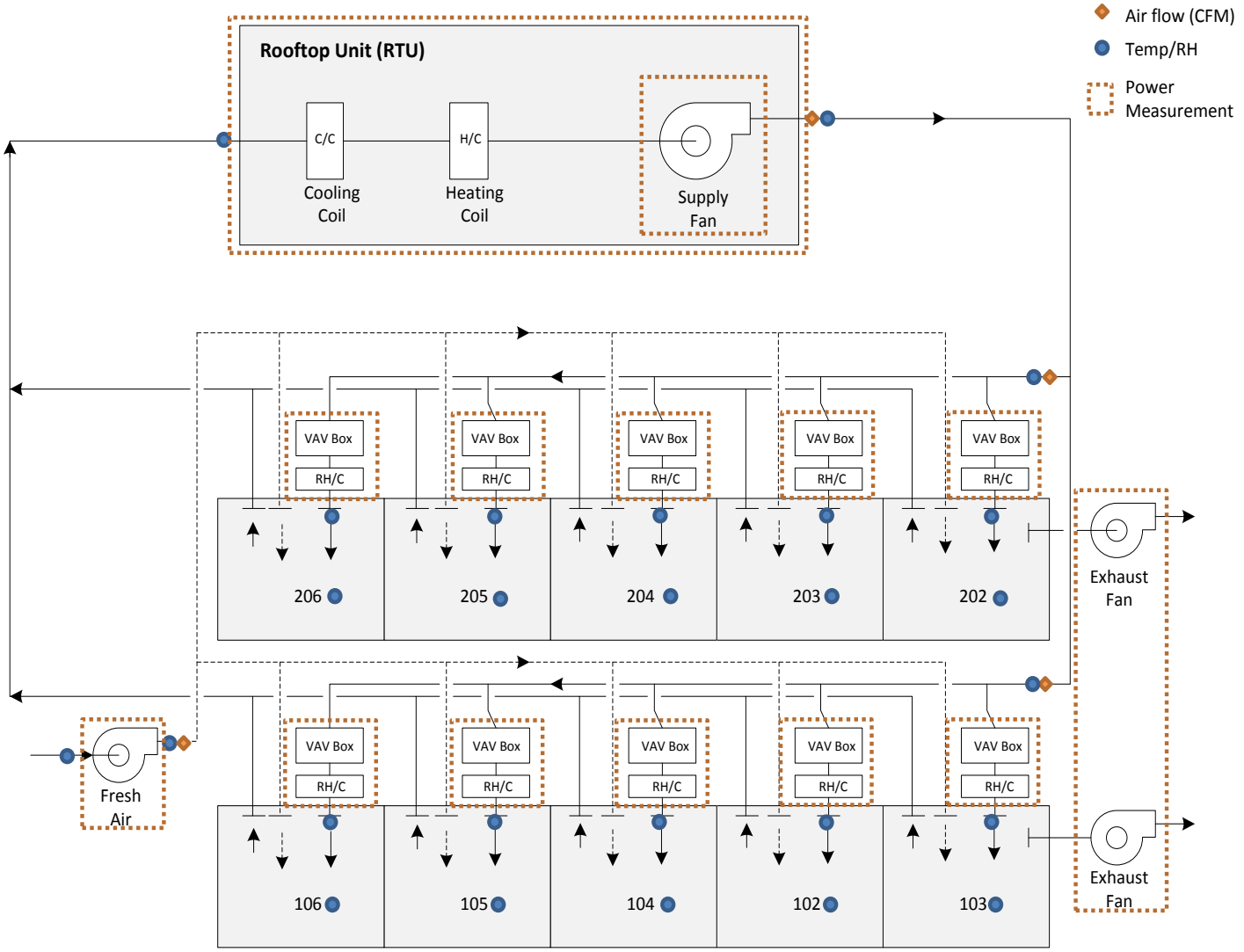
Electrical power

Refrigerant temperature and pressure

Airflow

Air temperature/relative humidity

Layout of Measurements



Technical Specs of Measurement

Sensors	Measurement	Accuracy
Campbell Sci HC2S3-L	Temperature/relative humidity (RH)	±0.1°C and ±0.1% RH @ 23°C
Continental Controls WNB-3D-240P	Power	±0.5% of reading
Omega 44031 immersion thermistor probes	Temperature	@ 0 to 70°C is ±0.1°C
Omega PX409-750-A5V pressure transducers	Pressure	±0.08% best straight line maximum
Sierra BT620 thermal flowmeter	Gas flow	±1% of full scale (actual gas calibration) and ±1% of full scale/±3% of reading (correlation); repeatability ±0.2% of full scale
Air monitor fan evaluators paired to DPT2500 Plus transmitters	Air flow	DTP2500—0.25% of natural span, including hysteresis, deadband, nonlinearity, and nonrepeatability; fan evaluator—±2%

