ASHRAE RP-1729

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

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BUILDING ENERGY & ENVIRONMENTS

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Department of Civil, Architectural and Environmental Engineering

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.”

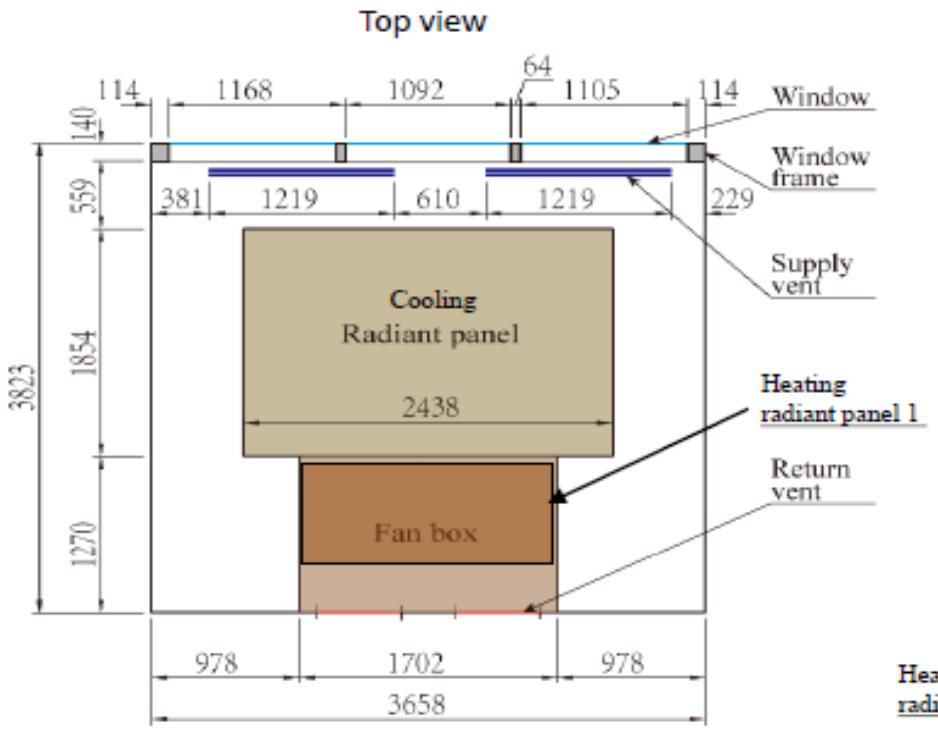
NOTE

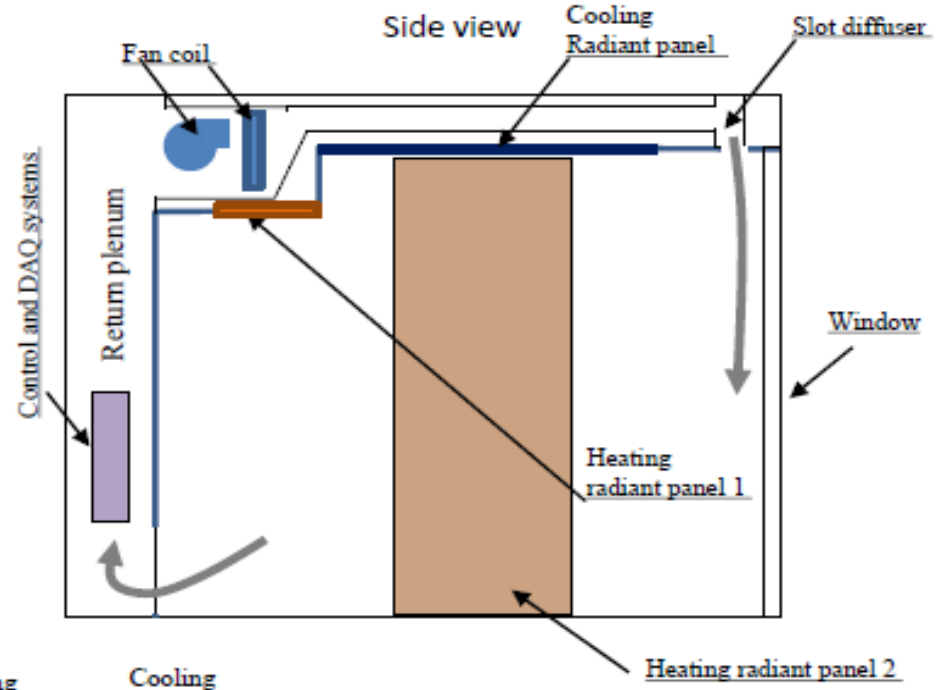
- TOOLKIT Code repair and
- Modeling results will be discussed later

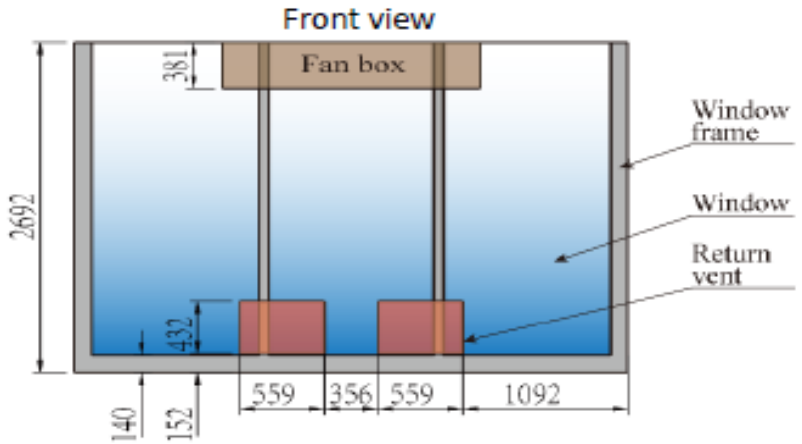
Outline of the presentation

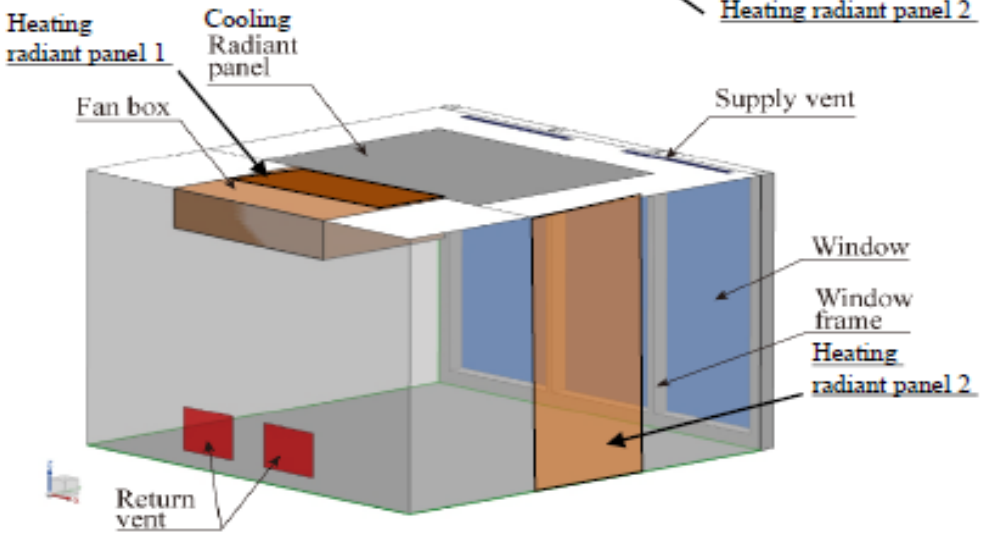
- Experimental set-up (previous and new additions)
- Experimental Matrix of finished experiments
- Results from finished Tests
- Effects of direct sun patch
- Operative temperature calculation & control
- Suggestions for the final experiment list

