Optimizing Radiant Systems For Energy Efficiency and Comfort

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Overview

Objective

- Investigate the feasibility of replacing vaporcompression based cooling
- Develop and experimentally test control strategies for HTMR
- Develop web-based tools and guidelines for HTMR

Approach

Modeling/simulation and field studies

Funding

CEC EPIC program and CBE match funding



Infrared picture of TABS system.

These studies focus on high thermal mass radiant systems (HTMR)



High thermal mass radiant

Differences in energy heat transfer



How fast do radiant systems response after a control change?



Ning, Baisong, Stefano Schiavon, and Fred S. Bauman. 2017. "A Novel Classification Scheme for Design and Control of Radiant System Based on Thermal Response Time." *Energy and Buildings* 137 (February): 38–45. <u>https://doi.org/10.1016/j.enbuild.2016.12.013</u>.

HTMR presents challenges due to its high thermal mass, yet it opens the opportunity for innovative design and control options.

Radiant systems should use warmer water temperatures for cooling

Study type ○ Laboratory △ Field □ Simulation ◇ Steady-state heat balance Radiant type ● RCP ● ESS ● TABS ● Unspecified



Wet bulb temperatures from May to Oct. at the 90th percentile



Evaporative cooling feasibility increases with lower wet bulb temperatures



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Simulation procedure to find the warmest supply water temperature



Middle floor of commercial office building

- Envelope thermal properties set to minimum energy code requirements
 - ASHRAE 90.1-2016, Title 24-2016
- Design operative temperature: 26 °C (79 °F)
- Varied 24 total design parameters
 - Cooling plant start time & duration
 - WWR & orientation
 - Zone dimensions
 - Internal heat gains
 - Tube spacing, depth, diameter



Median percentage of waterside economizing operation



Managing zone heat gains improves high-temperature cooling

- 24-hour average heat gains are more important for high thermal mass radiant system design
 - Peak heat gains are important for supplemental cooling design
- 24-hour average HG ≤ 25 W/m² (8 Btu/hr-ft²) enables supply water temperatures greater than 15°C (59°F)



Increasing plant operation duration facilitates high-temperature cooling

- Increasing operation duration from 10 to 18 hours:
 - Increases required SWT by ~3°C (5°F)
 - Reduces cooling plant size by **43%**
- Still avoid unfavorable operation hours
 - High electricity prices
 - High greenhouse gas emission rates
 - Peak outdoor conditions
- Benefits include:
 - Lower cooling costs
 - Higher HVAC efficiency
 - Smaller mechanical footprint



Control of high thermal mass radiant systems

Field study building overview



Building 1 (B-1)

- Four story, 42K ft² (3.9K m²) LEED Platinum
- Moderate window-to-wall ratio (WWR) and well shaded
- Multi-tenant; 150 occupants
- Berkeley, CA



- Baseline: Jul Oct 2016
- Intervention: Jul Oct 2018
- Max: 94°F (34°C) | Min: 46°F (8°C)
- Daily averages
 - Mean: 62°F (17°C) | Range: 15°F (8°C)
 - Day-to-day variability: 1.6°F (0.9°C)

Field study building overview



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- Cooling tower only
 - Two position valves
- UFAD ventilation
- 2-pipe system for whole building
- Whole building tested



CBE control sequences for high thermal mass radiant system



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Baseline Mean air temperature profiles 78°F 70°F 8 16 Hour



Intervention

Baseline Intervention Daily air temperature profiles 26°C 78°F 21°C 70°F 16 16 8 8 Hour







Testing the TOS platform in a pilot study



Recruited 11 occupants and placed small sensor on their desk.

B-1 radiant system zone performance

Manifold valve operation

- Proxy for energy consumption
- Actuated significantly less time
- Daily average ON time
 - Baseline: ~4 hours
 - Intervention: <30 minutes
- Some days it did not turn on at all



B-1 radiant system plant performance



CBE Rad Tool

STEADY

(radiant.cbe.berkeley.edu)

Calculation type

- Steady-state
- ISO 11855 standard

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STEADY STATE

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Inputs

- Radiant system type
- **Design parameters**
- Metric/Imperial units

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RESOURCES



TRANSIENT

STEADY STATE

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RESOURCES

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Outputs

- Design values
 - Surface heat flux
 - Hydronic heat capacity
 - Waterflow rate
 - Pipe design
 - Surface temperature
- Visualization of the design space

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Layout of the webtool: Transient

STEAD

Calculation type

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- Over 2.5 million EnergyPlus simulations

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Layout of the webtool: Transient

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Calculation type

- Transient
- Over 2.5 million EnergyPlus simulations

Inputs

- Design parameters
- Time



Layout of the webtool: Transient

STEADY STATE

TRANSIENT

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Calculation type

- Transient
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Inputs

- Design parameters
- Time

Outputs

- 24-hour cooling day design values
 - Surface heat flux
 - Hydronic heat capacity
 - Operative temperature

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RESOURCES



24-hour transient profiles for different scenarios



Hour

Hour Center for the Built Environment | November 2021

Conclusions for high thermal mass radiant systems

High-temperature cooling feasible in all climates by:

- Managing average heat gains in the space
 - 24-hr average \leq 25 W/m² (8 Btu/hr-ft²)
- Increasing the cooling plant operation duration
 - Operate 18 h on design day

Field studies show that a relatively simple control strategy can be implemented natively in BMS.

Maintains predictable temperatures and low discomfort exceedance hours

Benefits:

- Sustainable energy sources such as evaporative or ground cooling
- Cooling plant size, footprint, and first cost reductions
- Higher HVAC system efficiency
- Operating time flexibility:
 - Daytime | Afternoon | Nighttime | Grid optimal
- Future-proofing for uncertain energy prices



Construction site on a high thermal mass radiant system.

Q&A

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