Validation and Uncertainty Characterization for Energy Simulation

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

For: ASHRAE 140
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PIs – Piljae Im and Mahabir Bhandari
Outline

• Test building description and measurement setup
• Validation test plan
• Preliminary results: Measured vs. Simulation
• Summary
Flexible Research Platform (FRP)

HVAC System Performance Measurement, Modeling, and Validation

HVAC #1: RTU with VAV Reheating

Simulated Occupancy

Weather Station

Sensors & Data Acquisition
FRP Characteristics w/ Baseline RTU

<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>Aluminum 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>
# 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>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>
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; no internal loads
- 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 with real weather condition)

**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 set point 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: 12 a.m. through 6 a.m.: 88°F (31 °C); 6 a.m. through 6 p.m.: 75°F (24 °C); 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

Test 8: Heating Baseline:
- No occupancy emulation
- All internal lights are turned off; no internal loads
- No humidity control
- Fixed zone set point temp of 70°F (21°C)

Test 9: Heating with setback thermostat:
- Zone set point includes setup/setback: through 6 a.m.: 59°F (15°C)
- ; 6 a.m. through 6 p.m.: 70°F; 6 p.m. through 12 a.m.: 59°F ).
- Rest of the conditions same as in Test 6
Develop FRP model

As-Built initial model

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

Modifications

- Building envelope model updates
  - Update exterior walls per partial wall retrofit
  - Update infiltration rate per blower door tests
  - Update power densities per Interior light intensity and schedule; Plug load intensity and schedule
  - Add interior shading devices
- Using actual weather data

Selected 17 days (when the RTU fully conditioned the building) of data for preliminary comparison
Preliminary results: Lighting/Plug load
Preliminary Results: RTU Cooling

![Graph showing outdoor air temperature vs. cooling coil electric energy use]

- **Cooling Coil Elec Energy Use (kWh)**
- **Outdoor Air Temperature (F)**

- **Measured**
- **Simulated**

- **Air System Cooling Coil Elec. Energy (Comp. + cond.) [Wh]**

- **Time (h)**

- **Cooling Coil Elec. Energy measured [W]**
- **Cooling Coil Elec. Energy simulated [W]**
Preliminary Results: VAV Reheating

![Graph showing VAV Reheating Energy Use (kWh) vs. Outdoor Air Temperature (F)]

- **VAV Reheating Energy Use (kWh)**
- **Outdoor Air Temperature (F)**

Graph Showing Measured vs. Simulated Data:
- **Measured**
- **Simulated**

![Graph showing VAV Reheat Coil Elec. Energy [Wh] vs. Time (h)]

- **VAV Reheat Coil Elec. Energy measured [W]**
- **VAV Reheat Coil Elec. Energy simulated [Wh]**

Time (h):
1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56  57  58  59  60  61  62  63  64  65  66  67  68  69  70  71  72  73  74  75  76  77  78  79  80  81  82  83  84  85  86  87  88  89  90  91  92  93  94  95  96  97  98  99  100

VAV Reheating Energy Use (kWh):
0  5  10  15  20  25

Outdoor Air Temperature (F):
0.0  20.0  40.0  60.0  80.0  100.0
Preliminary Results: HVAC Total

Outdoor Air Temperature (F)

Total HVAC Energy Use (kWh)

Measured
Simulated

RTU HVAC Energy measured [kW]  RTU HVAC Energy simulated [kW]
Whole Building Energy Use Comparison

<table>
<thead>
<tr>
<th></th>
<th>Lights</th>
<th>Equipment</th>
<th>Cooling</th>
<th>Heating:Gas</th>
<th>Heating:Elec.</th>
<th>Fan</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured</td>
<td>541.1</td>
<td>1071.7</td>
<td>563.4</td>
<td>56.9</td>
<td>722.6</td>
<td>454.0</td>
<td>3409.8</td>
</tr>
<tr>
<td>Simulated</td>
<td>551.1</td>
<td>1151.1</td>
<td>605.9</td>
<td>16.3</td>
<td>862.5</td>
<td>378.8</td>
<td>3565.8</td>
</tr>
</tbody>
</table>
Summary/Results so far

• Developed an experimental plan for validation study
• Instrumented the building for heating and cooling season tests
• Modified existing FRP model to incorporate the envelope modifications
• Heating season test is ongoing
Questions/Discussion

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Additional/Reference slides
**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

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**Graphs**

1. **FRP2 Weekday Lighting Target (Wh)**
   - FRP2 Weekday Lighting Target (Wh)

2. **Occupancy - Weekday**
   - Occupancy %

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**Oak Ridge National Laboratory**

Managed by UT-BATTELLE for the U.S. Department of Energy
Add latent, sensible, and lighting load to space according to occupancy schedule

**Internal Heat Loads**

- **Sensible**: from occupants and MELs
  - Image of a heater

- **Latent**: from occupants
  - Image of an air purifier

- **Lighting**
  - Image of a light fixture

**Operate/Control**

- Image of a control panel
Validation Example – FRP1 Sensible

Hourly targets
Oct 15, 2013
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