SCHEMATIC OF EXPERIMENTAL SETUP





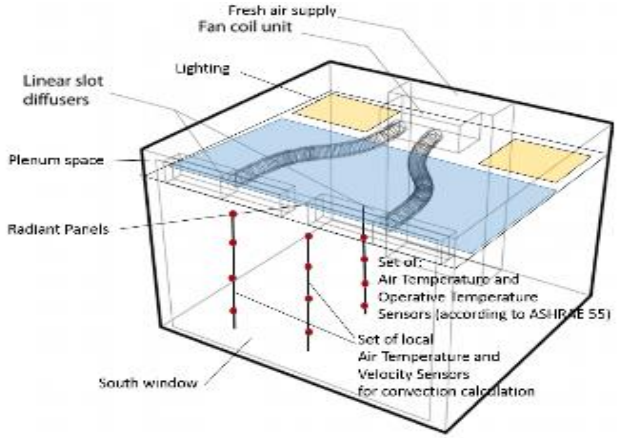


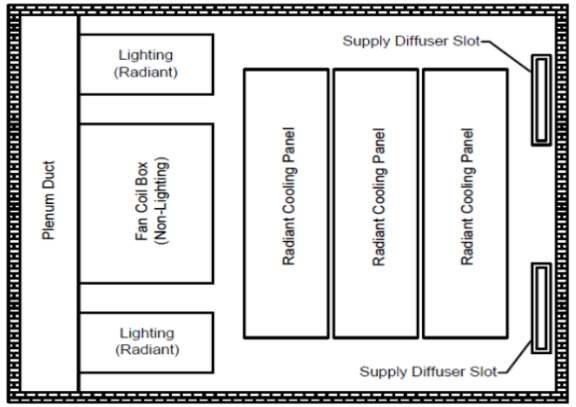


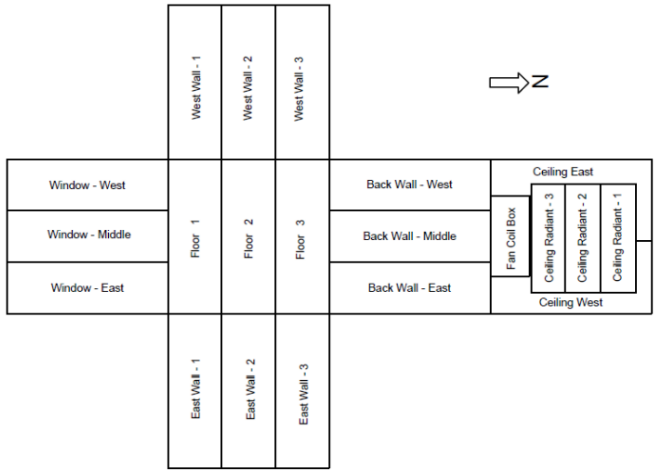
EXPERIMENTAL PROGRAMME

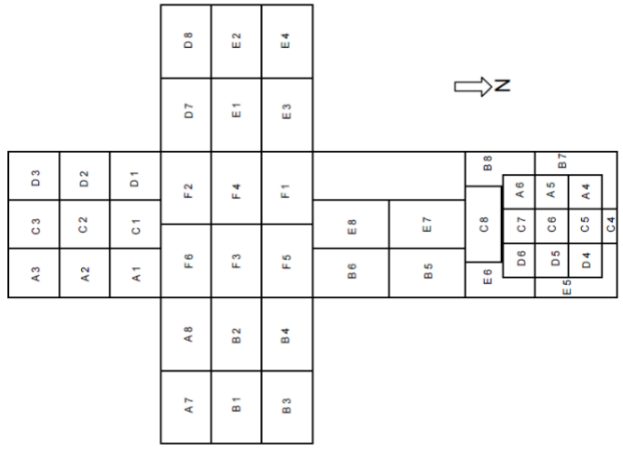
➢ EXPERIMENTAL PROTOCOLS

- 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

Variables	Instrument used	Measurement Accuracy
Surface Temperature	Omega 44033 thermistors	± 0.1 (c)
Coil Water temperature	Omega 44033 thermistors	± 0.1 (c)
Coil flow rate	Omega FTG-9500	2% of measured value
Specific heat and density of fluid	Experimentally tested	Assumed constant
Internal equipment loads	Brand Electronic ONE power meter Watt's up power data meter	± 1 %
Global horiz. Radiation 2	Onset pyranometer S-LIBM003	Greater of ±10 $\left(\frac{W}{m^2}\right)$or ±5%
Global diff. radiation	Eppley PSP	Within ±1% of WRR
Global normal radiation (interior)	Onset pyranometer S-LIBM003	Greater of ±10 $\left(\frac{W}{m^2}\right)$ or ±5%
Outdoor air temperature	Davis External temp sensor	± 0.5 (c) under 43 (c)
Wind direction	Davis Anemometer 6410	±4 degrees
Wind speed	Davis Anemometer 6410	Greater of ±3 (km/h) or ±5%
Precipitation	Davis Rain collector II	Calibrated 0.01" (0.003 m) increments

Solar pyranometer

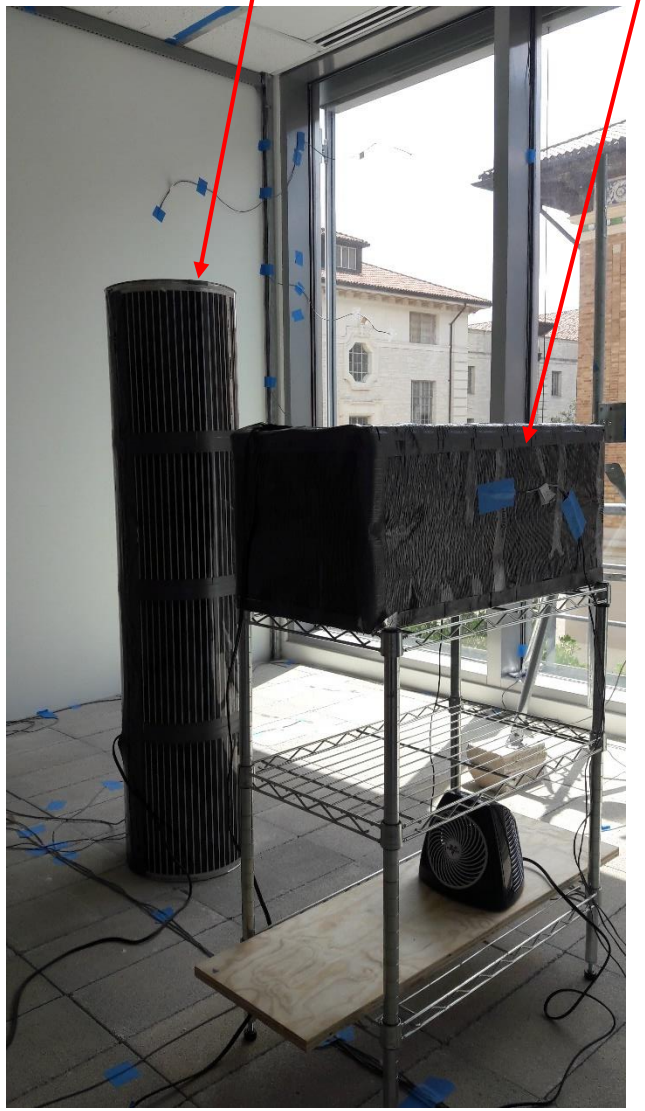
Air Temperature sensors on vertical stand

- **Internal heat sources**

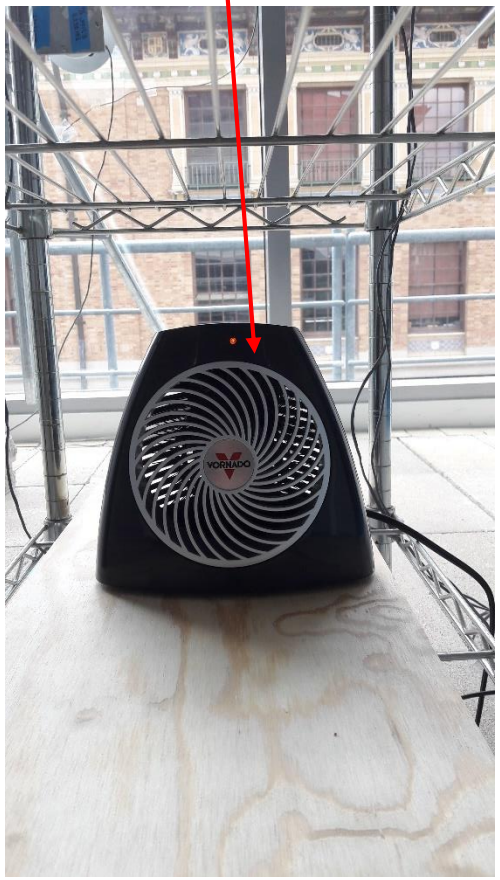
Radiative Side Panel

Internal Cylinder Heater

Internal Box Heater



Pure Convective Heater



X-10 Module

Data logger

Rheostat (Power Control)

EXPERIMENTAL MATRIX OF FINISHED EXPERIMENTS

No. of Case Study	Studied Phenomena Description	Case Condition Description
1	Effect of solar and radiative heat gains	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
2	Effect of internal convective and radiative loads	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
3	Effect of constant internal loads	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
4	Effect of ON-OFF typical office working schedule	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
5	Effect of Dominant Solar heat gain	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

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

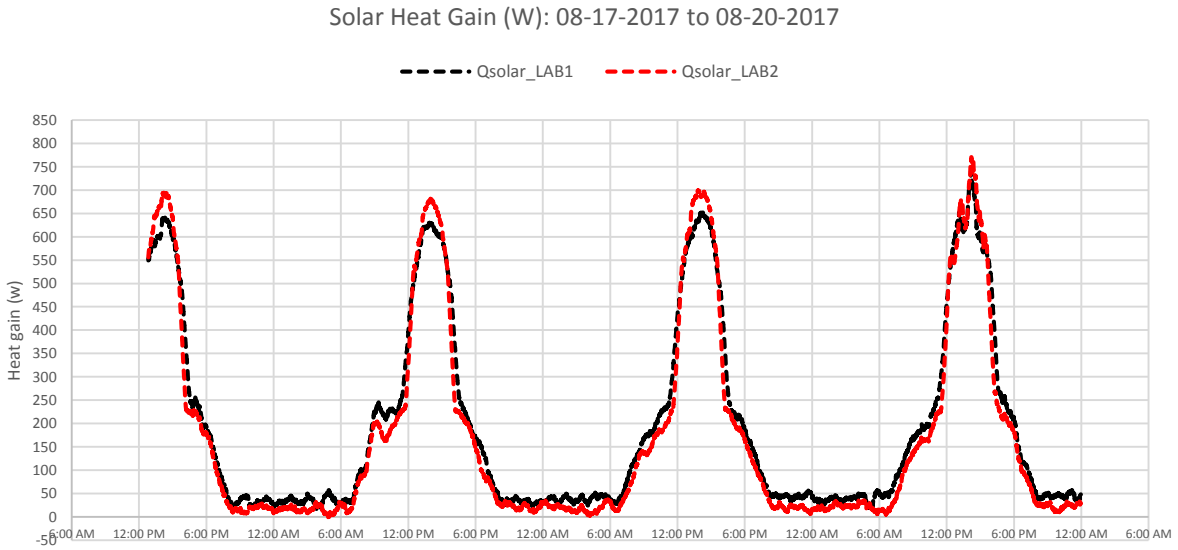
NOTE: in this first example we are giving you details about experimental set-up while in the following 4 examples we will show you just summary of the major results for different set-ups (examples #1,2,4,5) from the table

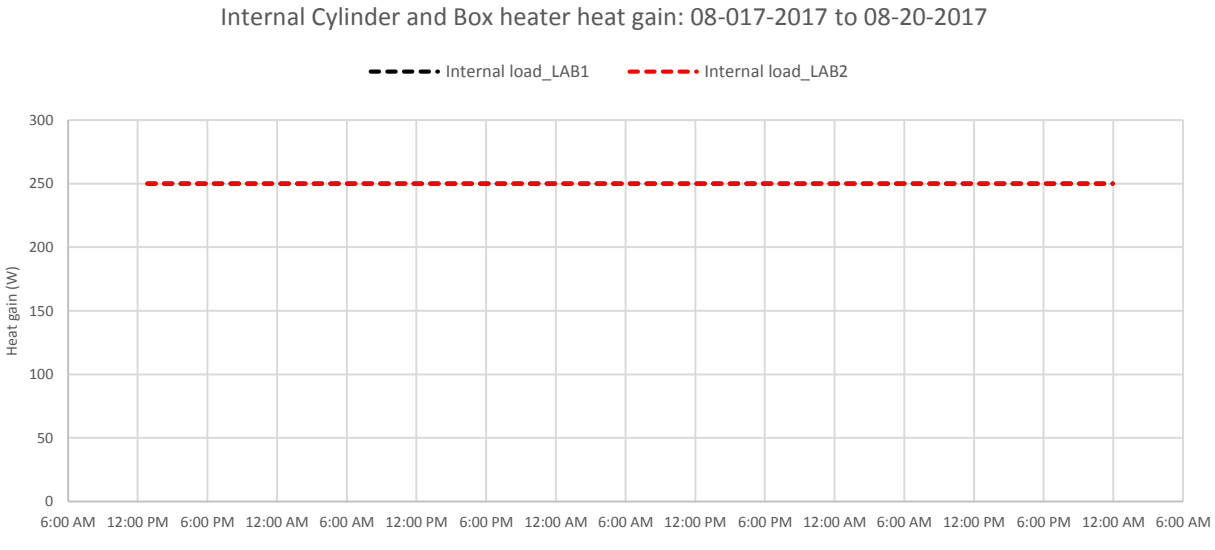
➢ Experiment No. 1: Radiant panel vs All-Air system under solar diffuser load and constant internal loads

