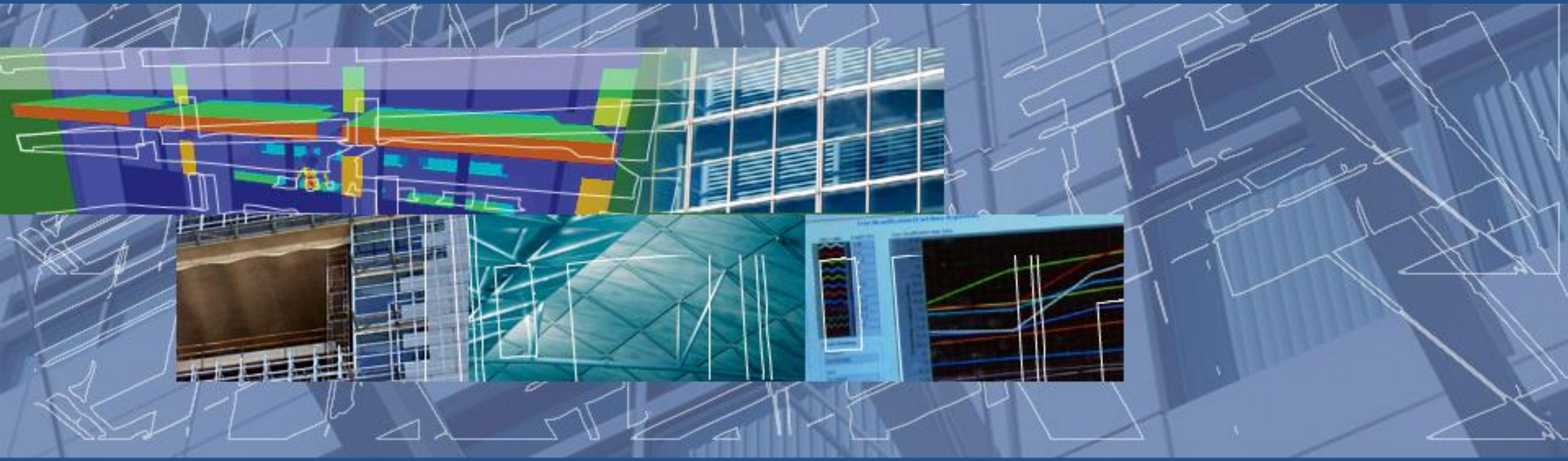
Radiant Cooling Design: Performance Prediction and Modeling Methods

Jingjuan (Dove) Feng, PhD Candidate
Center for the Built Environment

University of California Berkeley



Center for the Built Environment   October 2013

Agenda

Background

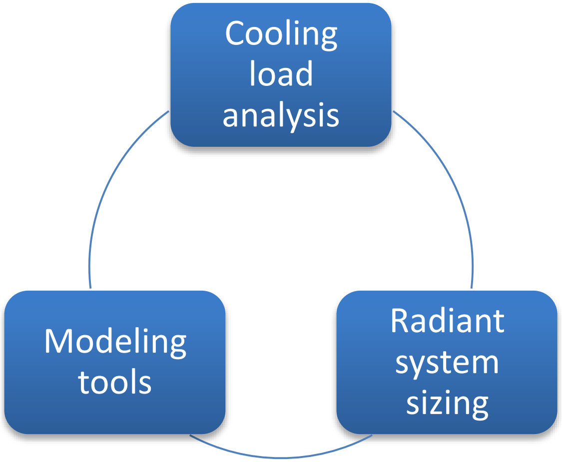
Cooling load prediction methods and tools

- What's available and what's been used?
- Are they accurate?
- Investigation by experiment and simulation

Design recommendations

- Cooling load prediction method
- Modeling tool selection
- Implications for sizing

Modeling for code compliance and LEED



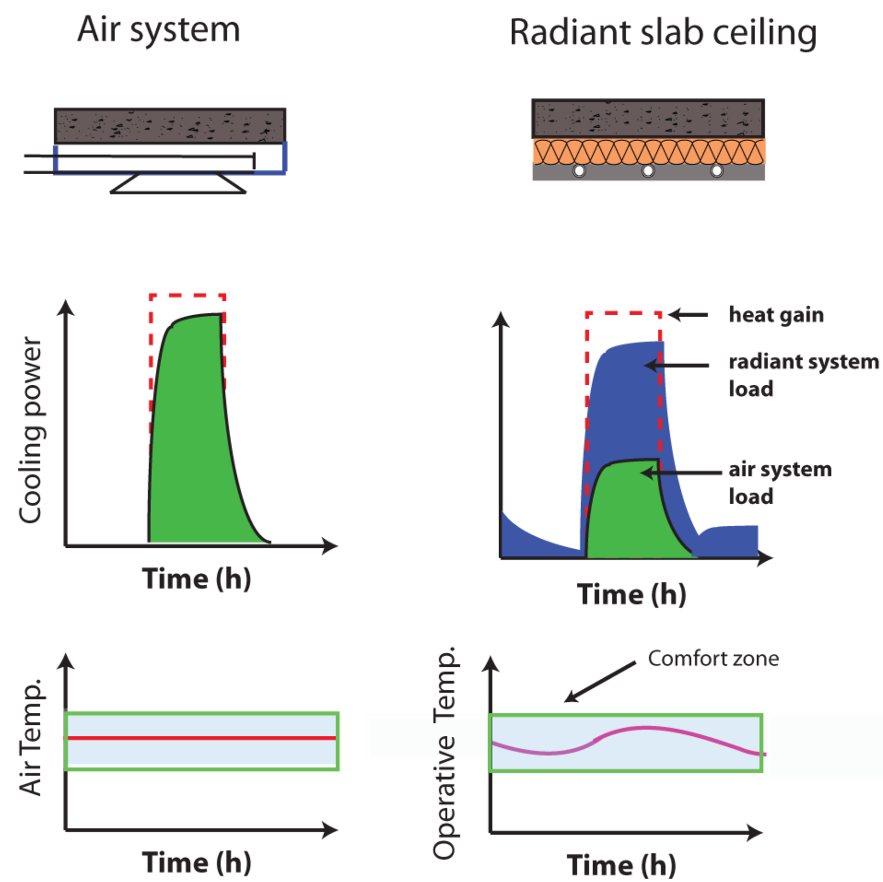
Backgrounds: Air systems vs. Radiant systems

Air systems

- Ventilation + space conditioning
- Design to meet a single peak cooling load value
- Remove heat using convection

Radiant systems

- Decoupled ventilation and space conditioning
- Allow pre-conditioning the radiant layer
- Remove heat using convection + radiation



1. Is the cooling load the same for radiant systems as for air systems?

2. Can we use the same method to size radiant system as air system?

3. Which modeling tools can be used to assist design?

What methods and tools are available and being used ?

Literature review

- ASHRAE HOF (2013)
- ISO 11855 (2012)
- RHVEA Guidebook
- Price Engineer's HVAC Handbook (2011)

Case studies + Survey

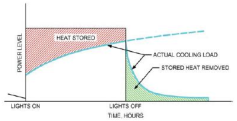
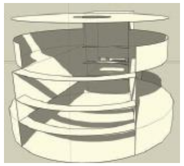
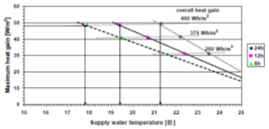
- 5 case studies
- 11 responses from designers from Europe and North America

1) ASHRAE HOF ; 2) ISO 11855 (2012)

Building names	applications	Load features	Rad system type
Bankok Airport	Lobby/atrium	solar + stratification	radiant floor
David Brower Center	office	Typical	radiant ceiling slab
Walmart at Sacramento	retail with skylight	Typical	radiant floor cooling
Manitoba Hydro	office	Typical	TABS ceiling
NREL Research Support Facility	office	Typical	radiant slab ceiling
William Jefferson Clinton Presidential Library	Lobby/atrium	Typical load+stratification	radiant floor
Lobby of Hearst headquarters	Lobby/atrium	solar + stratification	radiant floor
SMUD building office area	office	Typical	radiant ceiling slab
St Meinrad Archabbey church	Church	Typical load+stratification	radiant floor

