Optimizing Radiant Systems For Energy Efficiency and Comfort

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CBE
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Overview

Objective

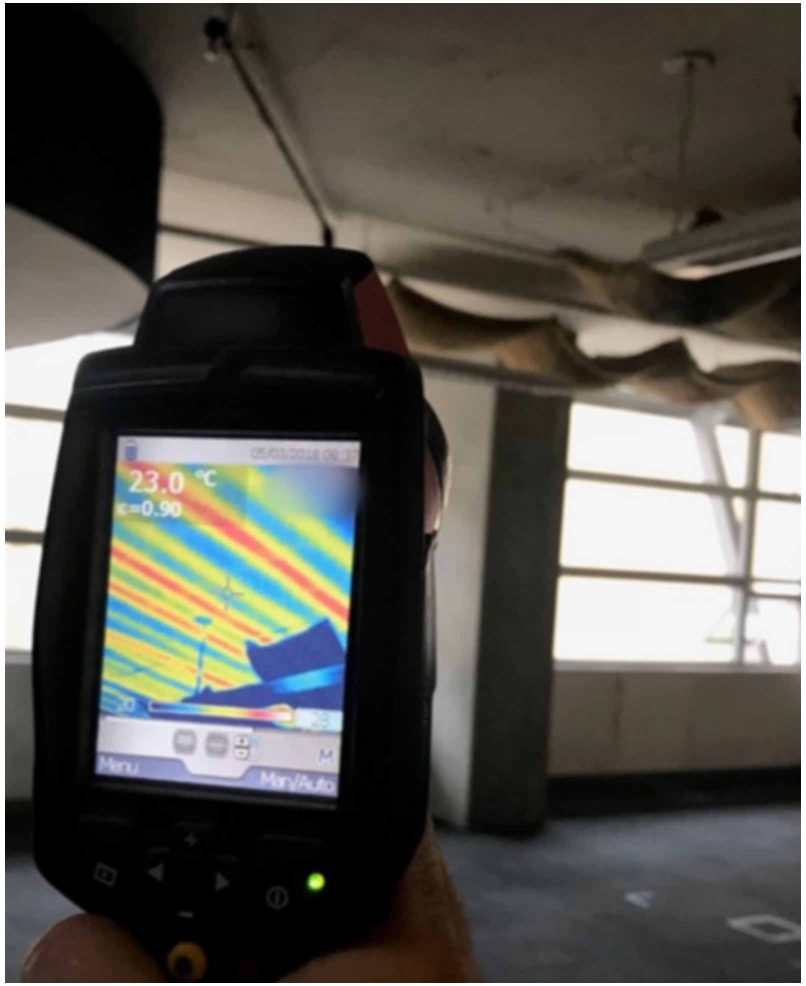
- Investigate the feasibility of replacing vapor-compression based cooling
- Develop and experimentally test control strategies for HTMR
- Develop web-based tools and guidelines for HTMR

Approach

- Modeling/simulation and field studies

Funding

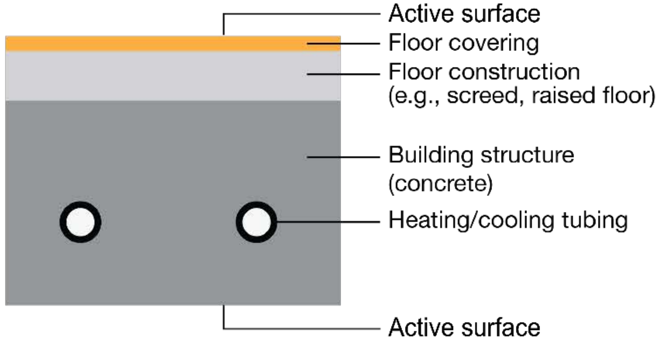
- CEC EPIC program and CBE match funding



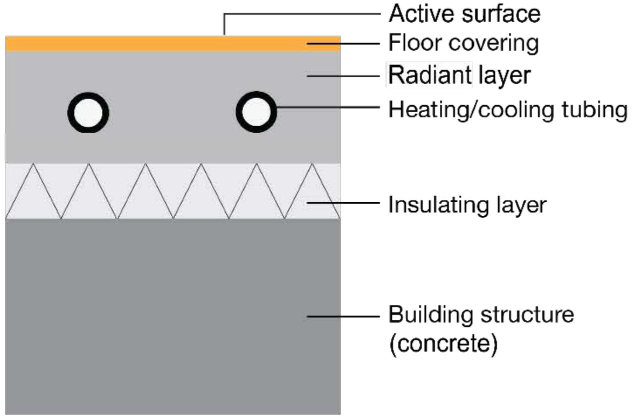
Infrared picture of TABS system.