Evaluation Metrics/Validation Parameters

#	Parameters	Sub-parameters	Unit	Note
1 - 3	RTU energy use	DX cooling	Wh	2 stage cooling coil
		Evaporative fan	Wh	Main supply fan with VFD
		VAV box (electric reheat)	Wh	Individual electric reheating for each VAV box
4	RTU discharge temperature		F	Fixed discharge temperature for RTU
5	RTU return air temperature		F	Mixed return air temperature from 10 zones
6	RTU supply air flow		CFM	
7	Supply air flow for each zone		CFM	TBD—no sensors are available for zone-level air flow measurement yet
8	Room temperature for each zone		F	10 measurement points. Temperature sensor is located in the middle of each zone
9	Room RH for each zone		%	10 measurement points. RH sensor is located in the middle of each zone

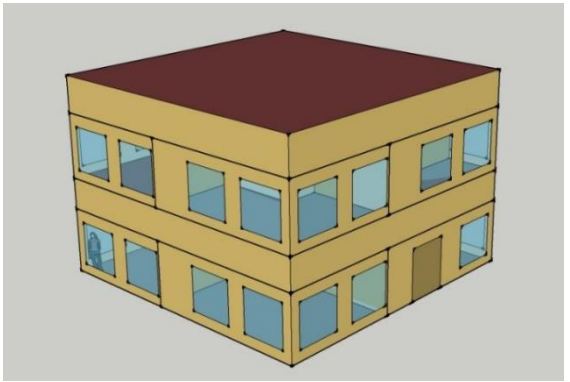
Develop and calibrate FRP model

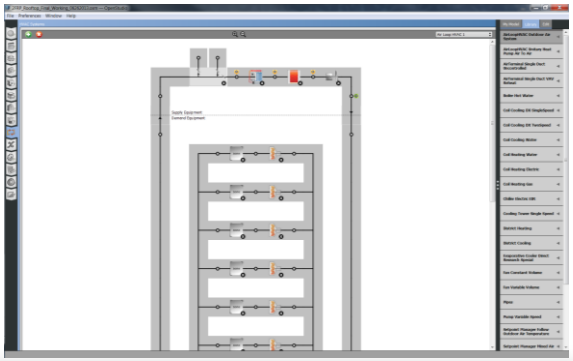
As-Built model

- Use previously developed model with RTU
- Modify the model with recent envelop retrofit and system changes

Calibrate the model

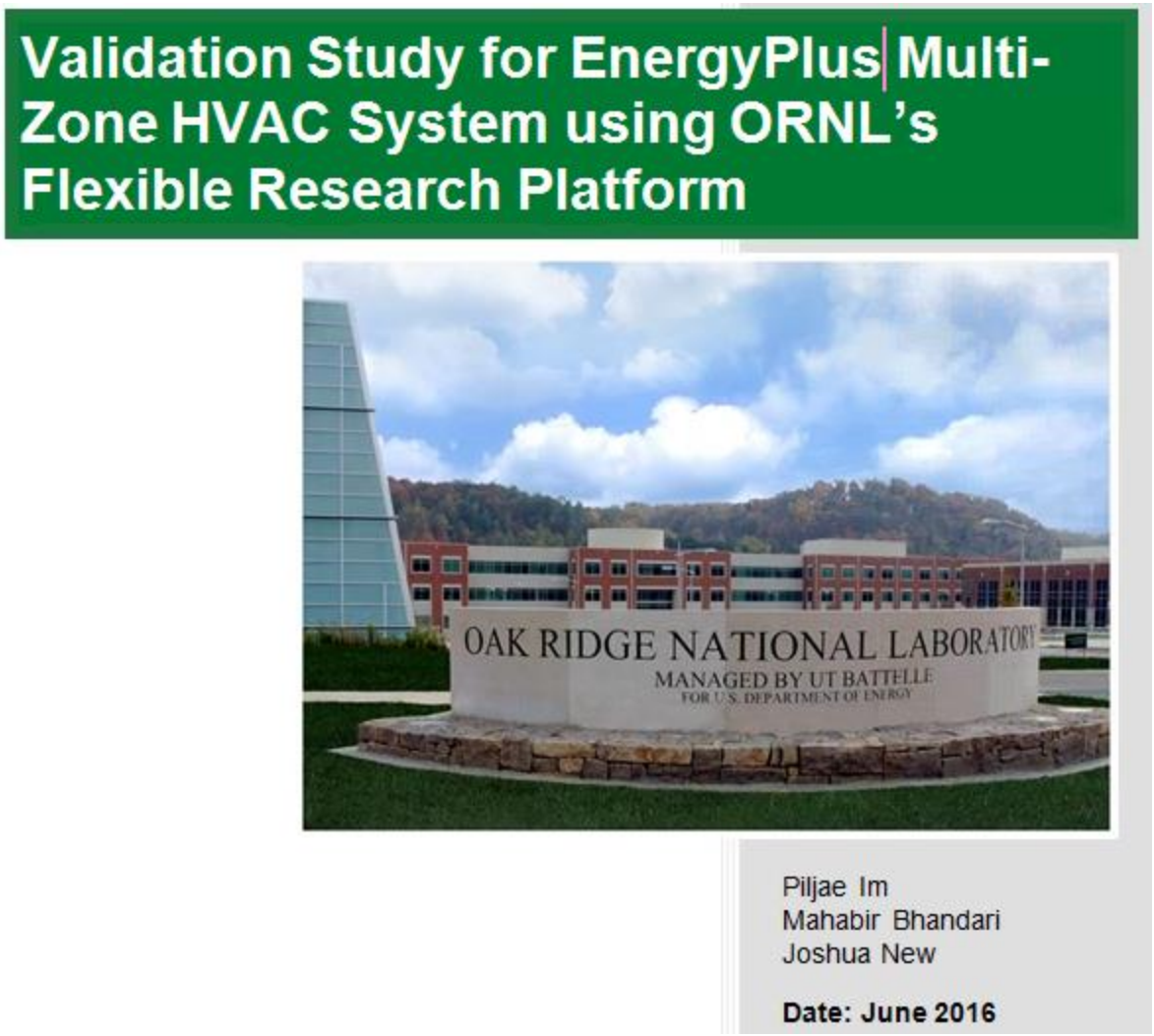
- Use existing measured data : Summer 2015-Spring 2016
- Run FRP with 3 full days without HVAC & no internal gains, no exhaust (Summer FY 16)
- Run FRP with 3 full days with HVAC without setback and no internal gains, no exhaust (Summer FY 16)
- Run FRP with 3 full days without HVAC & no internal gains, no exhaust (Winter FY 17)
- Run FRP with 3 full days with HVAC without setback and no internal gains, no exhaust (Winter FY 17)





