ASHRAE RP-1729

Experimental Verification of Cooling Load Calculations for Spaces with Non-Uniform Temperature Radiant Surfaces

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Objective

Discuss
• Current and
• Future experiments

For objective #1:
“Conduct experiments in test rooms to assess the differences in peak and hourly cooling loads between radiant and convective cooling systems.”

NOTE
• TOOLKIT Code repair and
• Modeling results will be discussed later
Outline of the presentation

• Experimental set-up (previous and new additions)
• Experimental Matrix of finished experiments
• Results from finished Tests
• Effects of direct sun patch
• Operative temperature calculation & control
• Suggestions for the final experiment list
SCHEMATIC OF EXPERIMENTAL SETUP
EXPERIMENTAL PROGRAMME

- EXPERIMENTAL PROTOCOLS
  - Lab No. 1 (Left side) conditioned with Radiant cooling panel
  - Lab No. 2 (Right side) equipped with All-air system
  - One-day Pre-conditioning cycling used to capture incremental changes in loads before running full-scale experiment
MEASUREMENT INSTRUMENTATION

Temperature Measurement

- 46 Omega 44033 thermistors for wall surface temperature measurement
- 9 Omega 44033 thermistors for monitoring radiant panel surface temperature
- 9 Omega 44033 thermistors for window surface temperature measurement
- 6 Omega 44033 thermistors installed on a vertical stand at standard height levels (0.1, 0.6, 1.1, 1.6, 2.1, 2.6 m) for air temperature measurement
- Air Temp. sensors installed on supply and Return vents for control purpose
Internal heat sources

- Radiative Side Panel
- Internal Cylinder Heater
- Internal Box Heater
- Pure Convective Heater
- Rheostat (Power Control)
- X-10 Module
- Data logger
### EXPERIMENTAL MATRIX OF FINISHED EXPERIMENTS

<table>
<thead>
<tr>
<th>No. of Case Study</th>
<th>Studied Phenomena Description</th>
<th>Case Condition Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Effect of solar and radiative heat gains</td>
<td>Cooling performance of Radiant panel with no air vs. All-Air system under constant radiative heat gain by side radiative resistive panels and daily solar heat gain</td>
</tr>
<tr>
<td>2</td>
<td>Effect of internal convective and radiative loads</td>
<td>Cooling performance of Radiant panel with air vs. All-Air system under internal convective and radiative heat gains provided by side panel and internal cylinder and box heaters</td>
</tr>
<tr>
<td>3</td>
<td>Effect of constant internal loads</td>
<td>Cooling performance of Radiant panel with air vs. All-Air system under solar and constant internal heat gains provided by interior cylinder and box heaters</td>
</tr>
<tr>
<td>4</td>
<td>Effect of ON-OFF typical office working schedule</td>
<td>Cooling performance of Radiant panel with air vs. All-Air system under solar and internal heat gains according to ON-OFF working schedule in typical office spaces</td>
</tr>
<tr>
<td>5</td>
<td>Effect of Dominant Solar heat gain</td>
<td>Cooling performance of Radiant panel with air vs. All-Air system under dominant solar heat gain with ON-OFF working schedule for the cooling system in typical office spaces</td>
</tr>
</tbody>
</table>

NOTE: We conducted ~15 experiments and, above and in the following slides, we are showing some successful examples. Some are repetitions and many experiments were there for learning what we CAN AND CANNOT DO.

In all experiments we enforce strict control like: relevant boundary conditions, precise control of setpoint temperature, energy balance (in the control spaces and whole chambers), …
EXPERIMENTAL MEASUREMENT TESTS

NOTE: in this first example we are giving you details about experimental set-up while in the following 4 examples we will show you just summary of the major results for different set-ups (examples #1,2,4,5) from the table

➢ Experiment No. 1: Radiant panel vs All-Air system under solar diffuser load and constant internal loads