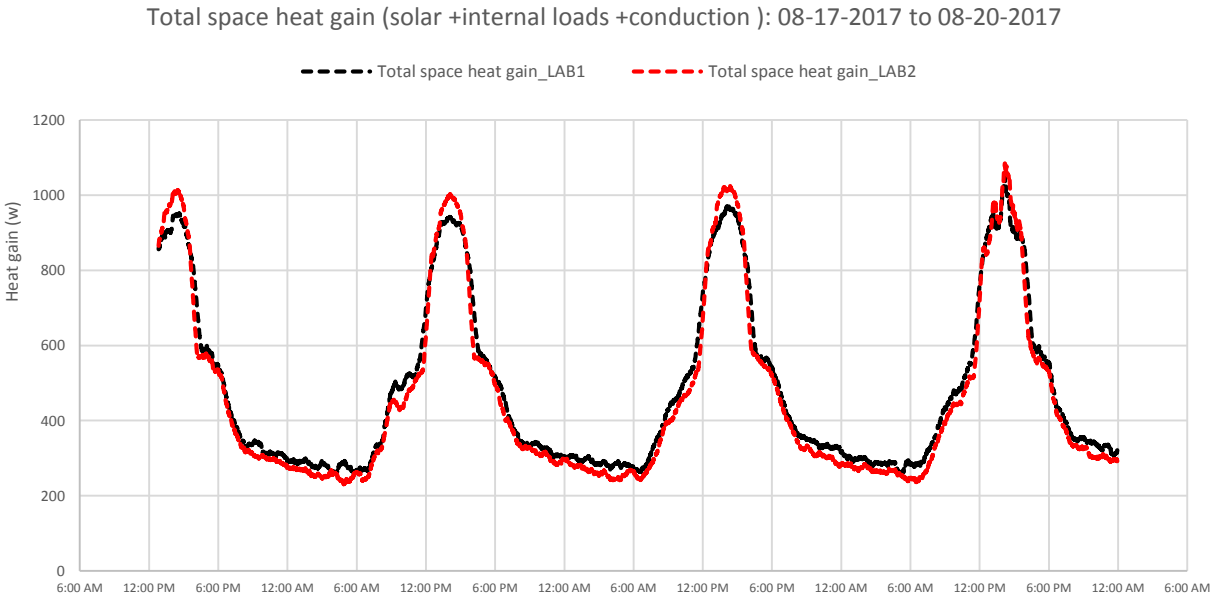
- **Purpose**: Comparative study for cooling performance of combined Radiant Panel and ventilation system vs All-Air system under solar and constant internal loads
- **Load Type**: Solar heat gain + constant internal convective and radiative heat gains provided by cylinder and box heaters (250 W)
- **Load 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:

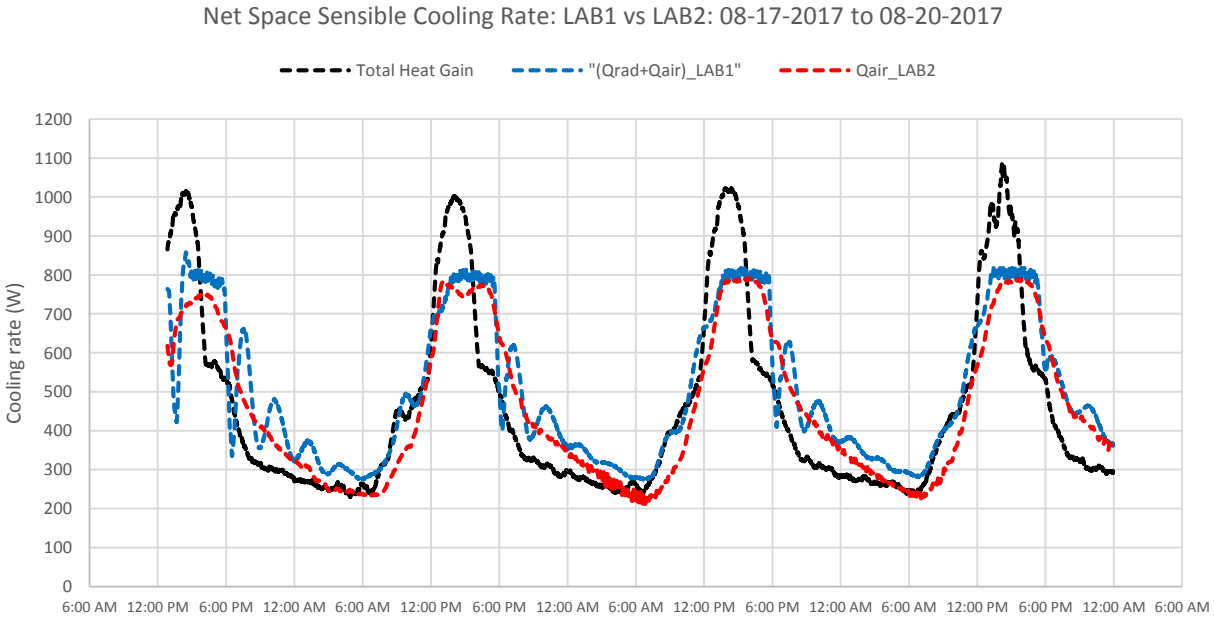
$$Q_{\text{Radiant Panel}} = Q_{\text{Rad}} = \dot{m}_{\text{w}} C_{\text{p}_{\text{w}}} \left(T_{\text{CWR}} - T_{\text{CWS}}\right)$$

$$Q_{\text{air}} = \dot{m}_{\text{a}} C_{\text{p}_{\text{a}}} (T_{\text{RA}} - T_{\text{SA}})$$