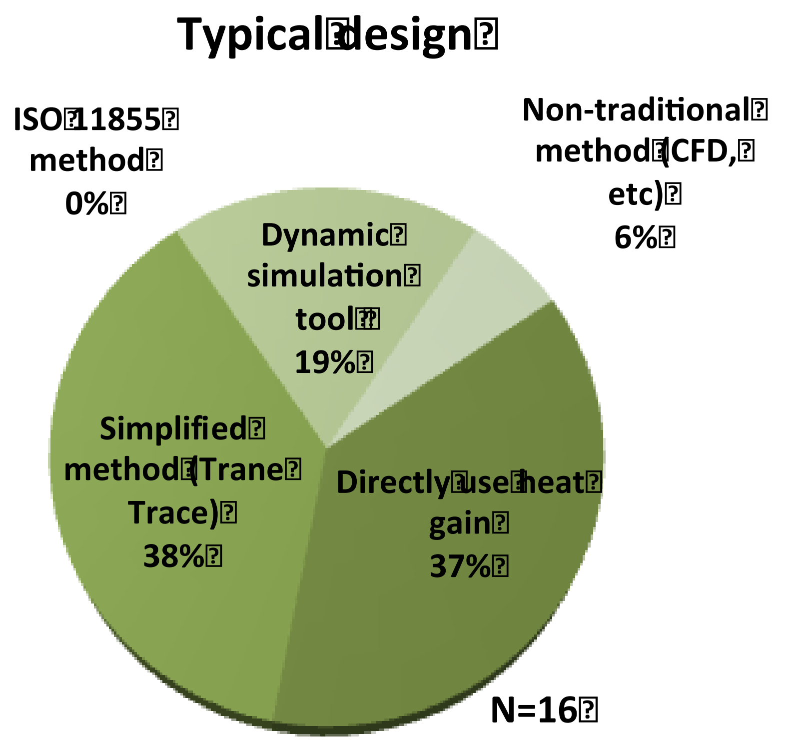
Case study building list

Available cooling load prediction methods/tools

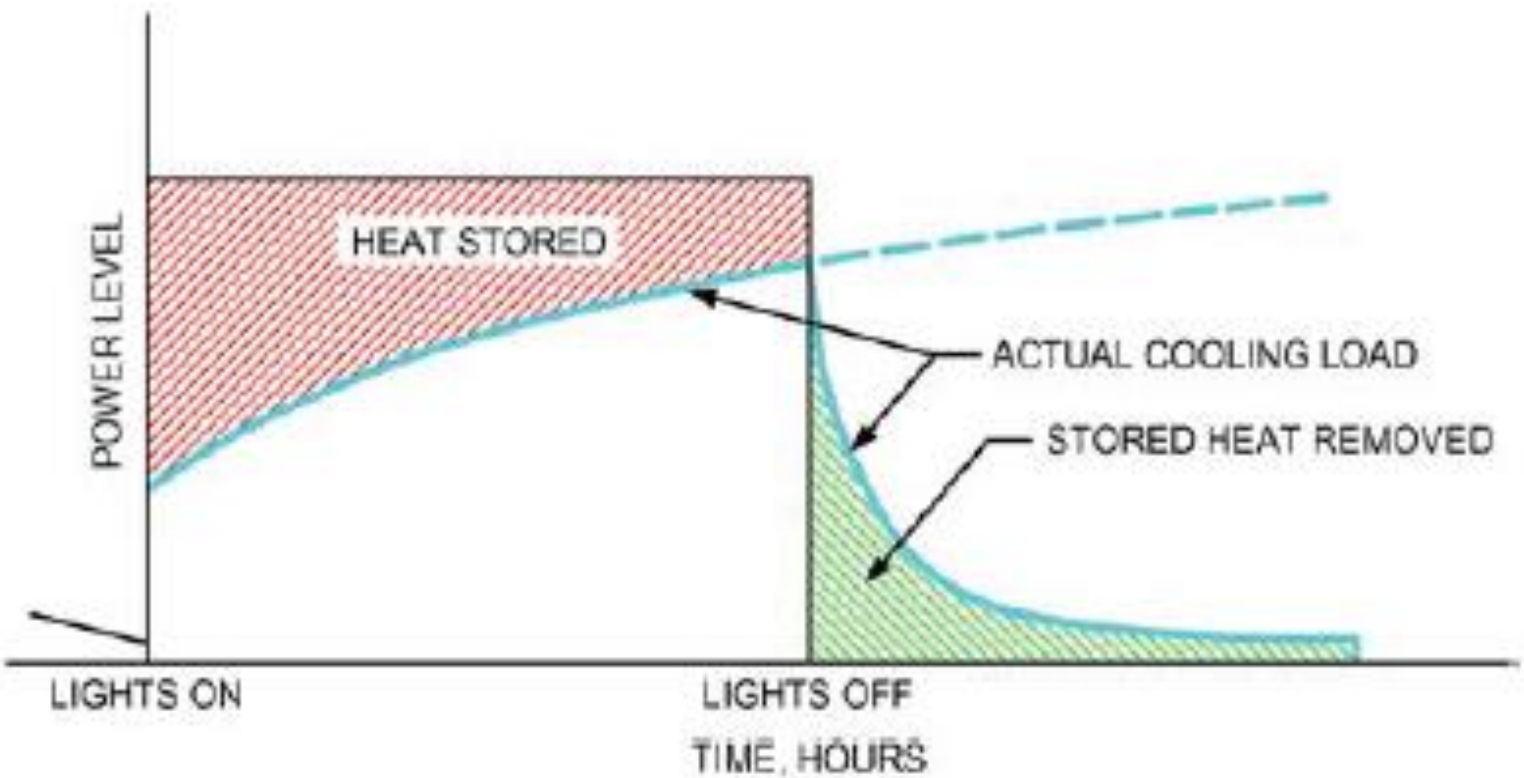
		Method		Tools
#1		**Heat gain**	Ignore thermal mass effect	Spreadsheet
#2		**Simplified methods**	RTS,CLTD/CLF/SCL, weighting factor method, etc. (air system only)	TRACE, DOE-2, eQUEST, etc.
#3		**HB method**	Radiant system simulated with dynamic simulation tool	EnergyPlus, IES-VE, TRNSYS, etc.
#4		**Non-traditional**	Used mostly for applications with intensive solar and stratification	Solar simulation tools, CFD
#5		**ISO-11855 (2012)**	Diagram based on design day energy gain, operation hour, and etc. **(TABS only)**	Proprietary tools

Thermal load analysis method/tool in practice

- 13 out of 16 designers we interviewed assume the same cooling load for radiant systems as air systems
- Radiant cooled surfaces were not directly modeled



Differences between Heat gain and cooling load



Thermal mass effect for convection based (air) system
(source: ASHRAE Fundamental 2013)

Space cooling load definition

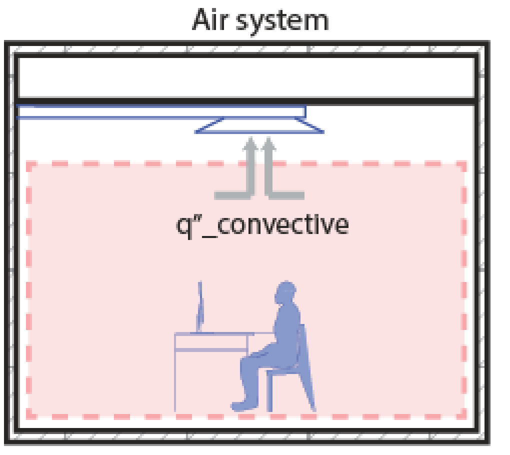
What is the difference in cooling load for radiant vs. air systems?