- **Purpose:** Comparative study for cooling performance of combined Radiant Panel and ventilation system vs All-Air system under solar and constant internal loads
- **Load Type:** Solar heat gain + constant internal convective and radiative heat gains provided by cylinder and box heaters (250 W)
- **Load schedule:**
  12:00 AM – 11:59 PM => internal load (250 W)
- **Starting Date:** 08-17-2017
- **Stop Date:** 08-20-2017
- **Set point zone air Temperature:** 28 (°C)
- **Lab No. 1** was conditioned with combined radiant panel and ventilation system to mimic real cooling operation in typical office buildings, while **Lab No. 2** equipped with All-air system
- **Employed Ventilation systems:**
  - Lab No. 1 => 2.8 ACH
  - Lab No. 2 => 8 ACH
- **Heat Extraction rate from the space:**
  \[ Q_{\text{Radiant Panel}} = Q_{\text{Rad}} = m_w c_{pw} (T_{\text{CWR}} - T_{\text{CWS}}) \]
  \[ Q_{\text{air}} = m_a c_p (T_{\text{RA}} - T_{\text{SA}}) \]
Lab No. 1 => Radiant panel + air system
Lab No. 2 => All-Air system
Wall surface temperature (C): 08-17-2017 to 08-20-2017

AUST (Averaged unheated surface Temp)=MRT_no panel: 08-17-2017 to 08-20-2017

Air Sensor Temp on vertical stand (C): 08-17-2017 to 08-20-2017

Lab No. 1 => Radiant panel + air system
Lab No. 2 => All-Air system
- **Experiment No. 2: Radiant panel vs All-Air system under solar and radiative loads**

  - **Purpose**: Comparative study for cooling performance of Radiant Panel vs All-Air system under solar and radiative loads
  - **Load Type**: Solar heat gain + Radiative heat gains provided by side panel (300 W)
  - **Load schedule**: 6:00 PM – 8:00 AM => Side panel OFF
    8:00 AM – 6:00 PM => Side panel ON
  - **Set point** zone air Temperature: 28 (C)
  - **Start Date**: 08-01-2017
  - **Stop Date**: 08-05-2017
  - **Lab No. 1** conditioned with only radiant panel (not combined radiant panel and ventilation system)
  - A good agreement for space heat extraction between radiant panel and all-air system
  - Radiant panel preserved space cooling as well as all-air system with lower electricity consumption
Total Net space heat gain (solar+Internal load+Conduction): 08-01-2017 to 08-05-2017

Net Space Sensible Cooling Rate: LAB1 vs LAB2: 08-01-2017 to 08-05-2017

AUST (Averaged Unheated Surface Temp) = MRT_no panel: 08-01-2017 TO 08-05-2017

Air Temperature (C): LAB 1 vs LAB 2: 08-01-2017 to 08-05-2017

Lab No. 1 => Only Radiant panel
Lab No. 2 => All-Air system
Experiment No. 3: Radiant panel vs All-Air system with internal loads

- **Purpose**: Comparative study for cooling performance of Radiant Panel vs All-Air system under solar and radiative loads
- **Load Type**: Solar heat gain + Radiative heat gains provided by side panel (240 W) + Internal cylinder and box heaters (250 W)

- **Load schedule**:
  12:00 AM – 11:59 PM => Side panel ON
  6:00 PM – 8:00 AM => Internal loads OFF
  8:00 AM – 6:00 PM => Internal loads ON
- **Start Date**: 08-09-2017  
  **Stop Date**: 08-14-2017
- **Set point** zone air Temperature: 28 (C)
- Combined radiant panel and ventilation system (2.8 ACH) used in Lab No. 1

Total space heat gain (solar+internal load+conduction): 08-09-2017 to 08-14-2017

Lab No. 1 => Radiant panel + air system  
Lab No. 2 => All-Air system

**AUST (Averaged unheated surface temp)= MRT_no panel**

Setpoint Temp

**Net Space Sensible Cooling Rate: LAB1 vs. LAB2**: 08-09-2017 to 08-14-2017
Experiment No. 4: Radiant panel vs All-Air system with internal loads in typical office working schedule