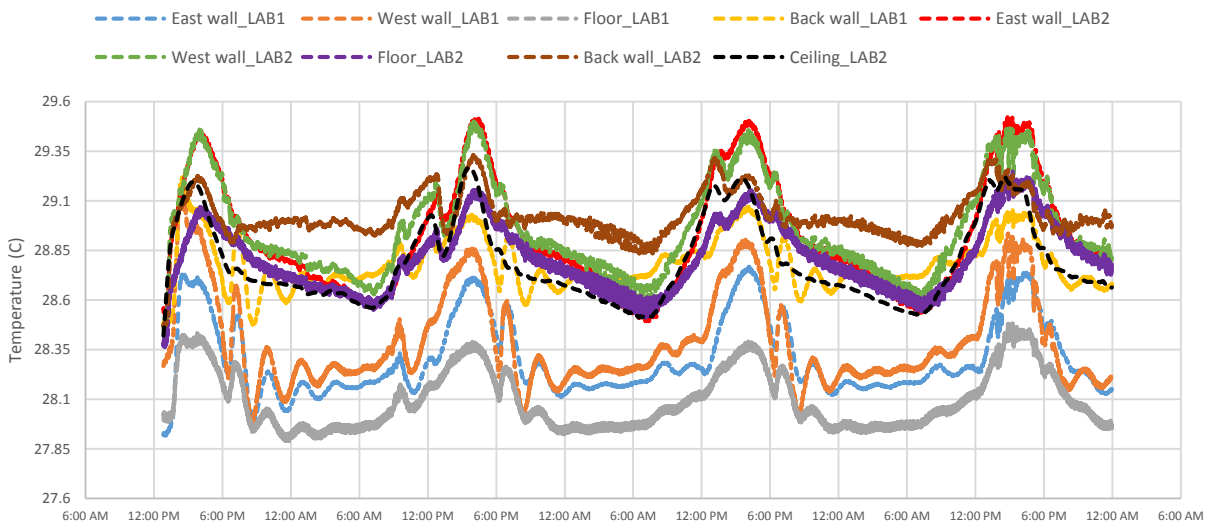


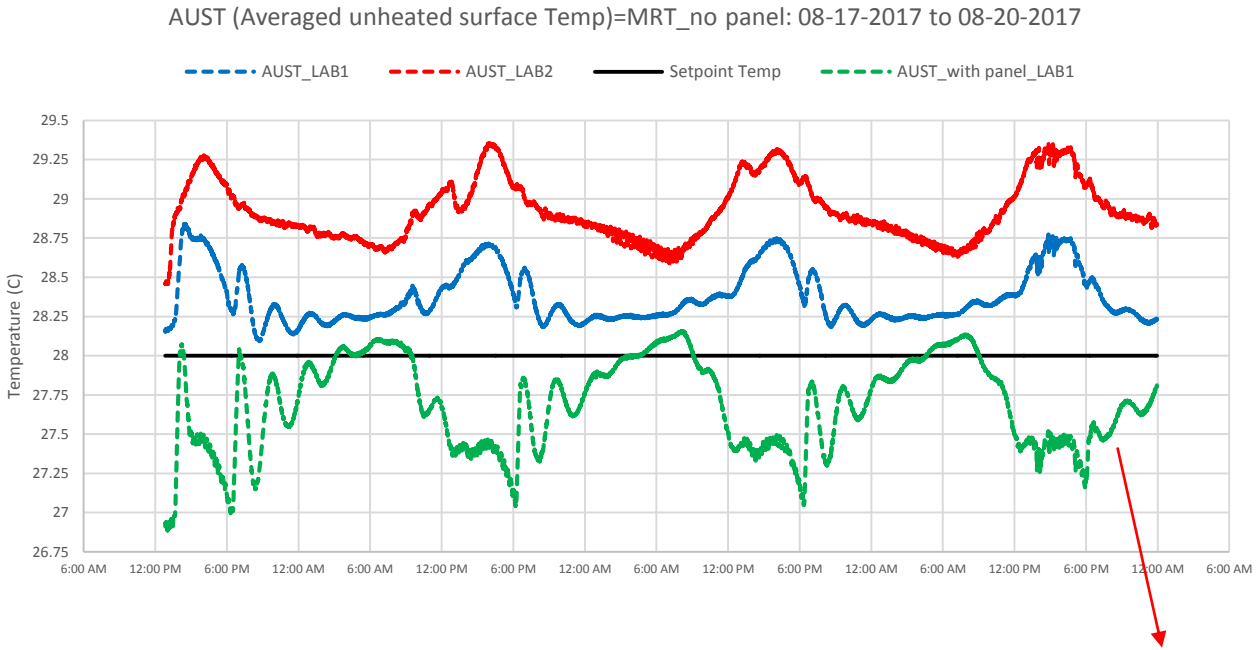




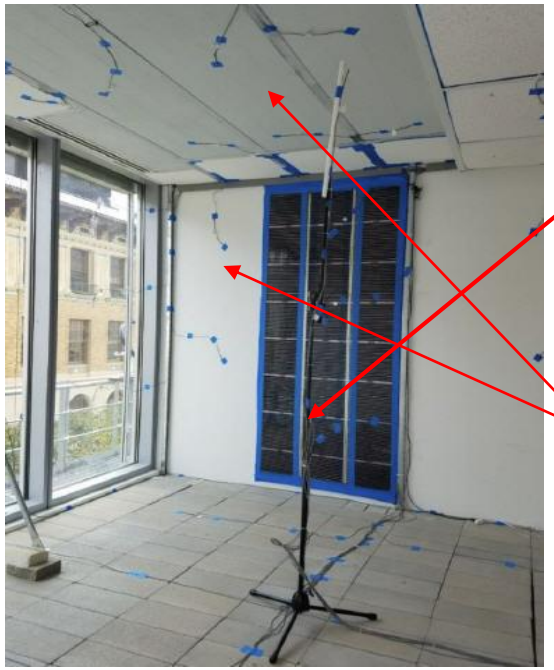


Lab No. 1 => Radiant panel + air system
Lab No. 2 => All-Air system



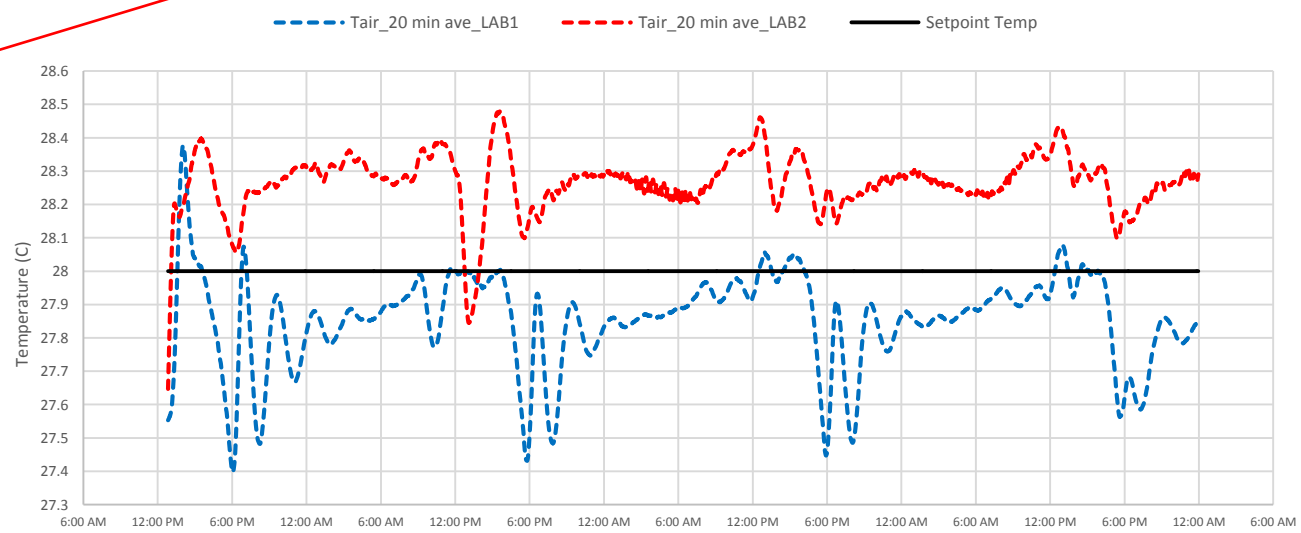


AUST with panel



Air Temperature sensors on vertical stand

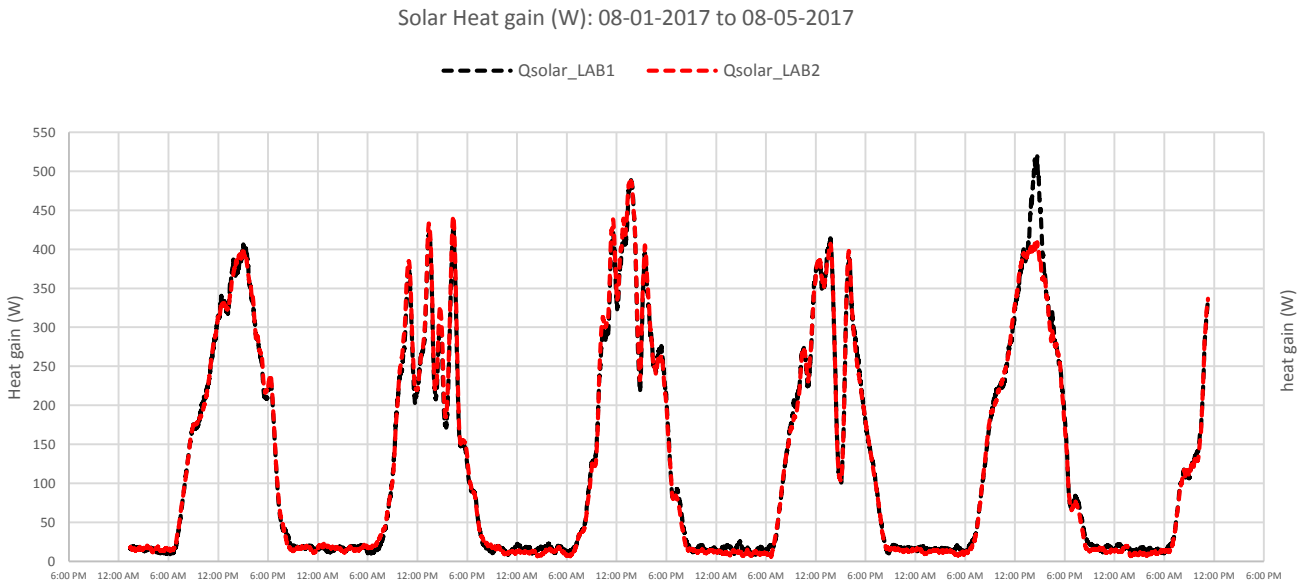
Wall surface Temperature measurement

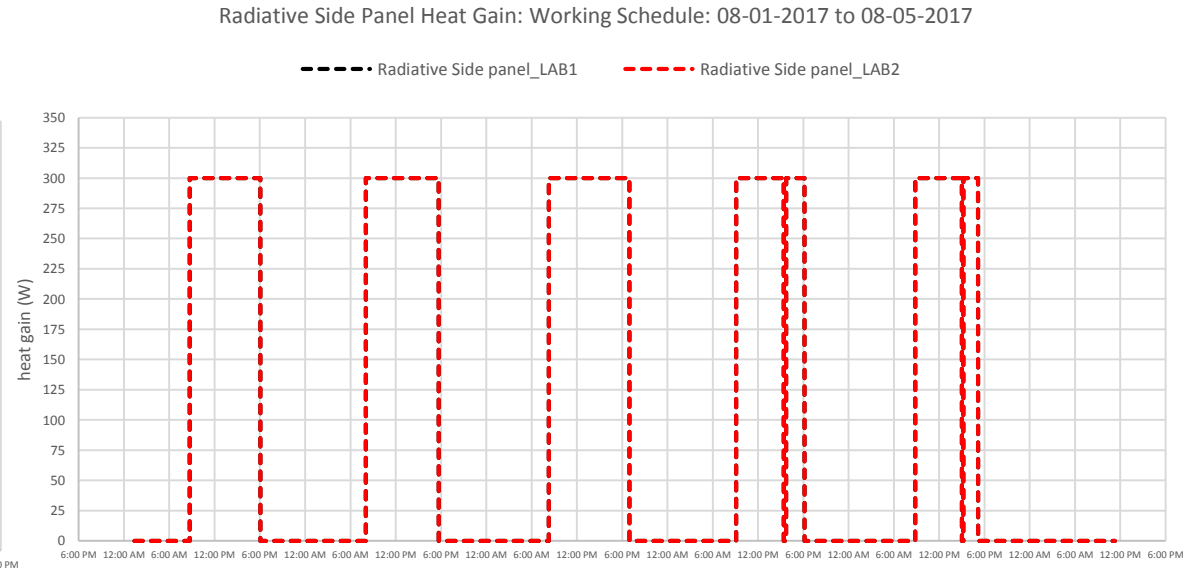


Lab No. 1 => Radiant panel + air system
Lab No. 2 => All-Air system

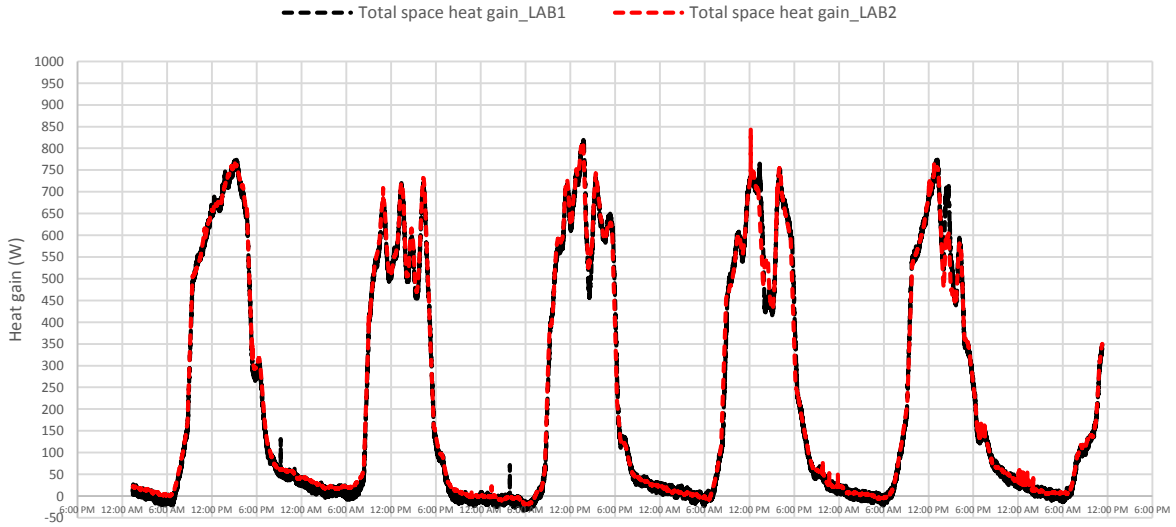
➢ Experiment No. 2: Radiant panel vs All-Air system under solar and radiative loads