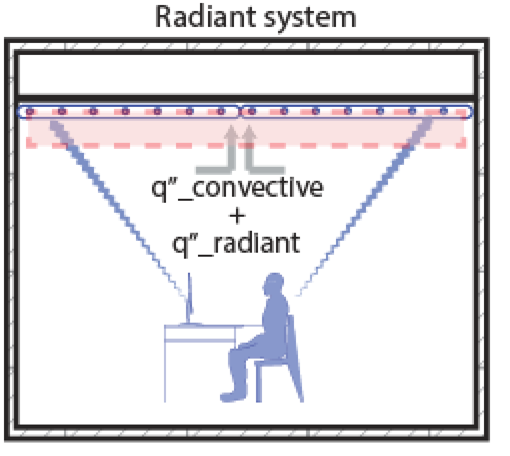
All-air systems

- Cooling load
  - Heat gain removed by convection only
  - Maintain fixed setpoint temperature
- Radiant heat gain
  - Absorbed by non-active thermal mass
  - Released as convective heat gain after time delay

Radiant systems

- Cooling load
  - Heat gain removed by radiation and convection at active chilled surface
  - Maintain operative temperature within comfort zone
- Radiant heat gain
  - Becomes cooling load instantly





Are they the same?

$$\text{Cooling load}_{\text{RADIANT}} \neq \text{Cooling load}_{\text{AIR}}$$

Laboratory testing and simulation study will compare the following:

- Instantaneous cooling rate
- peak cooling rate

Laboratory testing: Cooling load comparison

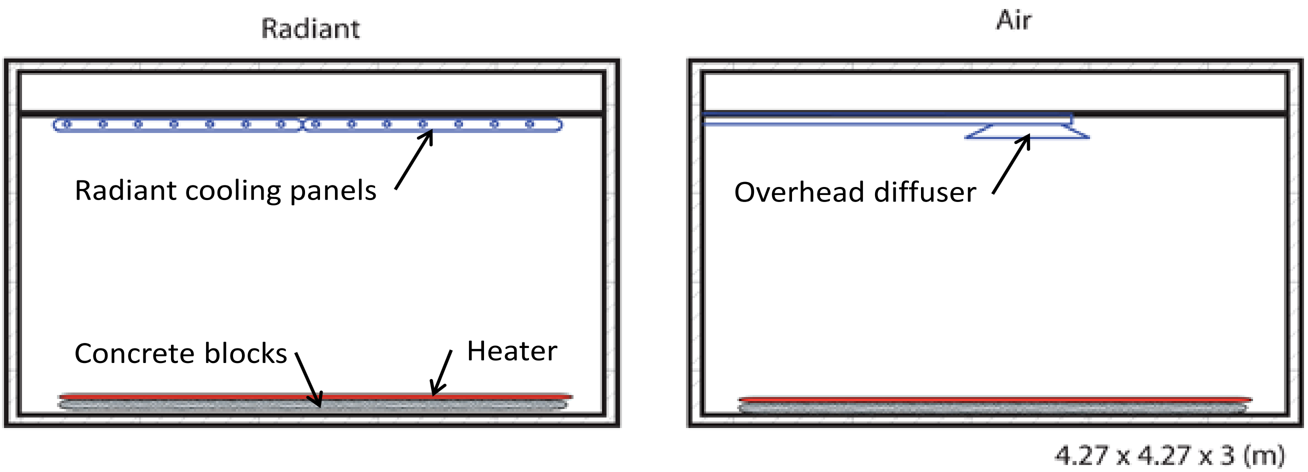
Objectives

- Verify that cooling loads for radiant system are different from air system

Experimental approach

- Concrete blocks (thermal mass) on floor with heating mats on top (internal heat gain)
- Conduct 12-hour tests with heaters on for 6 hours and off for 6 hours
    - Radiant chilled ceiling panels
    - Overhead air system
    - Maintain the same operative temperature

Test chamber configurations



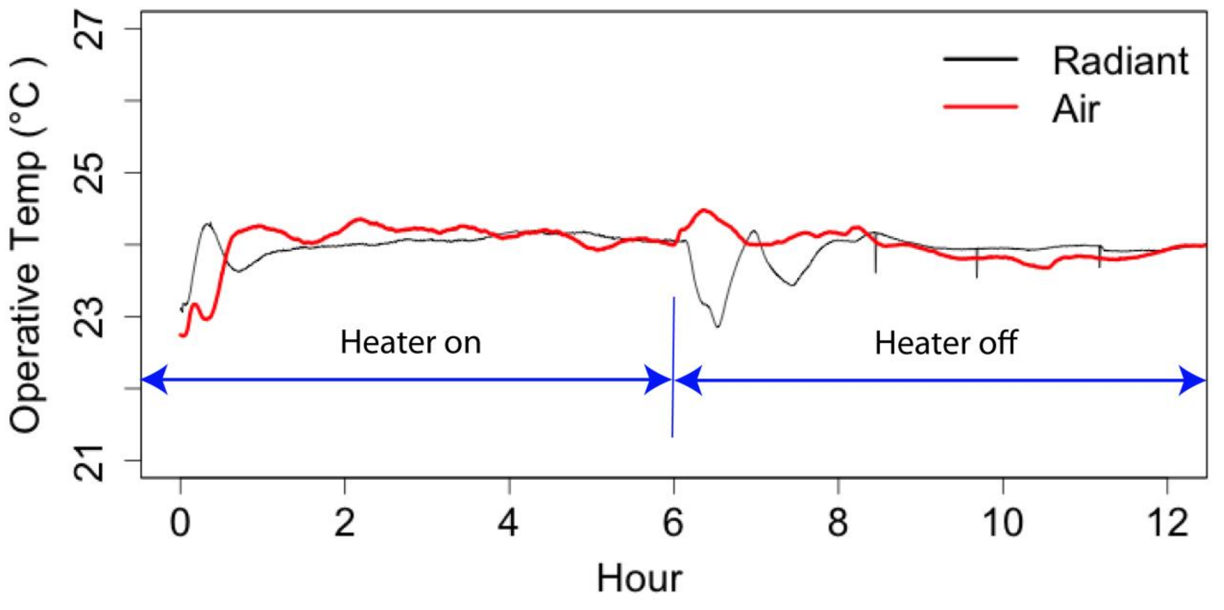
Radiant panel and air diffuser setup **Installing concrete paver** **Heater on the floor**

Feng, J. Bauman, F. and Schiavon, S. (2013) Experimental comparison of zone cooling load between radiant and air systems, *To be submitted to Energy and Building*.

Experimental results: Operative temperature

Maintain the same thermal comfort level

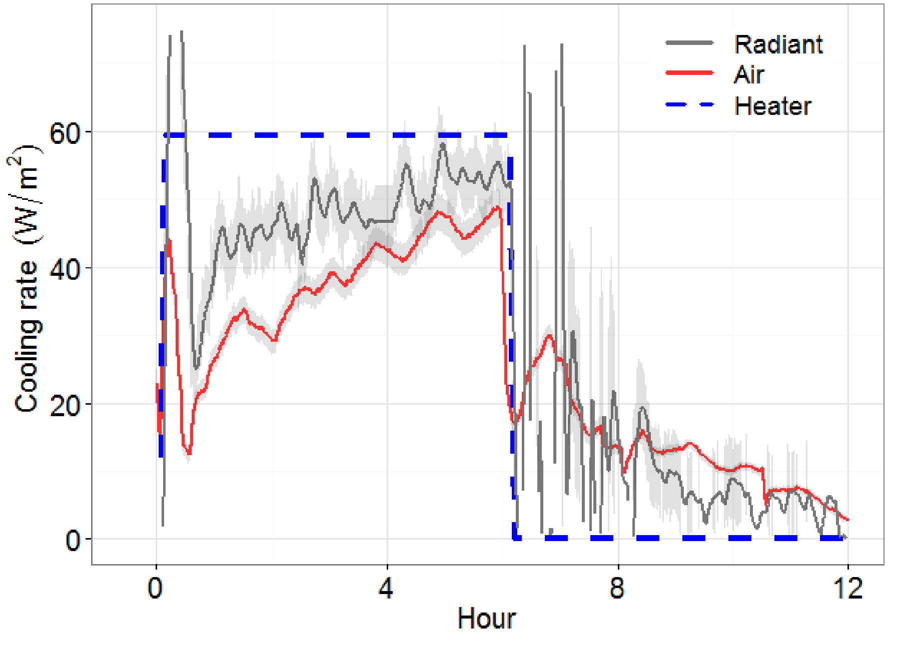
- Control to the same operative temperature at 24°C (75.2 °F)