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

Thermally activated building systems (TABS)

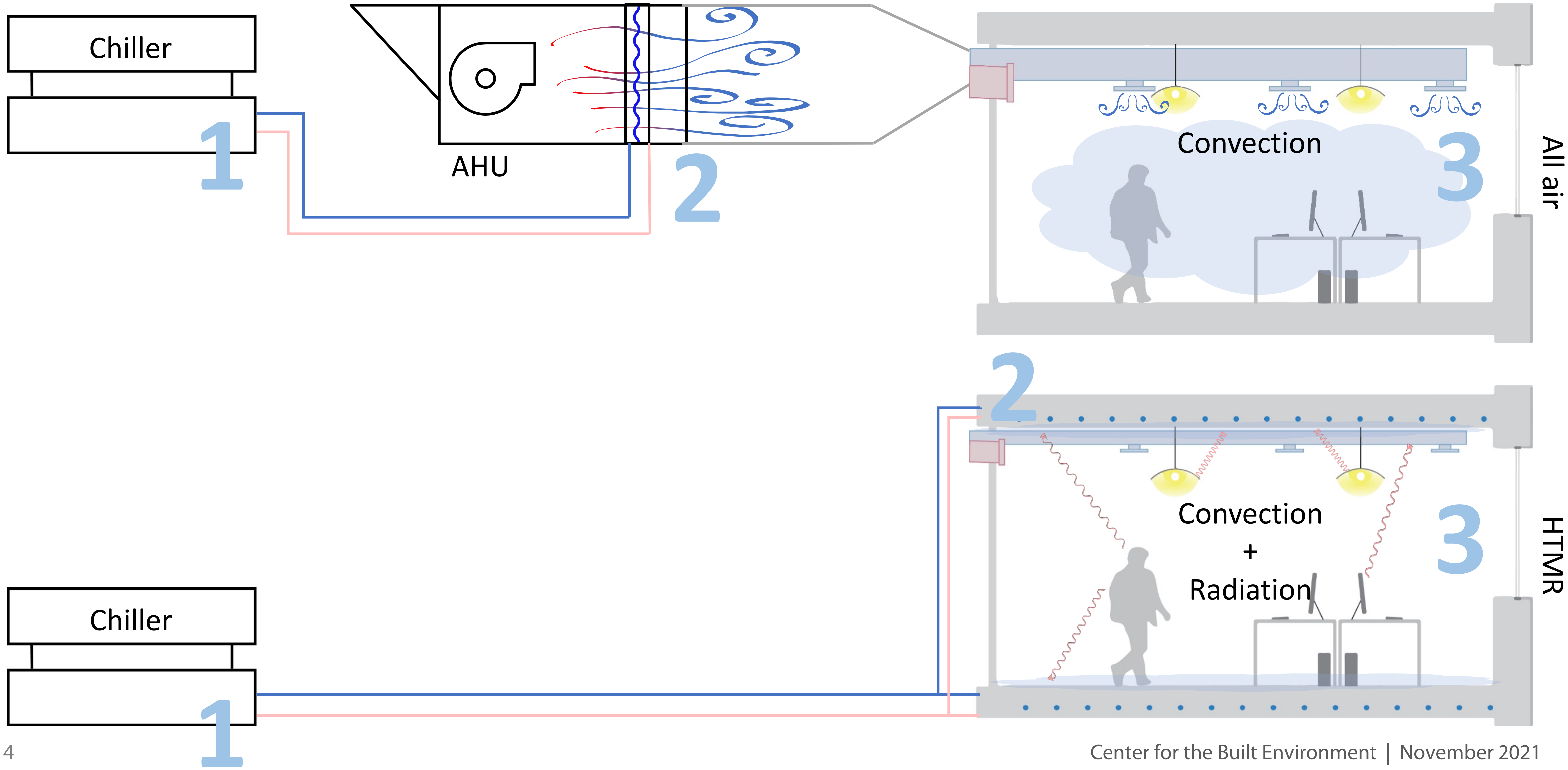


Embedded surface systems (ESS)