- **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

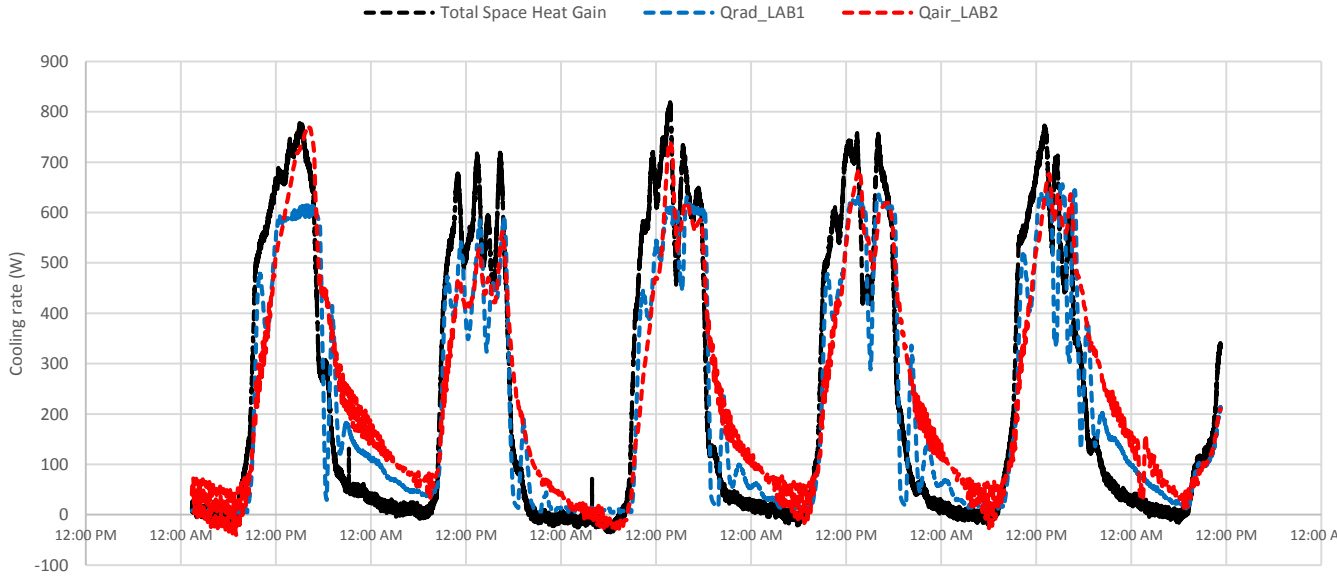




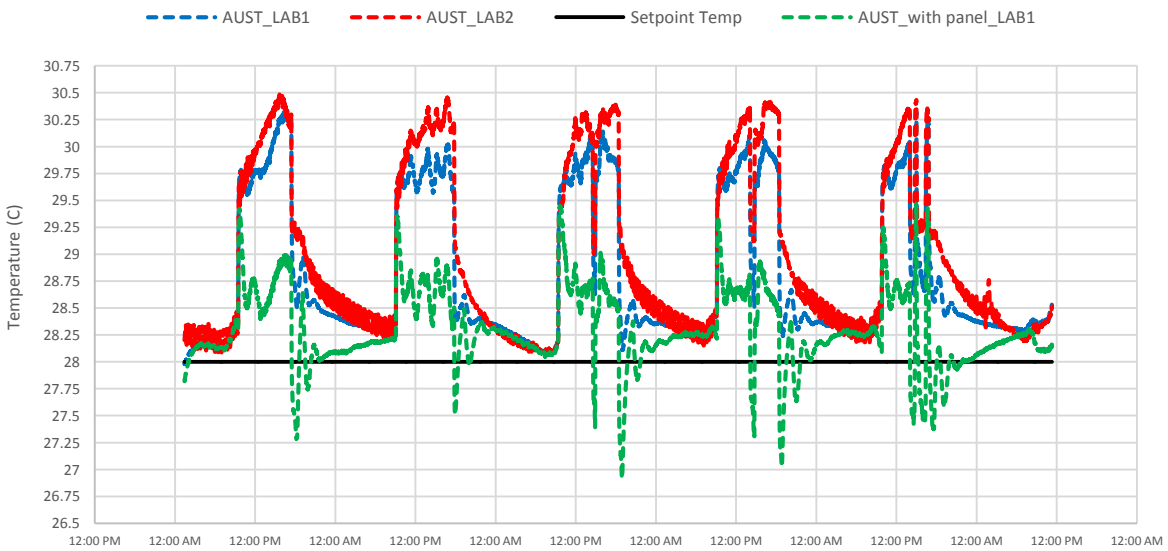
Total Net space heat gain (solar+Internal load+Conduction): 08-01-2017 to 08-05-2017



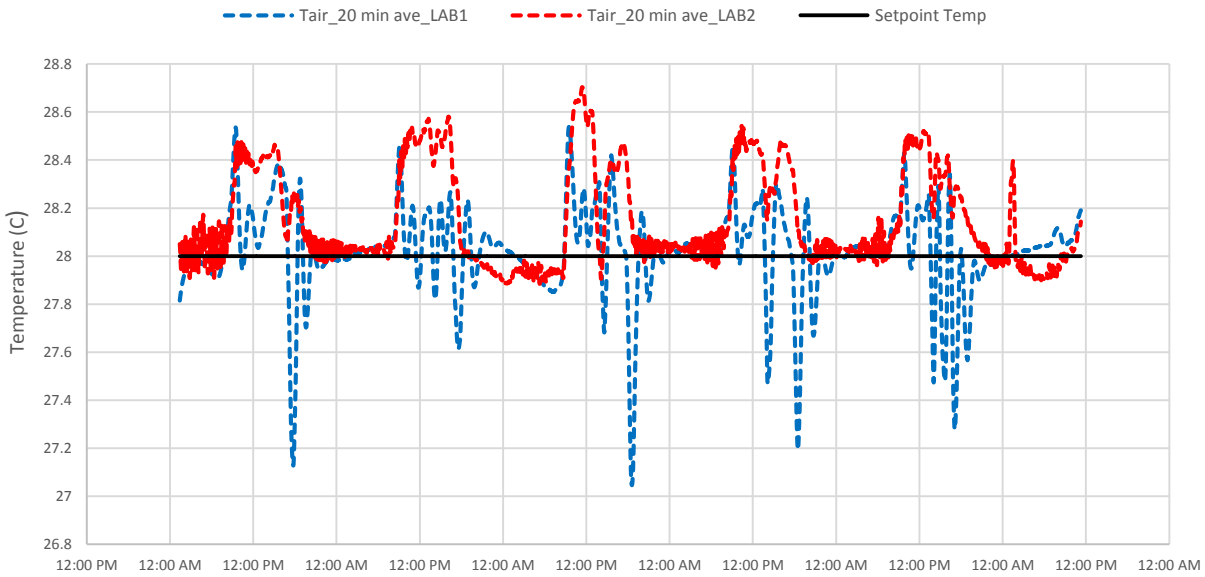
Net Space Sensible Cooling Rate: LAB1 vs LAB2: 08-01-2017 to 08-05-2017



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



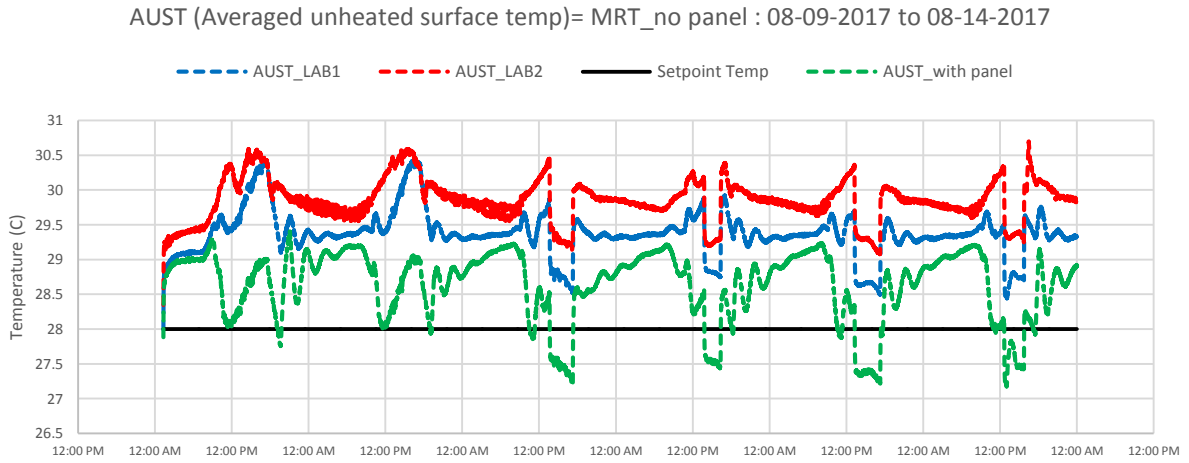
Lab No. 1 => Only Radiant panel
Lab No. 2 => All-Air system

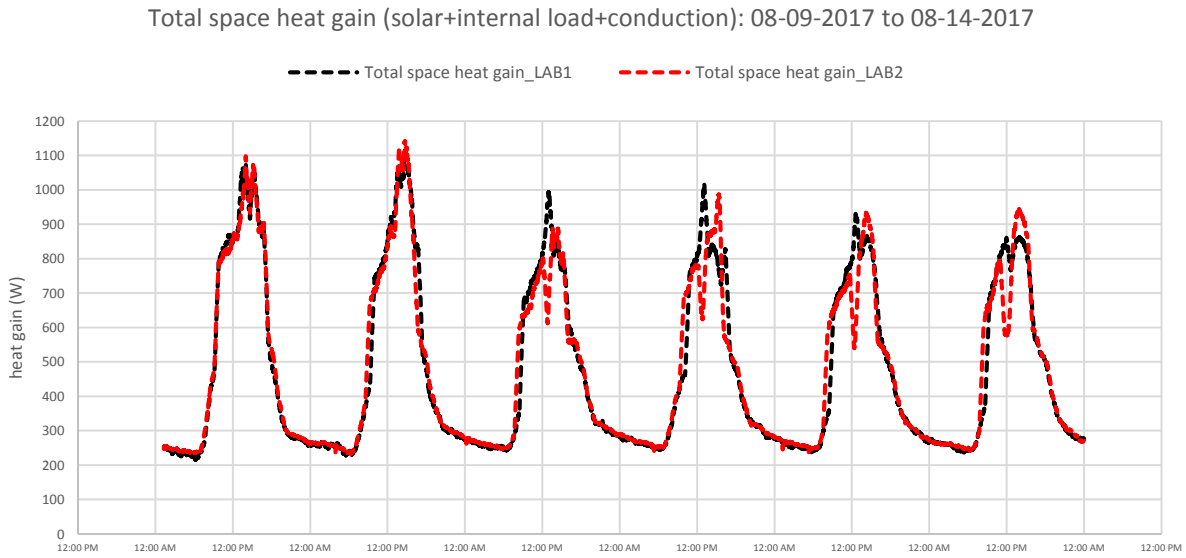
➢ Experiment No. 3: Radiant panel vs All-Air system with internal loads