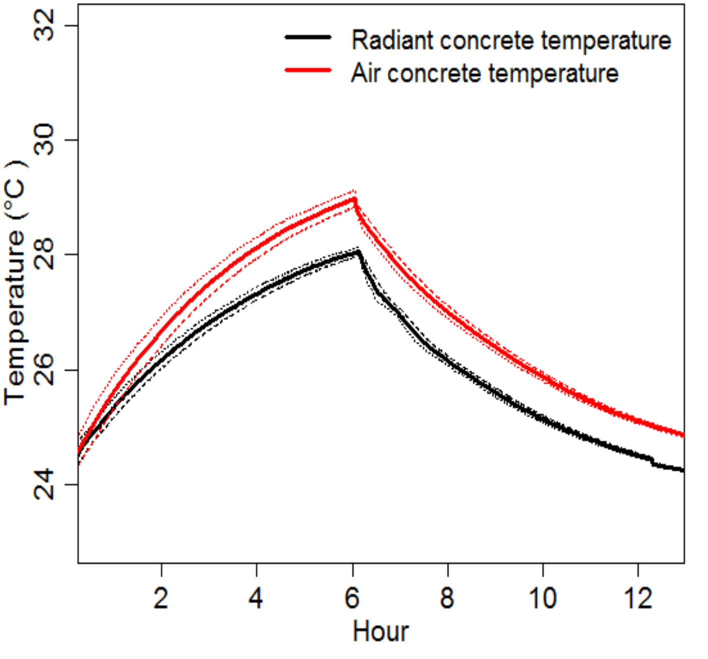


Experimental results: Instantaneous cooling rate

Radiant system has a higher cooling rate than the air system

- 18% higher during hour 6 (peak cooling load)

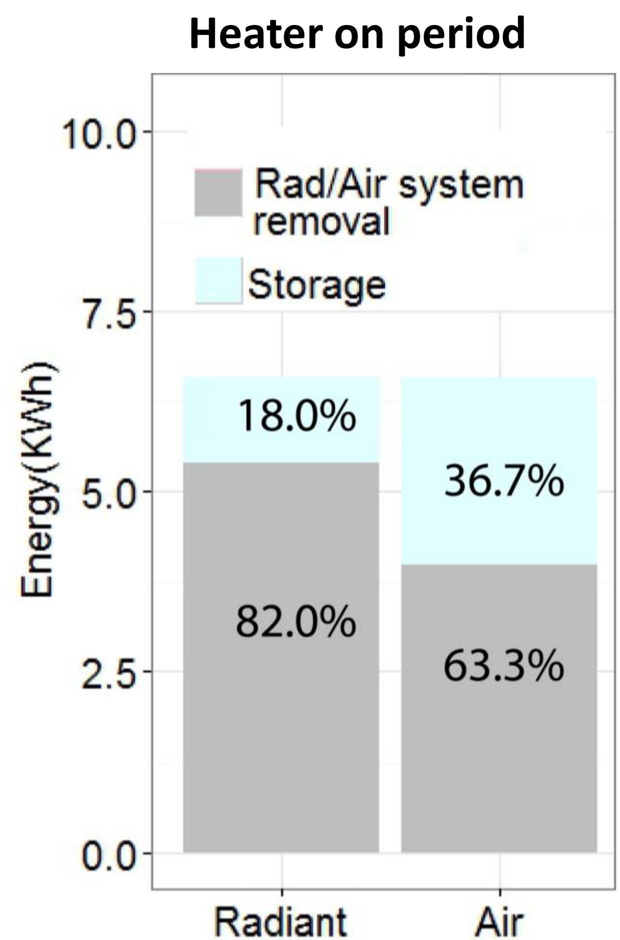




Experimental results: Total energy removal

Radiant system removes heat faster during heater-on period

- Radiant system removes 82% of total heat gain
- Air system removes 63.3% of total heat gain



Simulation study of different design cases

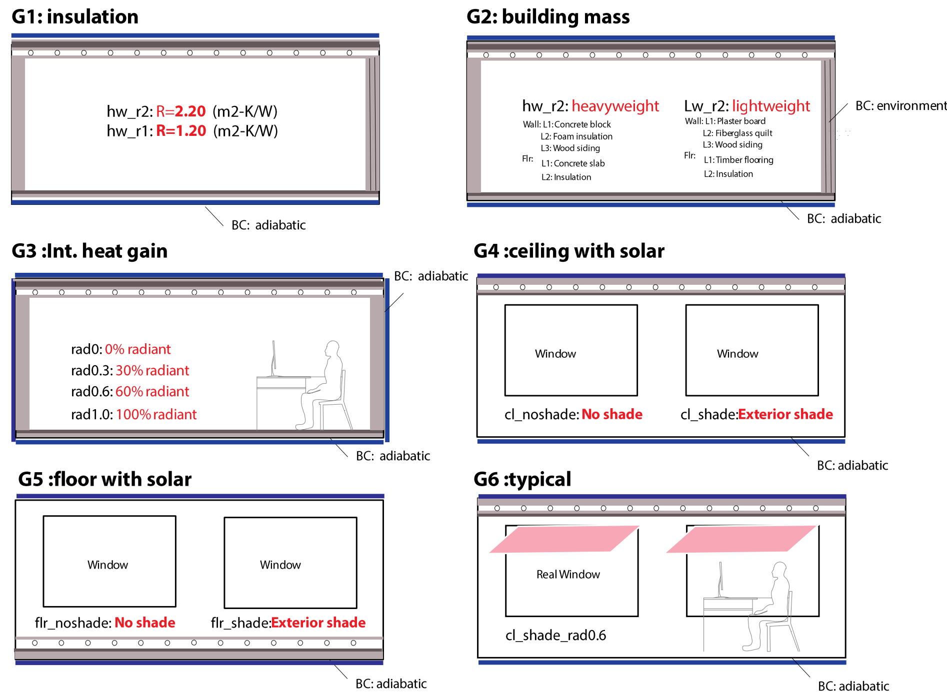
Radiant system types

- Radiant panel/Lightweight radiant slab/Heavyweight radiant slab

Parameters studied

- Thermal insulation
- Building mass
- Radiative/convective split of internal load
- Solar heat gain
- Active ceiling/floor

Cooling design day simulation



Feng, J., Schiavon, S. and Bauman, F. (2013) Cooling load differences between radiant and air systems, *Energy and Buildings*, 65, 310-321.

Results: Peak cooling load

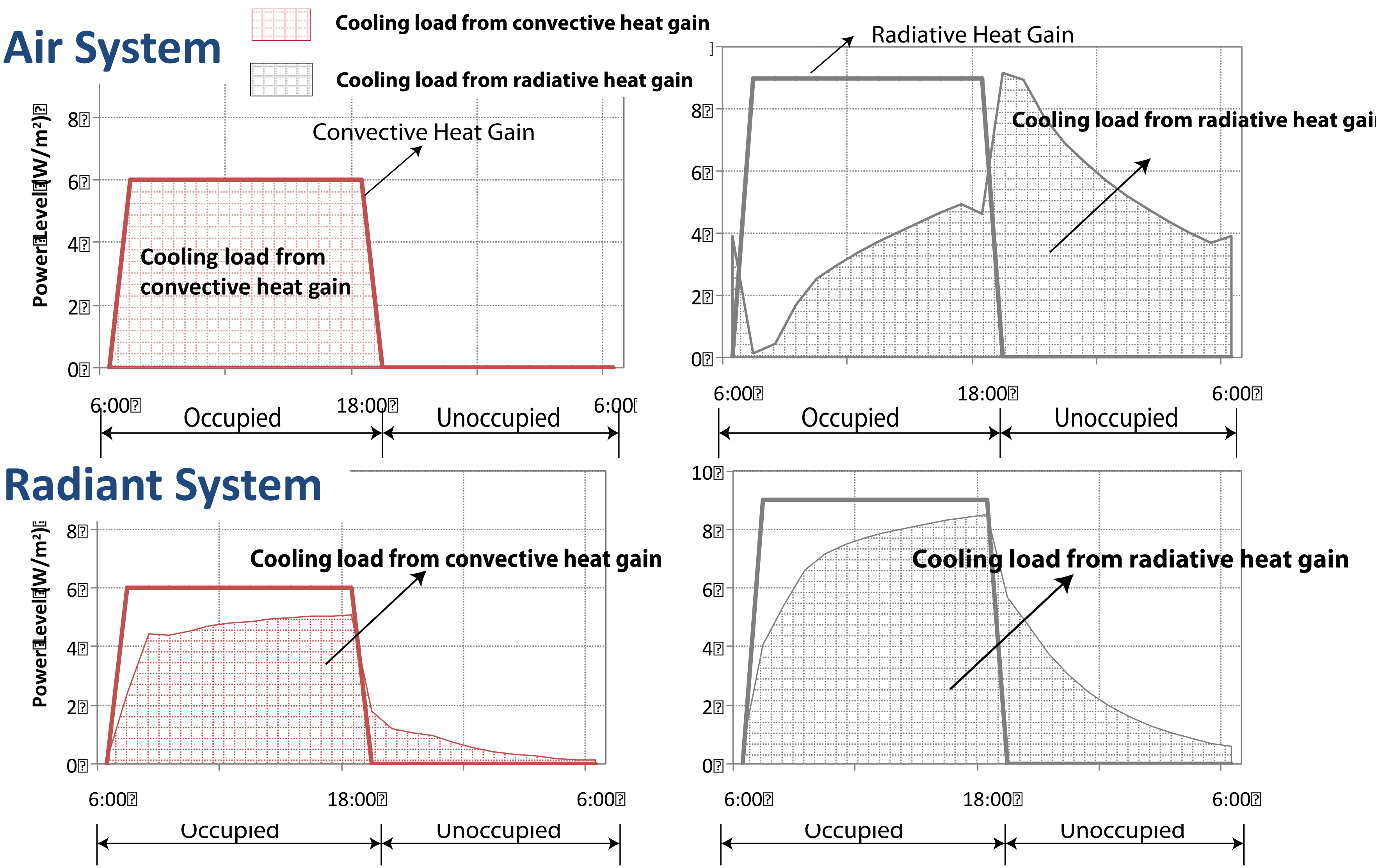
Higher peak cooling load for studied cases:

