New design tools and controls for load-shifting with radiant systems

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Overview

Objective

β Develop new controls for high thermal mass radiant systems

Approach

β Interview experts
β Review controls and trend data from existing buildings
β Develop new controls and iteratively test in simulation
β Demonstrate in two buildings
Interviews with designers

- Interviewed 11 prominent professionals who have designed over 330 radiant cooled buildings

Findings

- Generally a wide diversity of design and control solutions - reveals opportunities for standardization and improvement
- Very rarely leverage thermal mass to shift load.

Example results: Radiant zone control device

<table>
<thead>
<tr>
<th>How do you control radiant zones?</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two position zone valves</td>
<td>6</td>
</tr>
<tr>
<td>Modulating zone valves</td>
<td>4</td>
</tr>
<tr>
<td>Pumps with 3-way control valves at the zone</td>
<td>3</td>
</tr>
<tr>
<td>Constant speed pump</td>
<td>1</td>
</tr>
<tr>
<td>Variable speed pump</td>
<td>1</td>
</tr>
</tbody>
</table>
Trend data from a radiant building (in July)

- **27 °C (81 °F)**
- **23 °C (73 °F)**

Peak building demand

Peak electricity prices

Warmest outside temperatures

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- **Noon on Monday**
- **Noon on Tuesday**
- **Noon on Wednesday**
- **Noon on Thursday**
- **Noon on Friday**
- **Noon on Saturday**
- **Noon on Sunday**
Motivation

How can we help designers benefit from the load shifting potential of radiant systems?
Simulation results: Common control strategy

Results from a single zone energy simulation on the cooling design day.

Conditions
- Variable flow
- Constant temperature (18 °C | 64 °F)
- Modulating valves 0.5 °C (1 °F) band

Advantages
- Simple, familiar controls
Effect of different operating times

**Conditions**

- Constant temperature (18 °C | 64 °F)
- Constant flow (two position valves)
- Constant duration of operation (9 hours)
- Varying time of operation
Effect of different operating times

**Conditions**
- Constant temperature (18 °C | 64 °F)
- Constant flow (two position valves)
- Constant duration of operation (9 hours)
- Varying time of operation

**Result**
- Can maintain comfort regardless of time of operation
Design/operation possibilities: Afternoon shutoff

**Conditions**
- Constant temperature
- Constant flow (on/off valves)
- Operates during the morning and early afternoon

**Advantages**
- More uniform daily comfort conditions
- Reduces peak energy charges
- Avoids building peak demand charges

Less variation than simple proportional controller

0.9 °C | 1.7 °F

Less variation than simple proportional controller
Design/operation possibilities: Daytime shutoff

**Conditions**

- Constant temperature
- Constant flow (on/off valves)
- Operates only during the night

**Advantages**

- Low energy charges
- No demand charges
- Chilled water plant operates at night, when dry- and wet-bulb temperatures are lowest
Design/operation possibilities: Constant flow

**Conditions**
- Constant supply temperature 4 °F higher than previous cases: 68 °F (20 °C)
- Operates 24 hours per day

**Advantages**
- Low peak plant load
- Small chiller, low initial cost
- High supply water temperatures
Controls for radiant systems
Overview of the controls (sequences publicly available)

- First loop responds to slab temperature and controls the radiant zone valve.
- Second control loop adjusts slab setpoint once per day based on previous day’s zone conditions.
- Choose enabled time period each day. Radiant system is disabled at all other times.
- Heating or cooling mode separated by at least one day.
- Supplemental zone cooling/heating systems:
  - Prioritizes radiant system
  - Limits systems operating in opposing heating/cooling modes on the same day.
Example cooling day operation from field study demonstration

- Comfort bounds
- Safety factor
- Enabled period
- Occupied period

Indoor air max
Error
Reset slab SP at end of occupied hours
Example thermal comfort comparison in one zone