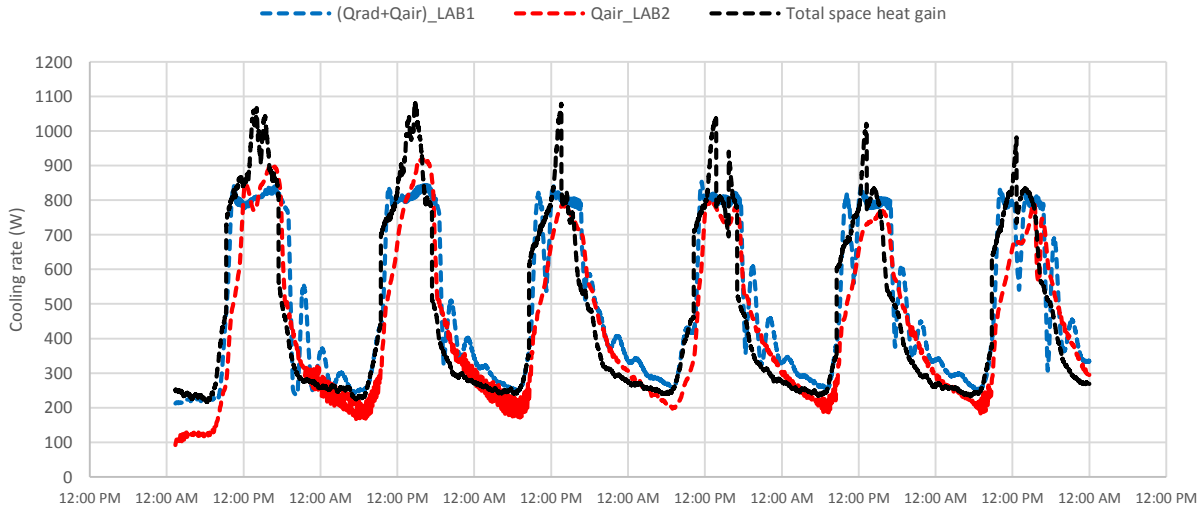
- **Purpose**: Comparative study for cooling performance of Radiant Panel vs All-Air system under solar and radiative loads
- **Load Type**: Solar heat gain + Radiative heat gains provided by side panel (240 W) + Internal cylinder and box heaters (250 W)

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

- **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





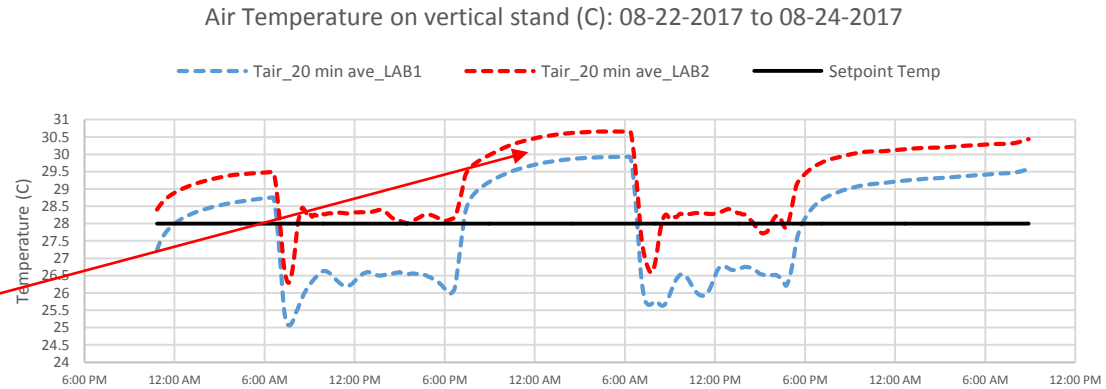


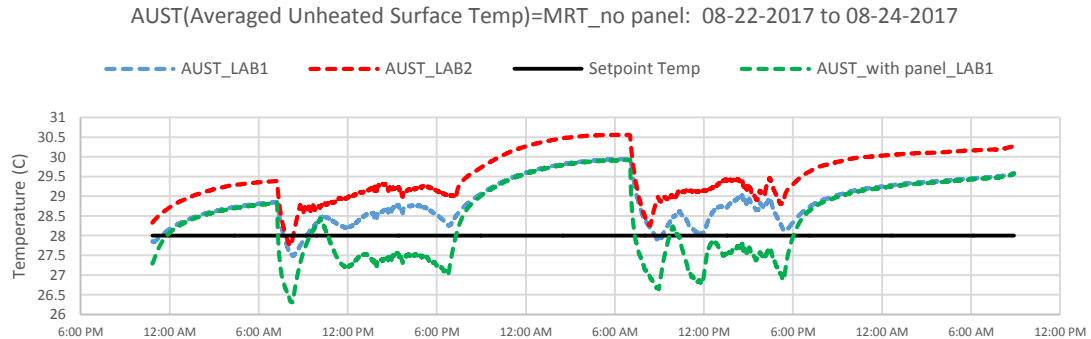
➢ Experiment No. 4: Radiant panel vs All-Air system with internal loads in typical office working schedule

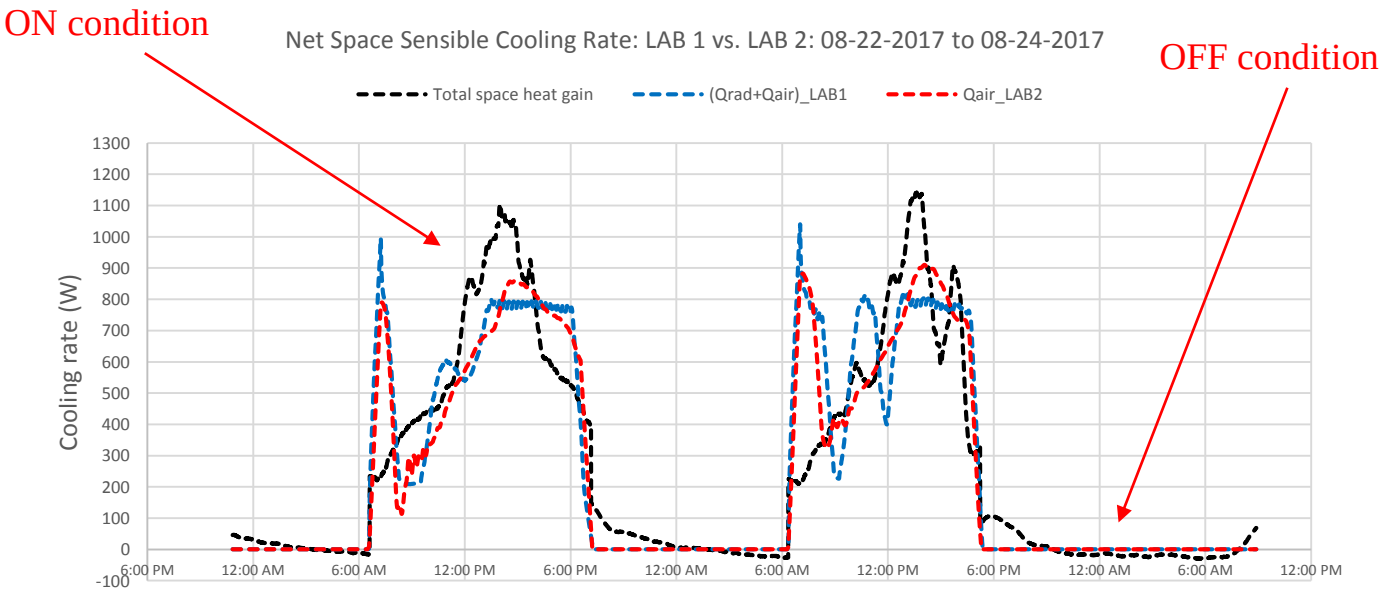
- **Purpose**: Comparative study for cooling performance of Radiant Panel vs All-Air system under solar and radiative loads
- **Load Type**: Solar heat gain + Internal cylinder and box heaters (250 W)
- **Load schedule**:
  6:00 PM – 8:00 AM => Internal loads OFF
  8:00 AM – 6:00 PM => Internal loads 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)

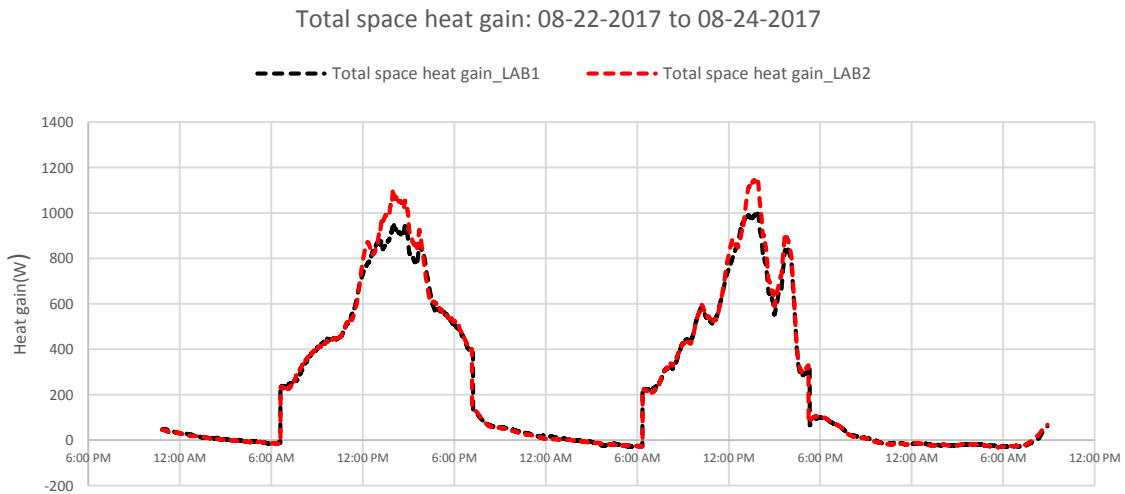
Lab No. 1 => Radiant panel + air system
Lab No. 2 => All-Air system