- Interior space: 7-27%
- Perimeter space without solar: 12-35%
- Perimeter space with solar: 48-85%

Implications

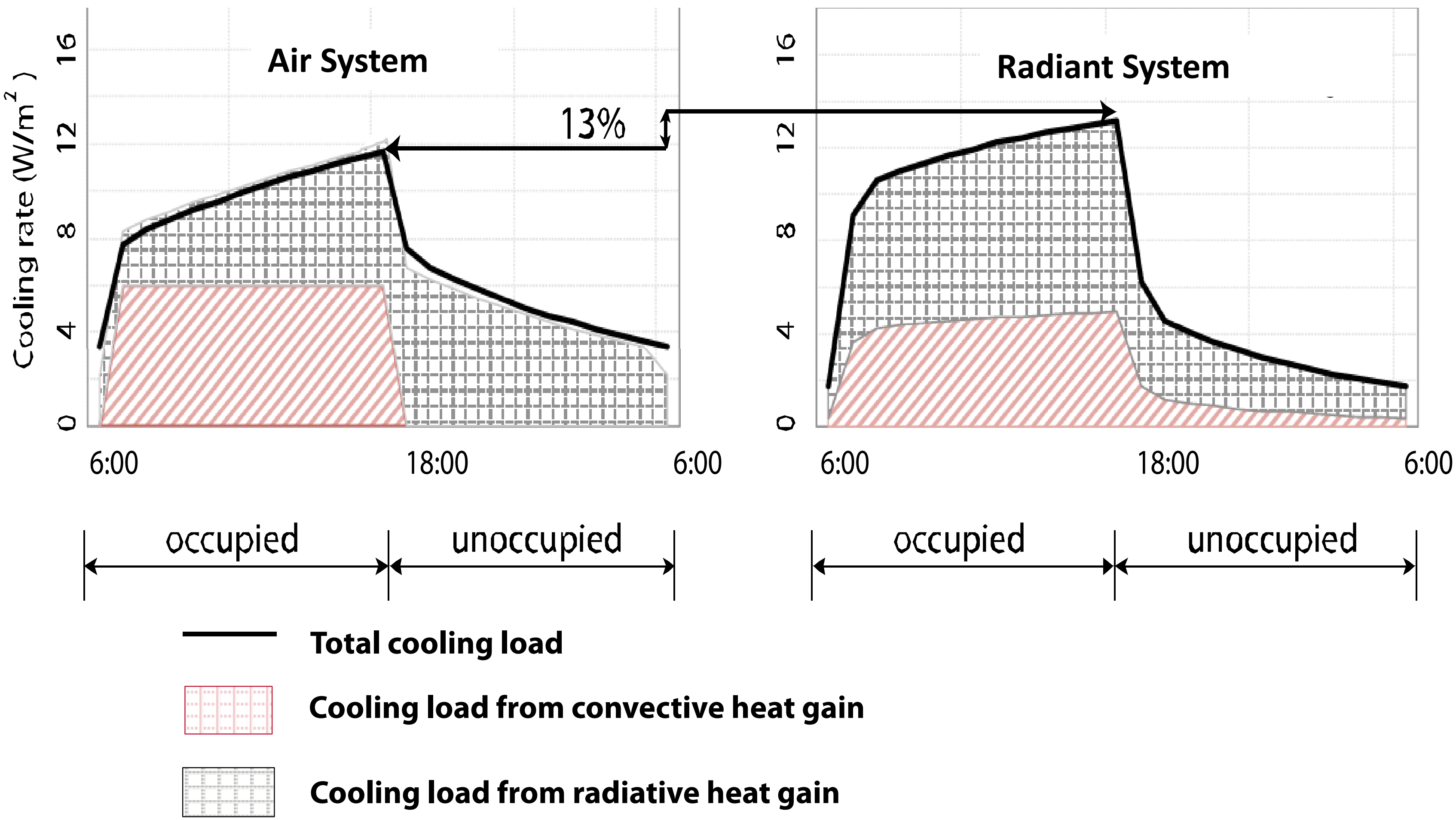
- Minimize solar load for design
- Especially effective for removing solar load
- High peak load ≠ high energy consumption!

Why are they different?



Comparison of cooling load profiles

- Case example: Internal load only_ radiative fraction= 0.6



What about cooling load prediction methods and modeling tools?

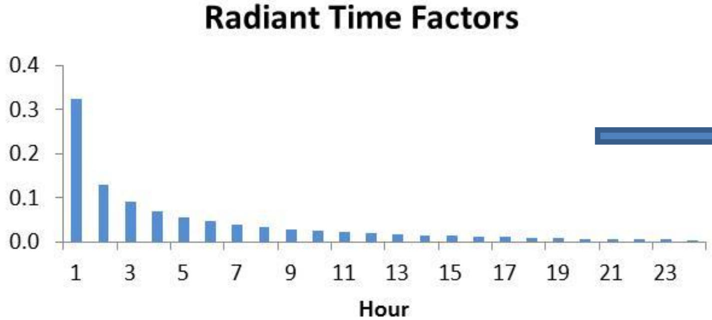
ASHRAE cooling load prediction methods

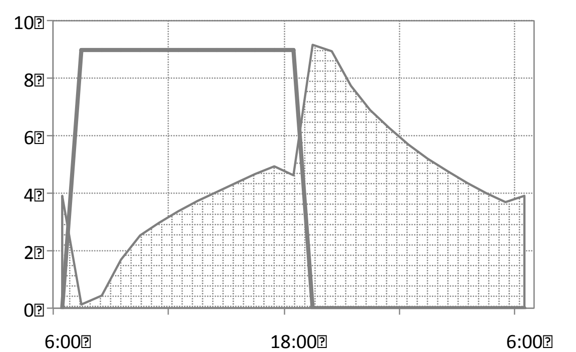
Heat balance (HB) method

- Based on first principles
- EnergyPlus 8.0

Radiant time series (RTS) method/weighting factor method

- Convective heat gain → instantaneous cooling load
- Radiative heat gain → convective cooling load with delay
- CTF/RTF Generator and excel (or TRACE)