Baseline

Intervention

Daily air temperature profiles

78°F

70°F

Hour

8 16

8 16
Example thermal comfort comparison in one zone

<table>
<thead>
<tr>
<th>Hour</th>
<th>Baseline</th>
<th>Average day-to-day variability</th>
<th>Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>78°F</td>
<td>0.94°F</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>78°F</td>
<td></td>
<td>0.47°F</td>
</tr>
<tr>
<td>8</td>
<td>70°F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>70°F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Oct 2019
Example thermal comfort comparison in one zone

Baseline  |  Exceedance percentage of total occupied hours  |  Intervention

78°F  |  12.3%  |  0.6%  |  70°F

Hour
Sacramento Municipal Utility District East Campus Operations Center (SMUD)

- Five story, 200K ft²
- LEED Platinum
- Low WWR and well shaded
- Single tenant; 900 occupants
- Sacramento, CA

- Cooling season weather summary 2017-2019
- Max: 111°F

- Daily averages
  - Mean: 74°F | Range: 30°F
  - Day-to-day variability: 2.7°F
Tested new control sequences

- Baseline: May - Nov 2017
- Controls implemented in Siemens Apogee system
- Split zones into two groups
- Intervention: May - Nov 2018
- Compared results

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**Baseline**

Group A and B zones cool whenever needed during the day or night

**Intervention**

Group A zones cool only from morning to early afternoon

Group B zones cool only during the night
SMUD radiant system thermal comfort performance in **all** zones

**Baseline**

- Variability: 0.42°F
- Group A: 0.46°F
- Group B: 0.35°F
- Exceedance: 8.9%

**Intervention**

- Variability: 0.29°F
- Group A: 0.28°F
- Group B: 0.30°F
- Exceedance: 1.1%
SMUD radiant system zone performance

Radiant system operation

- Proxy for pump consumption
- Actuated far less time
- Daily average ON time
  - Baseline: 2-4 hours
  - Intervention: 0.5 - 1 hour
- Some days does not turn on at all

![Graph showing daily average number of minutes radiant system is ON for different times of day and groups A and B.](image)
Resources

Please share, use and give us feedback.
Free webtool (steady-state performance): radiant.cbe.berkeley.edu

**Applications:**
- Heating and cooling
- Floor and ceiling systems
- Radiant systems with and without insulation and/or surface coverings
- Metric and I-P units

**Calculates:**
- Steady-state capacity (ISO 11855)
- Number of circuits, pipe length and pressure drop
Free webtool (transient performance): radiant.cbe.berkeley.edu

- Transient results from over 2.5 million simulations
- 13 user selectable design parameters incl. time and duration of operation

**Outputs**
- 24-hour cooling day design values
- Surface heat flux
- Hydronic heat capacity
- Operative temperature
Controls publicly available in resources: radiant.cbe.berkeley.edu

- Sequences of operation available
- English language, editable Word document
- Can be implemented in existing automation systems
- EnergyPlus examples available
- Available as a measure in OpenStudio
Design concept leveraging thermal storage
Example design concept leveraging thermal mass

- All-electric: Air (or ground) source heat pump for heating and cooling
- Dedicated outside air system (DOAS) and radiant can operate at different times and different temperatures, using the same heat pump
- Reduced design capacity
- Closed circuit cooling tower (fluid cooler) for economizer operation

Daytime (45-60 °F water)

Night-time (60-68 °F water)

~50% of annual DOAS cooling

80-90% of annual radiant cooling

Fluid cooler

Heat pump

DOAS

Radiant manifolds

Fluid cooler

Heat pump

DOAS

Radiant manifolds
Closing remarks
Annual grid greenhouse gas emissions

When solar panels generate power.

Source: Recurve.
Getting the storage we need to make the grid renewable is a huge challenge. Storing energy in concrete is as cheap and easy as it’s going to get.
New HVAC designs should leverage **inherent** thermal storage in buildings.
Questions?

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