- **Start Date**: 08-22-2017
- **Stop Date**: 08-24-2017







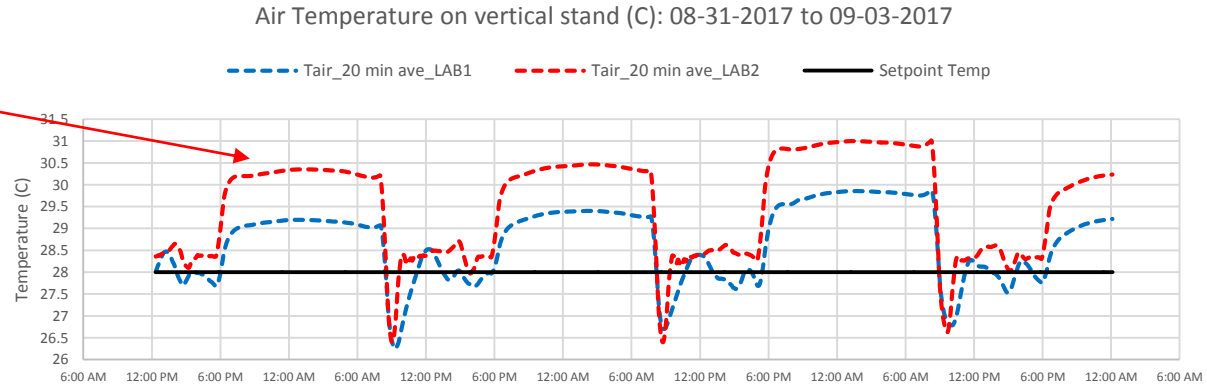


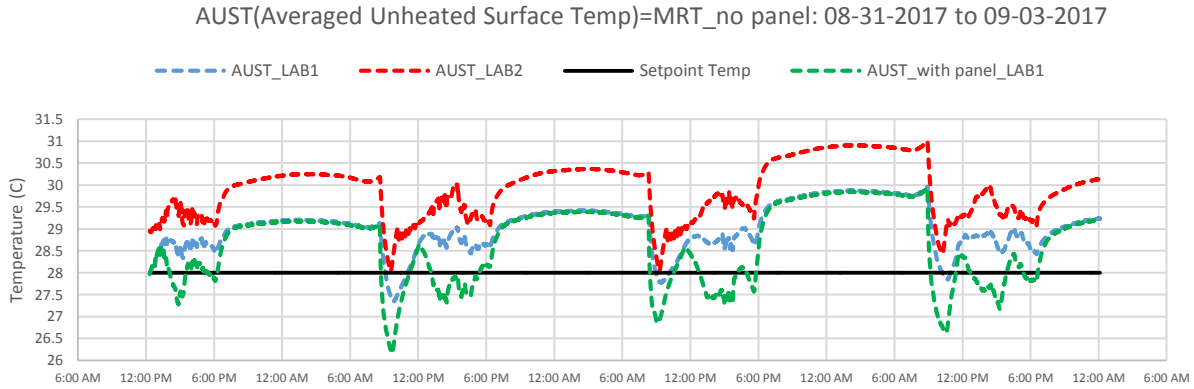
➢ Experiment No. 5: Radiant panel vs All-Air system under Dominant Solar Load

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

- **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

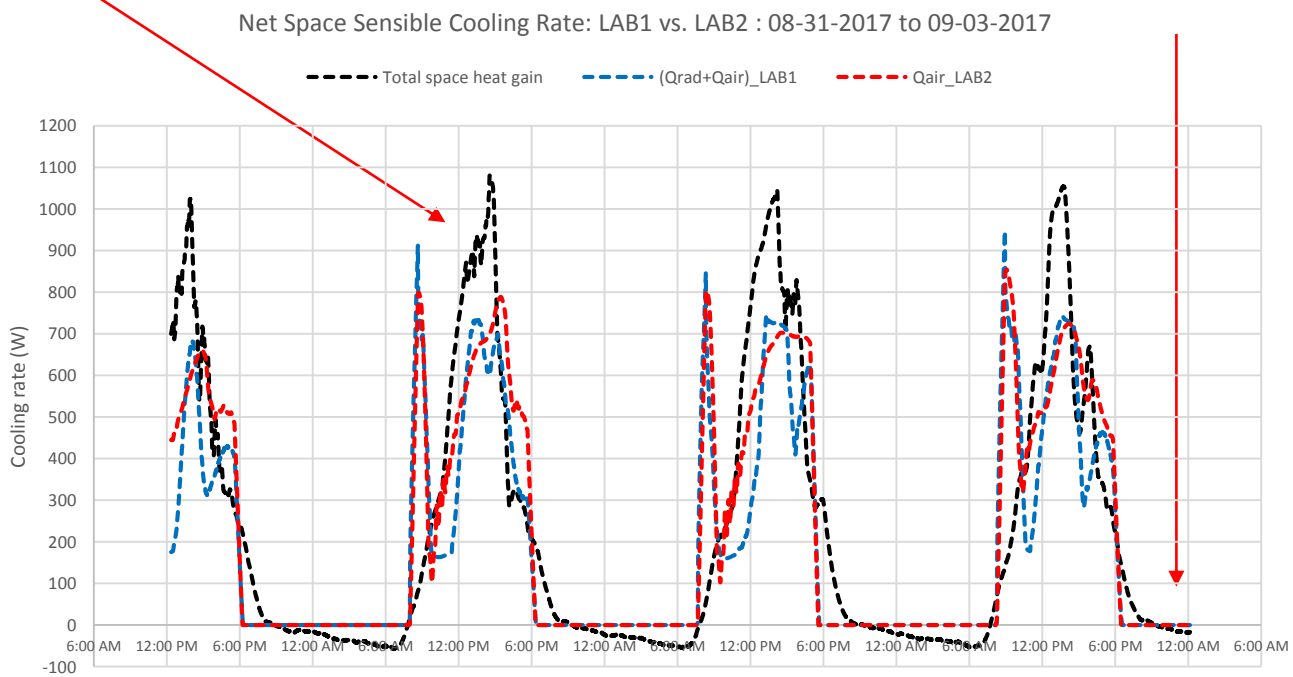
Free-Floating Temp

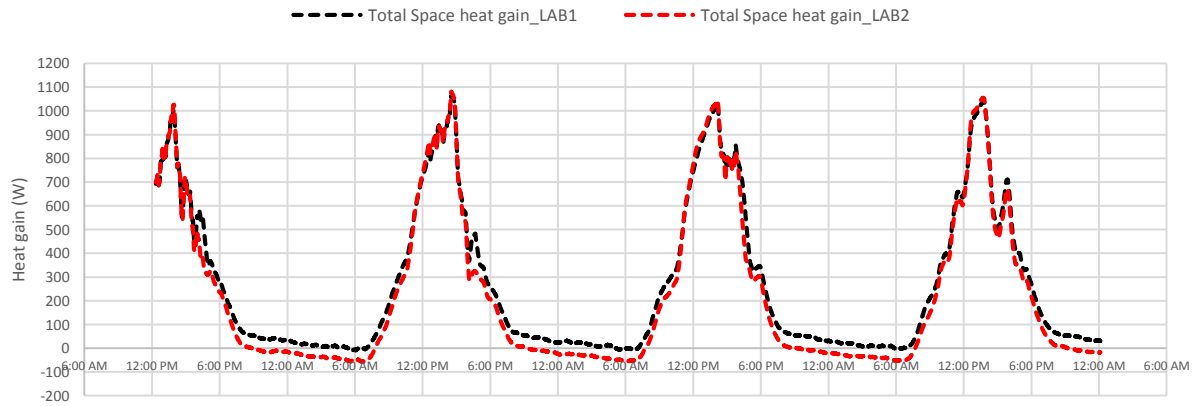


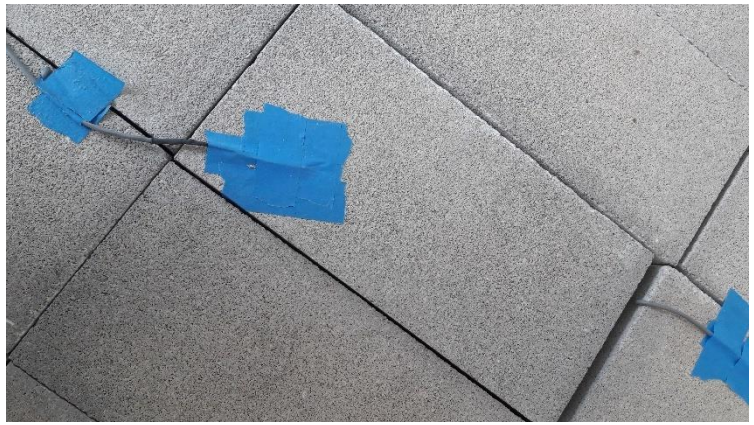


ON condition

OFF condition

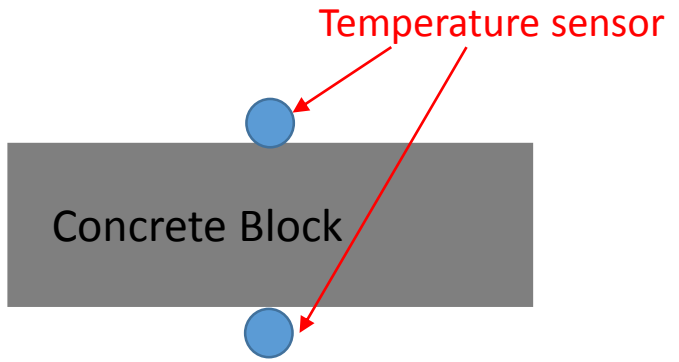




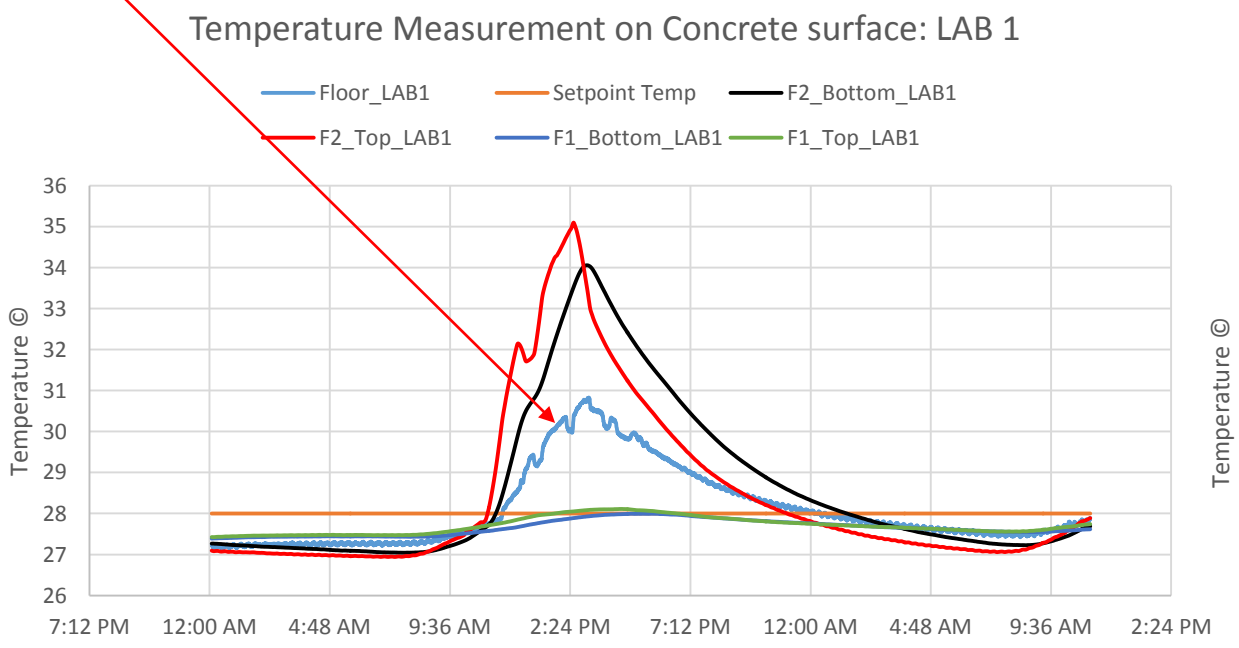


Sun Patch Matters !!!