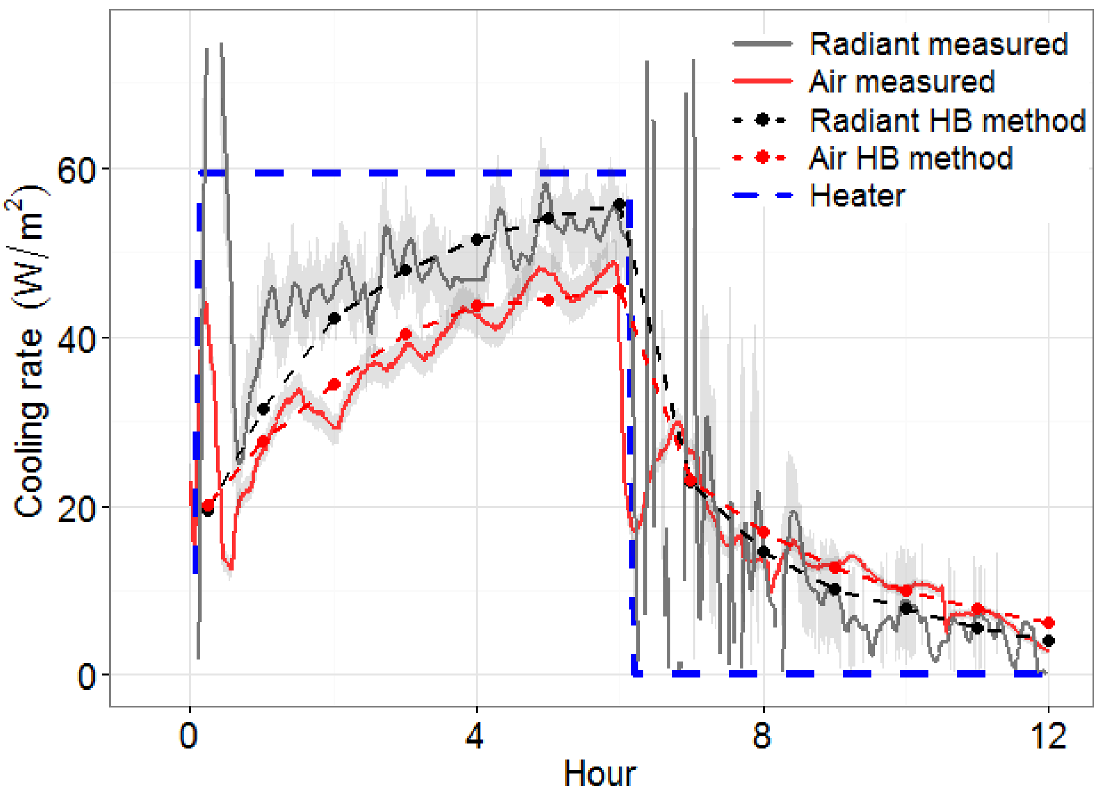
Quote: ASHRAE HOF chapter 19

When radiant cooling and heating systems are evaluated, the radiant source should be identified as a room surface. The calculation procedure considers the radiant source in the heat balance analysis. Therefore, the heat balance method is preferred over the weighting-factor method for evaluating radiant systems. Strand and Pedersen (1997) describe implementation of heat source conduction transfer functions that may be used for modeling radiant panels within a heat balance-based building simulation program.

--------- *ASHRAE Handbook of Fundamentals, (2013)*
Chapter 19: Energy estimating and modeling method

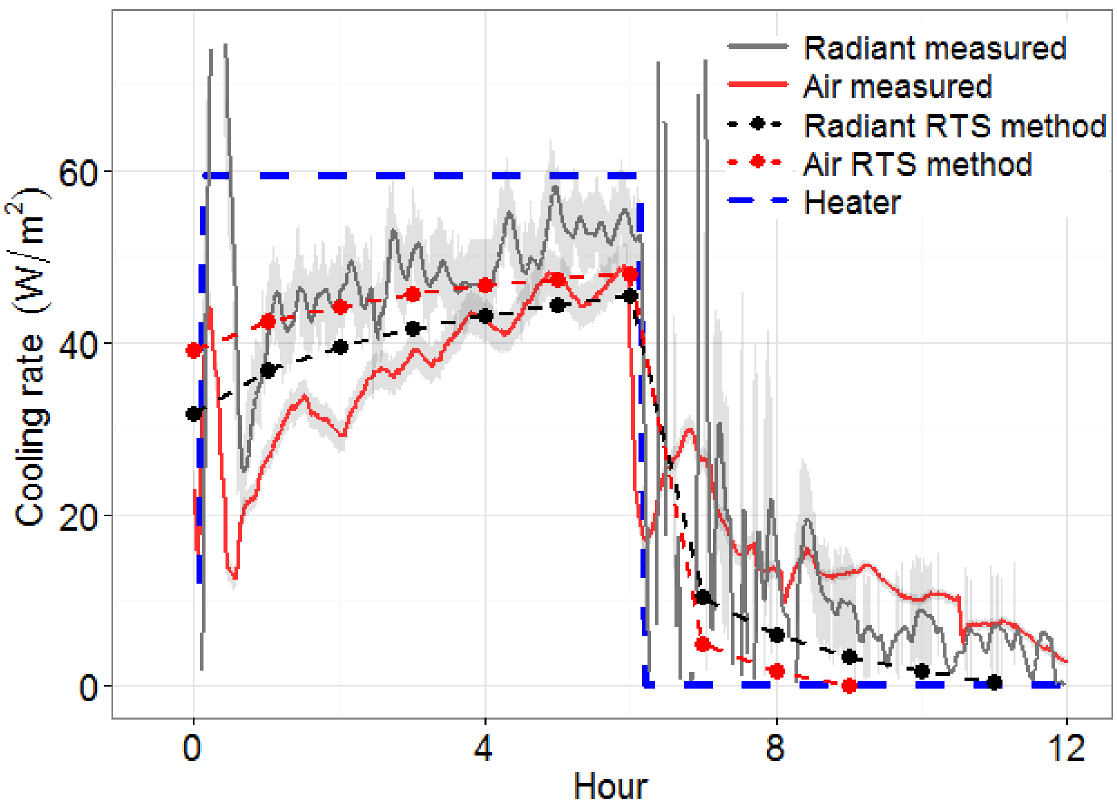
Measured vs. Prediction based on HB method

- EnergyPlus v8.0 model was developed to apply the HB method
- Match well with air system cooling load
- Radiant system cooling load: heat removed by the radiant ceiling panels



Measured vs. Prediction based on RTS method

- RTS method cannot predict cooling load correctly for the test chamber configuration



Modeling tool selection

Tools	Modeling method	Capability to capture the radiant dynamic
IES (VE)	HB method	
TRNSYS	HB method	
EnergyPlus	HB method	
ESP-r	HB method	
DOE-2	Weighting factor method	
eQUEST	Weighting factor method	
TRACE	RTS method or TF method	

Make sure to: 1) Model the radiant source as a room surface;
2) Define cooling load correctly

Design radiant floor cooling systems with solar load

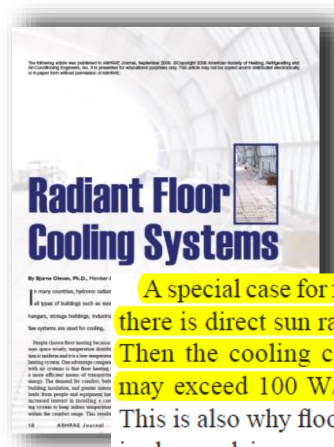
Applications

- Spaces with large glazed surfaces, such as atria, perimeter areas, etc.

Guidance is limited with solar

- Maximum cooling capacity in standard: 42 W/m^2 (13 Btu/h.ft^2)
- With solar: 100 W/m^2 (32 Btu/h.ft^2)