- **Purpose**: Comparative study for cooling performance of Radiant Panel vs All-Air system under solar and radiative loads
- **Load Type**: Solar heat gain + Internal cylinder and box heaters (250 W)
- **Load schedule**:
  - 6:00 PM – 8:00 AM => Internal loads OFF
  - 8:00 AM – 6:00 PM => Internal loads ON
- **HVAC working schedule**:
  - 6:00 PM – 8:00 AM => OFF condition (Fan, Cooling coil, pump, etc. turned off)
  - 8:00 AM – 6:00 PM => ON condition (Fan, Cooling coil, pump, etc. turned on)

- **Start Date**: 08-22-2017
- **Stop Date**: 08-24-2017
Experiment No. 5: Radiant panel vs All-Air system under Dominant Solar Load

- **Purpose**: Comparative study for cooling performance of Radiant Panel vs All-Air system under solar and radiative loads

- **Load Type**: Solar heat gain

- **HVAC working schedule**:
  - 6:00 PM – 8:00 AM => **OFF condition**
    (Fan, Cooling coil, pump, etc. turned off)
  - 8:00 AM – 6:00 PM => **ON condition**
    (Fan, Cooling coil, pump, etc. turned on)

- **Start Date**: 08-31-2017  
  **Stop Date**: 09-04-2017
Sun Patch Matters !!!

Lab 1 => Radiant panel + air system
Lab 2 => All-air system

F2 => Near the window => exposure to direct sun patch
F1 => Middle of the room => no exposure to sun patch
Operative Temperature Calculation

Measuring MRT on all wall surfaces
(6 Temperature values)

\[ T_{op} = \frac{h_r \times MRT + h_c \times T_a}{h_r + h_c} \approx 0.55MRT + 0.45T_a \]
SUGGESTIONS FOR FINAL EXPERIMENT LIST
<table>
<thead>
<tr>
<th>No. of Case Study</th>
<th>Proposed Experiment Description</th>
<th>Case condition Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Impulse function</td>
<td>To investigate cooling performance of radiant panel vs. all-air system when exposing to impulse pure convective heat source</td>
</tr>
<tr>
<td></td>
<td>All convective source</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Impulse function</td>
<td>To examine cooling performance of radiant panel vs. all-air system when exposing to impulse almost radiative heat source</td>
</tr>
<tr>
<td></td>
<td>Almost all radiative (solar)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Dominant Convective Loads</td>
<td>To determine capacity of radiant panel and all-air system in dealing with pure convective heat gain</td>
</tr>
<tr>
<td>4</td>
<td>Dominant Radiative Loads</td>
<td>To examine cooling performance of radiant panel vs air system in extracting pure radiant heat gain</td>
</tr>
<tr>
<td>5</td>
<td>Effects of Pre-Cooling</td>
<td>To investigate effects of pre-cooling phenomena by radiant panel and all-air system on sensible cooling rate</td>
</tr>
<tr>
<td>6</td>
<td>ON-OFF working schedule</td>
<td>To mimic performance of radiant panel and all-air system under working schedule used in typical offices</td>
</tr>
<tr>
<td>7</td>
<td>Effects of Load Range</td>
<td>To understand effects of small and intense heat gains on radiant panel and real effects of thermal mass</td>
</tr>
<tr>
<td>8</td>
<td>MRT vs. Operative Temperature</td>
<td>To figure out which of MRT or Operative Temperature is a more accurate metric to control radiant panel</td>
</tr>
<tr>
<td>9</td>
<td>Radiant only vs. Radiant &amp; Convection (Radiant only vs. DOAS)</td>
<td>To compare the cooling performance of only radiant panel vs. DOAS</td>
</tr>
<tr>
<td>10</td>
<td>Effect of Convection (significant variation of convective transfer)</td>
<td>To investigate the real effect of convection on driving total energy balance in the room</td>
</tr>
<tr>
<td>11</td>
<td>Effects of solar patch</td>
<td>To investigate effects of Direct vs Diffused Solar Radiation on radiant panel and all-air system</td>
</tr>
<tr>
<td>12</td>
<td>??? (No thermal mass, ..... )</td>
<td>Further suggestions</td>
</tr>
</tbody>
</table>
Thanks for your attention !!!!

Questions ???