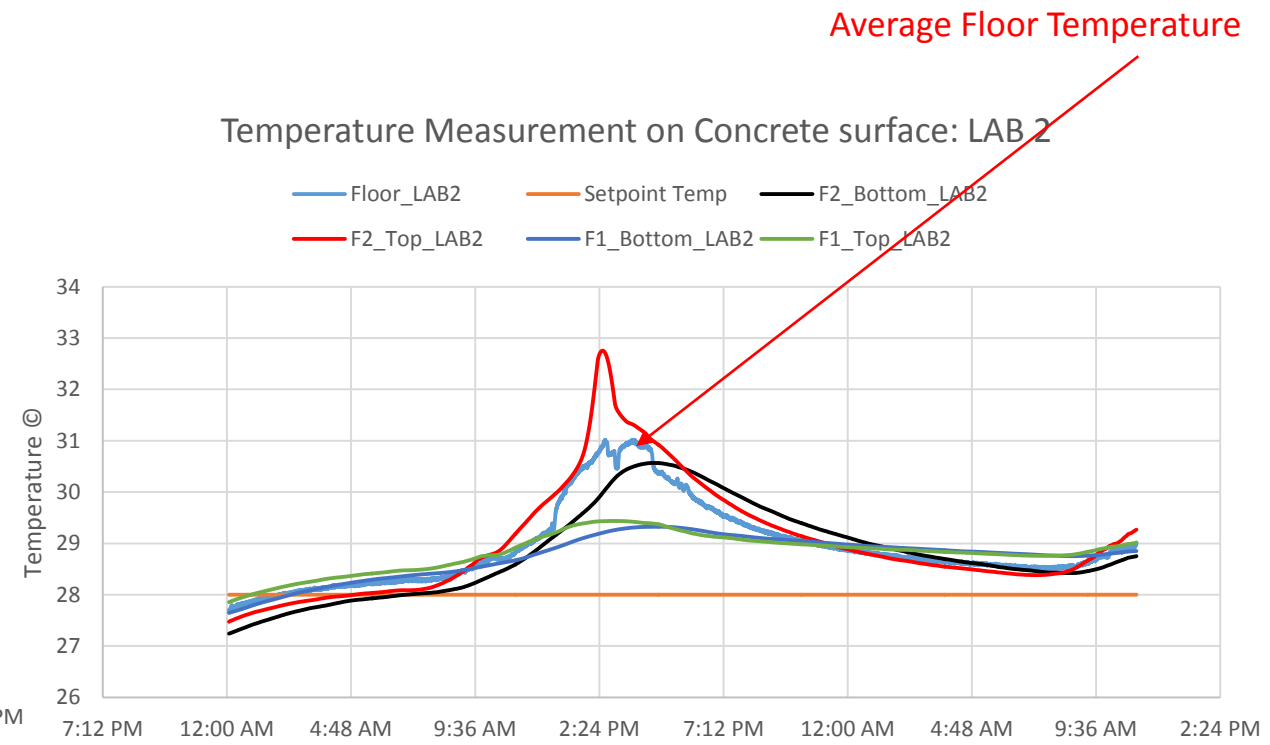
Lab 1 => Radiant panel + air system
Lab 2 => All-air system



Average Floor Temperature



Average Floor Temperature

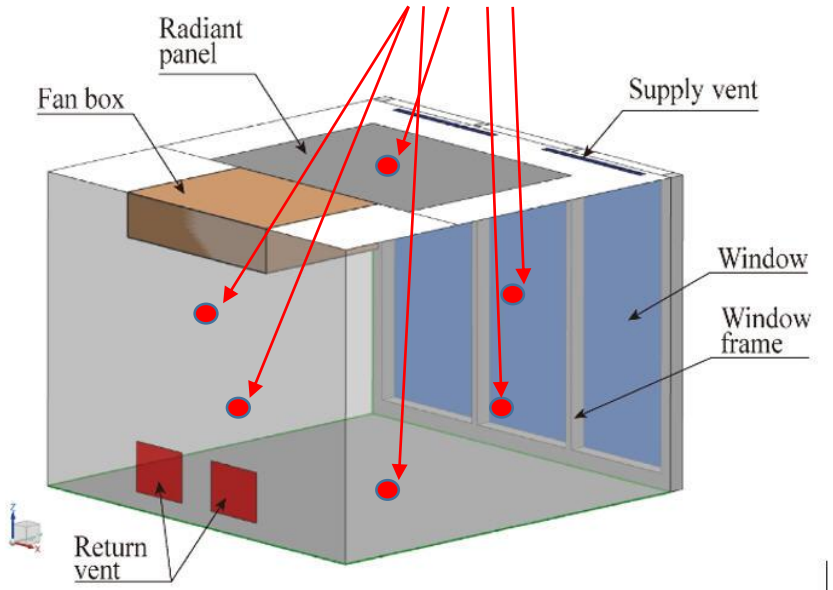


F2 => Near the window => exposure to direct sun patch

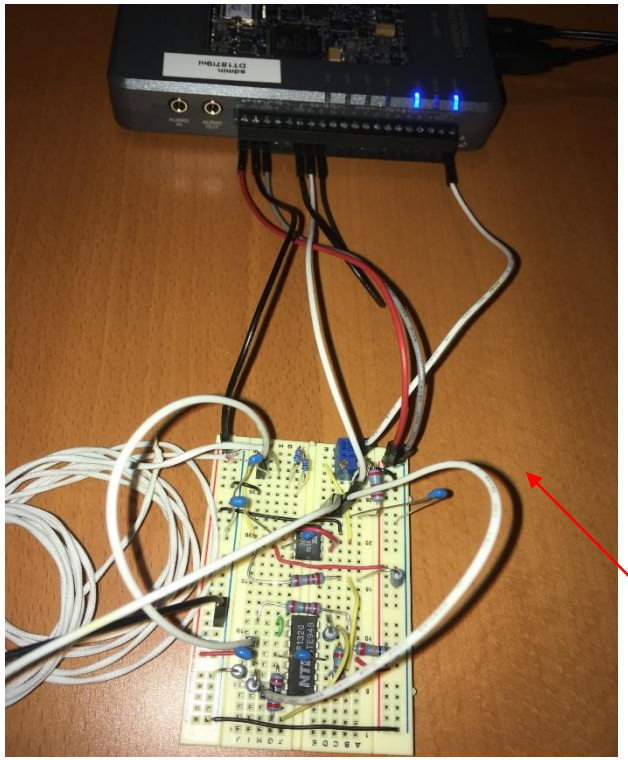
F1 => Middle of the room => no exposure to sun patch

Operative Temperature Calculation

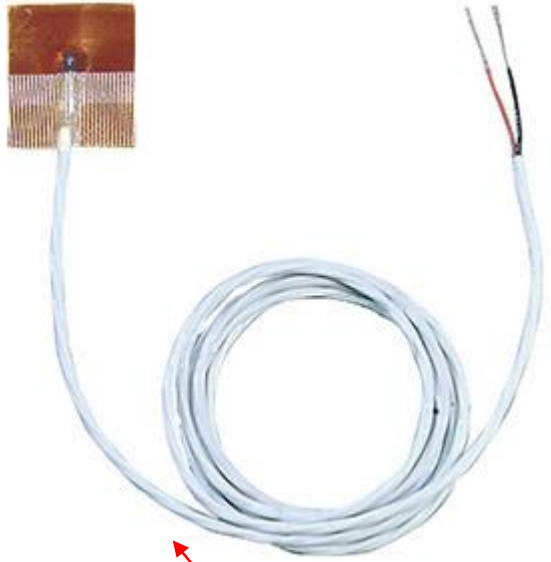
Measuring MRT on all wall surfaces (6 Temperature values)



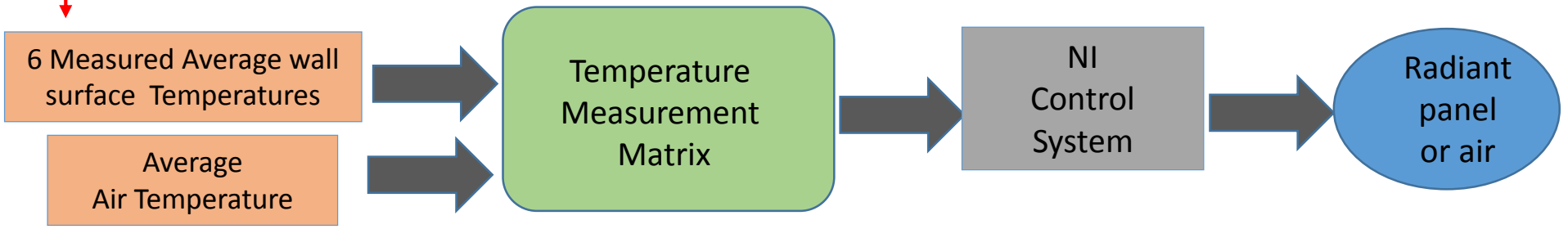
$$T_{op} = \frac{h_r \times MRT + h_c \times T_a}{h_r + h_c} \approx 0.55MRT + 0.45T_a$$



RTD (PPG 101 A1 US Sensor)



Thermistor Sensor Surface-Mount Stick-On or Cement-On (SA1-TH-44000 Series)



SUGGESTIONS FOR FINAL EXPERIMENT LIST

No. of Case Study	Proposed Experiment Description	Case condition Description
1	Impulse function All convective source	To investigate cooling performance of radiant panel vs. all-air system when exposing to impulse pure convective heat source
2	Impulse function Almost all radiative (solar)	To examine cooling performance of radiant panel vs. all-air system when exposing to impulse almost radiative heat source
3	Dominant Convective Loads	To determine capacity of radiant panel and all–air system in dealing with pure convective heat gain
4	Dominant Radiative Loads	To examine cooling performance of radiant panel vs air system in extracting pure radiant heat gain
5	Effects of Pre-Cooling	To investigate effects of pre-cooling phenomena by radiant panel and all-air system on sensible cooling rate
6	ON-OFF working schedule	To mimic performance of radiant panel and all-air system under working schedule used in typical offices
7	Effects of Load Range	To understand effects of small and intense heat gains on radiant panel and real effects of thermal mass
8	MRT vs. Operative Temperature	To figure out which of MRT or Operative Temperature is a more accurate metric to control radiant panel
9	Radiant only vs. Radiant & Convection (Radiant only vs. DOAS)	To compare the cooling performance of only radiant panel vs. DOAS
10	Effect of Convection (significant variation of convective transfer)	To investigate the real effect of convection on driving total energy balance in the room
11	Effects of solar patch	To investigate effects of Direct vs Diffused Solar Radiation on radiant panel and all-air system
12	??? (No thermal mass, …..)	Further suggestions

Thanks for your attention !!!!

Questions ???