Akron art museum, OH

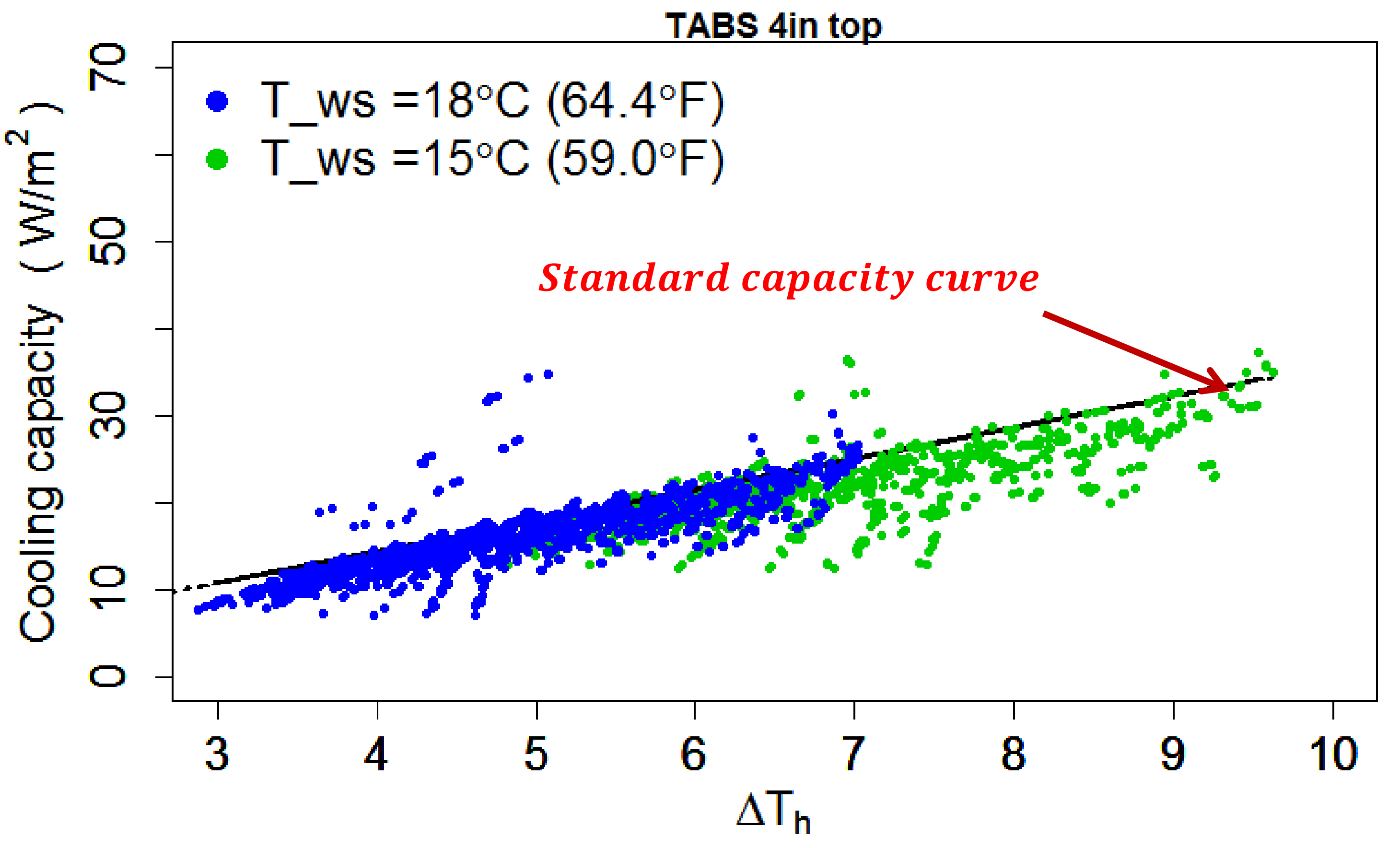


A special case for floor cooling is when there is direct sun radiation on the floor. Then the cooling capacity of the floor may exceed 100 W/m^2 (32 Btu/h·ft^2).[1] This is also why floor cooling is increasingly used in spaces with large glass surfaces such as airports,[3] atriums, and entrance halls.

B. Olesen, ASHRAE Journal (2008).

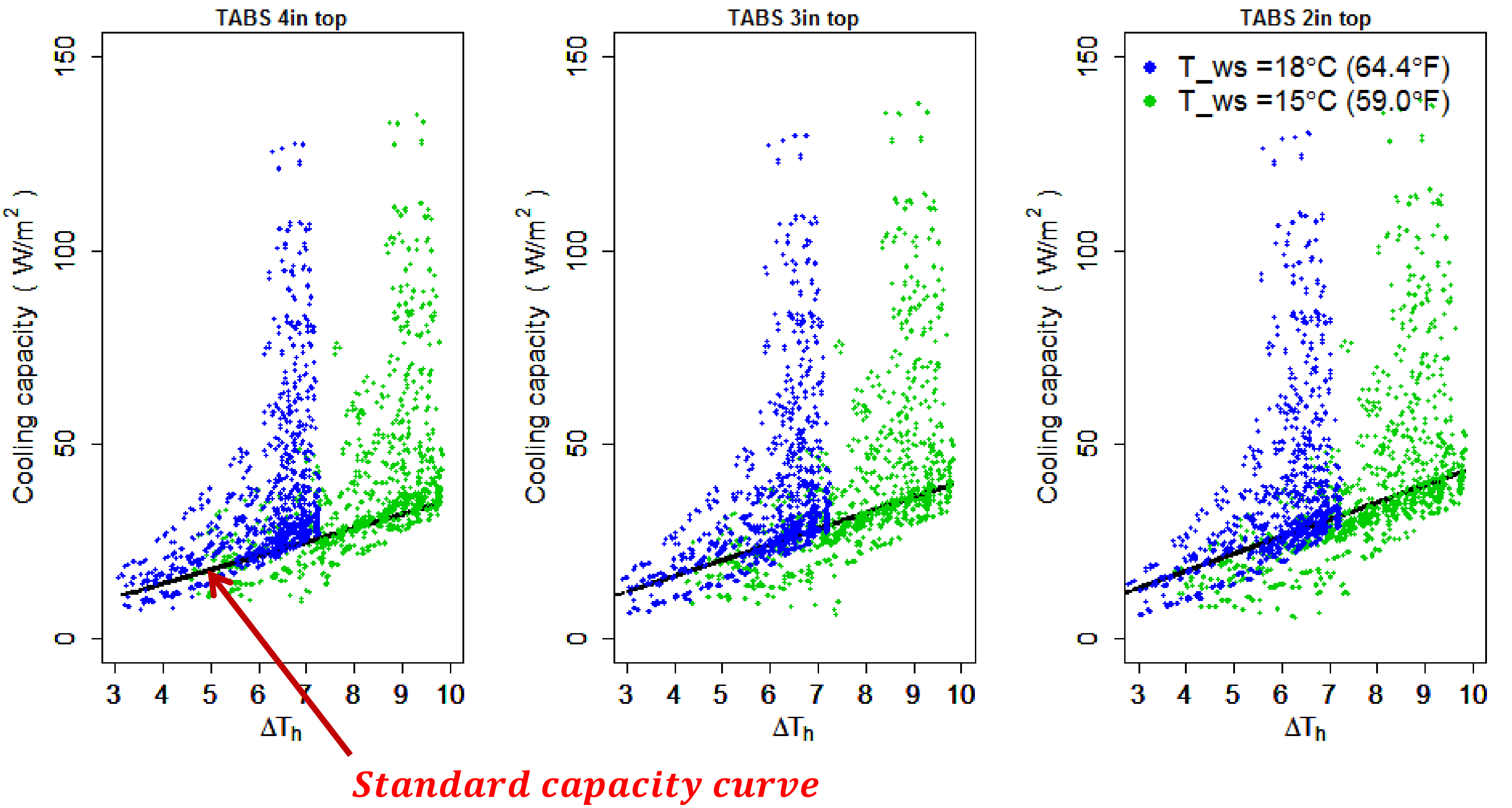
Simulated capacity vs. standard **without solar**

