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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Flexible Research Platform

- HVAC System Performance Measurement, Modeling, Calibration and Validation

HVAC #1: RTU with VAV Reheating

Weather Station

Sensors & Data Acquisition

Simulated Occupancy

Oak Ridge National Laboratory

MANAGED BY UT-BATTELLE FOR THE U.S. DEPARTMENT OF ENERGY
## 2 Story FRP Characteristics w/ Baseline RTU VAV Reheat

<table>
<thead>
<tr>
<th>Building component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Oak Ridge, Tennessee</td>
</tr>
<tr>
<td>Building width</td>
<td>40 ft</td>
</tr>
<tr>
<td>Building length</td>
<td>40 ft</td>
</tr>
<tr>
<td>Story height (floor to floor)</td>
<td>14 ft</td>
</tr>
<tr>
<td>Number of floors</td>
<td>2</td>
</tr>
<tr>
<td>Number of thermal zones</td>
<td>10 (8 perimeter and 2 core)</td>
</tr>
<tr>
<td>Wall structure</td>
<td>Concrete masonry unit (CMU) with face brick</td>
</tr>
<tr>
<td>Wall insulation</td>
<td>Fiberglass R-11</td>
</tr>
<tr>
<td>Floor</td>
<td>Slab on grade</td>
</tr>
<tr>
<td>Roof structure</td>
<td>Metal deck with polyiso and EPDM</td>
</tr>
<tr>
<td>Roof insulation</td>
<td>Polyiso R-18</td>
</tr>
<tr>
<td>Windows</td>
<td>Double clear glazing</td>
</tr>
<tr>
<td>Window-to-wall ratio</td>
<td>28%</td>
</tr>
<tr>
<td>Lighting power density</td>
<td>0.85 W/ft²</td>
</tr>
<tr>
<td>Equipment power density</td>
<td>1.3 W/ft²</td>
</tr>
<tr>
<td>Baseline RTU capacity</td>
<td>12.5 ton</td>
</tr>
<tr>
<td>EER</td>
<td>9.7</td>
</tr>
<tr>
<td>Reheat</td>
<td>VAV box with electric reheat</td>
</tr>
</tbody>
</table>
Occupancy Simulation

• Various sources to define the schedules & power density
  
  – ASHRAE 90.1-1989
  – Huang et al. (1990) 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

Internal Heat Loads

Sensible: from occupants and MELs

Latent: from occupants

Lighting

Operate/Control
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

Rooftop Unit (RTU)

C/C
Cooling Coil

H/C
Heating Coil

Supply Fan

VAV Box
RH/C

VAV Box
RH/C

VAV Box
RH/C

VAV Box
RH/C

VAV Box
RH/C

Air flow (CFM)

Temp/RH

Power Measurement

Fresh Air

Exhaust Fan

Supply Fan

Exhaust Fan
# Technical Specs of Measurement

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

<table>
<thead>
<tr>
<th>#</th>
<th>Parameters</th>
<th>Sub-parameters</th>
<th>Unit</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RTU energy use</td>
<td>DX cooling</td>
<td>Wh</td>
<td>2 stage cooling coil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evaporative fan</td>
<td>Wh</td>
<td>Main supply fan with VFD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VAV box (electric reheat)</td>
<td>Wh</td>
<td>Individual electric reheating for each VAV box</td>
</tr>
<tr>
<td>4</td>
<td>RTU discharge temperature</td>
<td></td>
<td>F</td>
<td>Fixed discharge temperature for RTU</td>
</tr>
<tr>
<td>5</td>
<td>RTU return air temperature</td>
<td></td>
<td>F</td>
<td>Mixed return air temperature from 10 zones</td>
</tr>
<tr>
<td>6</td>
<td>RTU supply air flow</td>
<td></td>
<td>CFM</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Supply air flow for each zone</td>
<td></td>
<td>CFM</td>
<td>TBD—no sensors are available for zone-level air flow measurement yet</td>
</tr>
<tr>
<td>8</td>
<td>Room temperature for each zone</td>
<td></td>
<td>F</td>
<td>10 measurement points. Temperature sensor is located in the middle of each zone</td>
</tr>
<tr>
<td>9</td>
<td>Room RH for each zone</td>
<td></td>
<td>%</td>
<td>10 measurement points. RH sensor is located in the middle of each zone</td>
</tr>
</tbody>
</table>
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 $\sim 567 \text{ h} \cdot \text{ft}^2 \cdot ^\circ\text{F}/\text{Btu}$, 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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