Multi-Year Plan

- Outlines current multi-year plan
  - 19 pages



Experimental Plan : Cooling Equipment Validation

ASHRAE 140 Cooling equipment cases

- Objective is to verify envelope and mechanical properties under idealized test conditions
- Building/system specification not consistent with FRP
- E.g., envelope R-value ~567 h•ft^2•°F/Btu, and the infiltration rate is zero, which cannot be realized in real buildings such as FRP.
- Reviewed CE100, CE110, CE120, CE130, CE150, CE160, and CE165
- Suggested a set of test conditions

Experimental Plan : Cooling Equipment Validation

Test period: One week in summer for each test case, 1 day for warm up and 3 days with HVAC operation

Test 1: Cooling Baseline

- No occupancy emulation
- All internal lights are turned off
- Fixed discharge temperature of 55°F and no Outdoor air ventilation or exhaust air
- No humidity control and no heating
- Fixed zone set point temp of 72°F

Experimental Plan : Cooling Equipment Validation

Test 2: Reduced outdoor dry-bulb temperature

- Same as ***Test 1*** (i.e., tested when colder than Test 1)

Test 3: Cooling with increased thermostat set point

- Increase zone set point to: 26.7°C (80°F)
- Rest of the conditions same as in ***Test 1***

Test 4: Cooling with low part-load ratio

- Modulate part load ratio – use internal heaters
- Rest of the conditions same as in ***Test 1***

Experimental Plan : Cooling Equipment Validation

Test 5: Latent load at high sensible heat ratio

- Use heaters and humidifiers
- Rest of the conditions same as in ***Test 1***

Test 6: Increased thermostat setpoint at high sensible heat ratio

- Increase zone set point to: 26.7°C (80°F)
- Rest of the conditions same as in ***Test 5***

Test 7: Variation of thermostat setpoint at high sensible heat ratio

- Zone set point includes setup/setback:
  - through 6 a.m.: 88°F
  - 6 a.m. through 6 p.m.: 75°F
  - 6 p.m. through 12 a.m.: 88°F
- Rest of the conditions same as in ***Test 6***

Experimental Plan : Heating Equipment Validation

ASHRAE 140 Heating equipment cases

- 140 test cases include a fuel fired furnace, but FRP is equipped with electric reheat only.
- Reviewed HE100, HE210, and HE220
- Suggested only two test conditions

Experimental Plan : Heating Equipment Validation

ASHRAE 140 Heating equipment cases

Test 8: Heating Baseline

- No occupancy emulation
- All internal lights are turned off
- Fixed discharge temperature of 55°F and no OA or EA (VAV terminal reheat, some rooms need cooling even during heating season; from RTU to VAV boxes, damper modulating)
- No humidity control
- Fixed zone set point temp of 68°F

Test 9: Heating with setback thermostat

- Zone setpoint includes setup/setback:
  - through 6 a.m.: 59°F
  - 6 a.m. through 6 p.m. 69°F
  - 6 p.m. through 12 a.m.: 59°F
- Rest of the conditions same as in ***Test 6***

Discussion

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