- Simulated capacity matches well with standard capacity curve without solar



Simulated capacity vs. standard **with solar**

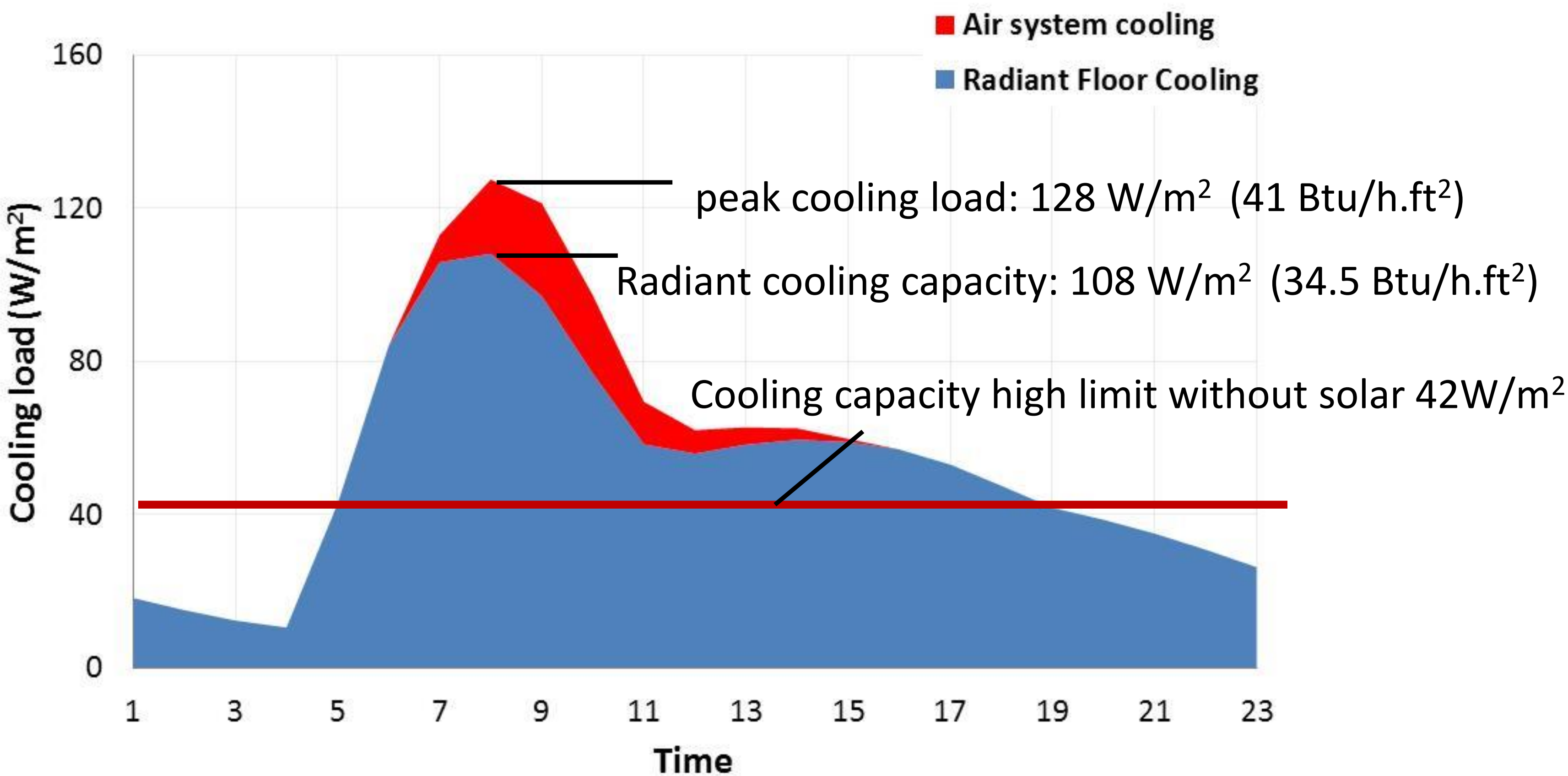
- Cooling capacity can reach 130 W/m^2 (42 Btu/h.ft^2)



Impact on air system sizing

Air system size: **Simulated:** 20 W/m² (6.4 Btu/h.ft²)

Guideline: 86 W/m² (27.5 Btu/h.ft²)



Modeling for code compliance and beyond code program

Title 24 (2013): Radiant floor cooling system

- Modeling requirements for compliance evaluation

Items	Modeling Input Restrictions
Temperature control	Mean air temperature
Hydronic Tubing Inside Diameter	Between a minimum of 1/2" and a maximum of ¾ "
Temperature Control	Fixed at Mean Air Temperature for compliance calculations
Condensation Control Dewpoint Offset	Minimum cold water supply Temperature fixed at 2°F above dewpoint
Cooling Low Water Temperature	55°F

- EnergyPlus will be available for code compliance (CBECC-Com) , Jan 2014, http://www.bees.archenergy.com

LEED

LEED topics	Possible points
Energy & Atmosphere Credit 1: Optimize energy performance Credit 3: Enhanced commissioning Credit 4: Enhanced refrigerant management Credit 5: Measurement & verification	26
Indoor Environmental Quality Credit 1: Outdoor air delivering monitoring Credit 2: Increased ventilation Credit 3: Construction IAQ plan Credit 6.2: Controllability of systems – thermal comfort Credit 7: Thermal comfort- Design&Verification	6
Innovation in design	5

Key takeaway

- **Cooling load prediction and modeling method for radiant systems**
  - Use design tools based on heat balance approach
  - Define cooling load as heat removed by actively cooled surface(s),i.e. , radiant source should be modeled
  - RTS or weighting factor method, may lead to incorrect results
- **Peak cooling loads may be higher than air systems, but…**
  - Radiant systems are known to be more energy efficient
  - Under some operating strategies radiant systems will have lower peak cooling loads (e.g., nighttime pre-cooling).

Acknowledgments

- California Energy Commission (CEC) Public Interest Energy Research (PIER) Buildings Program.
- Center for the Built Environment, University of California, Berkeley (www.cbe.berkeley.edu).
- Julian Rimmer, Brad Tully, and Tom Epp of Price Industries for the use of their Hydronic Test Chamber in Winnipeg.

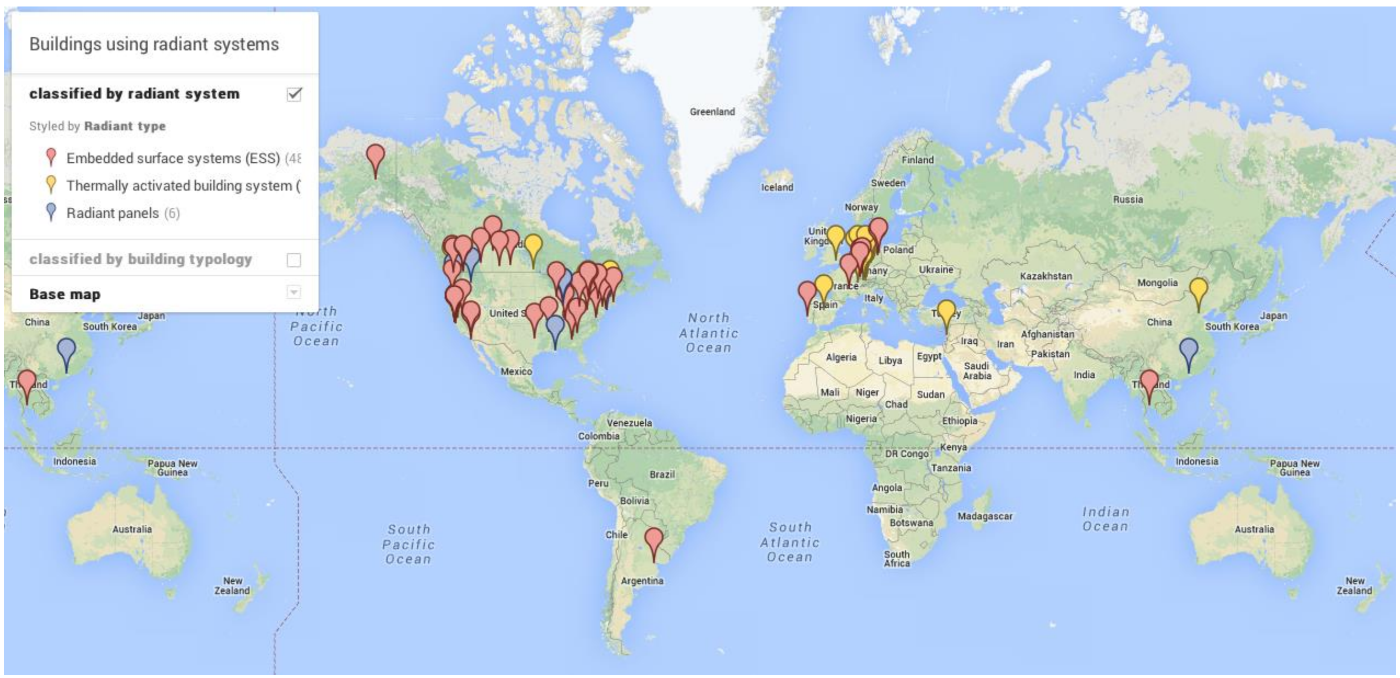
Radiant system building project

Link to the map: http://bit.ly/RadiantBuildingsCBE

Link to the form: http://bit.ly/RadiantFormCBE

Contact: Caroline Karmann, ckarmann@berkeley.edu

Fred Baumann, fbauman@berkeley.edu



Questions?

Jingjuan (Dove) Feng

jjfeng@berkeley.edu

Fred Bauman

fbauman@berkeley.edu

Stefano Schiavon

sschiavon@berkeley.edu