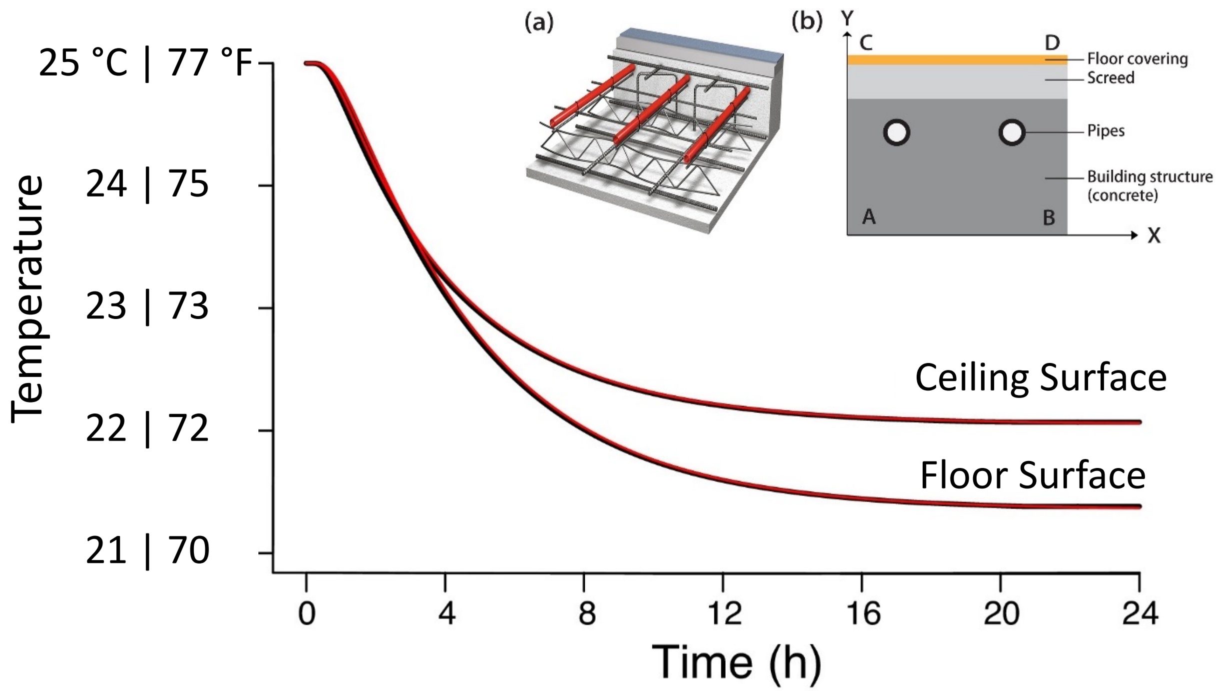


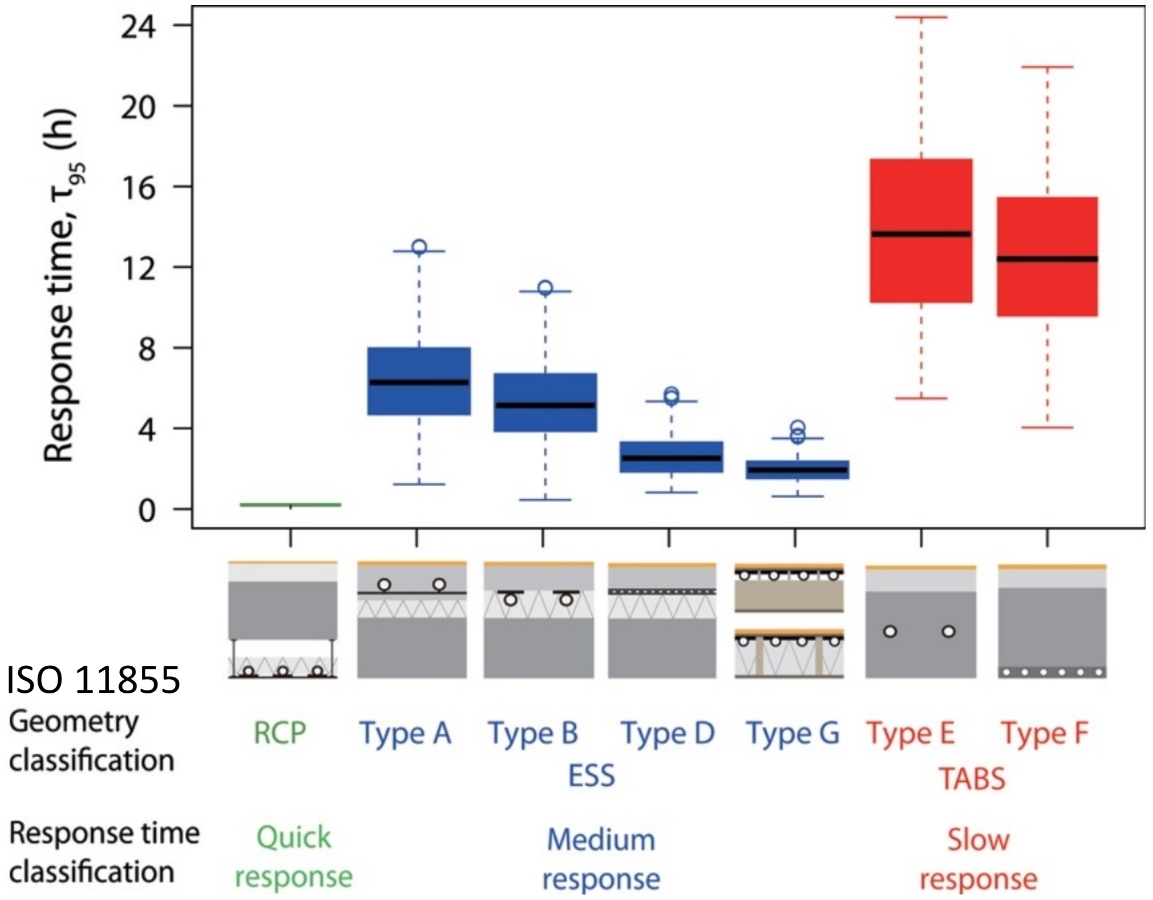
High thermal mass radiant

Differences in energy heat transfer



How fast do radiant systems response after a control change?

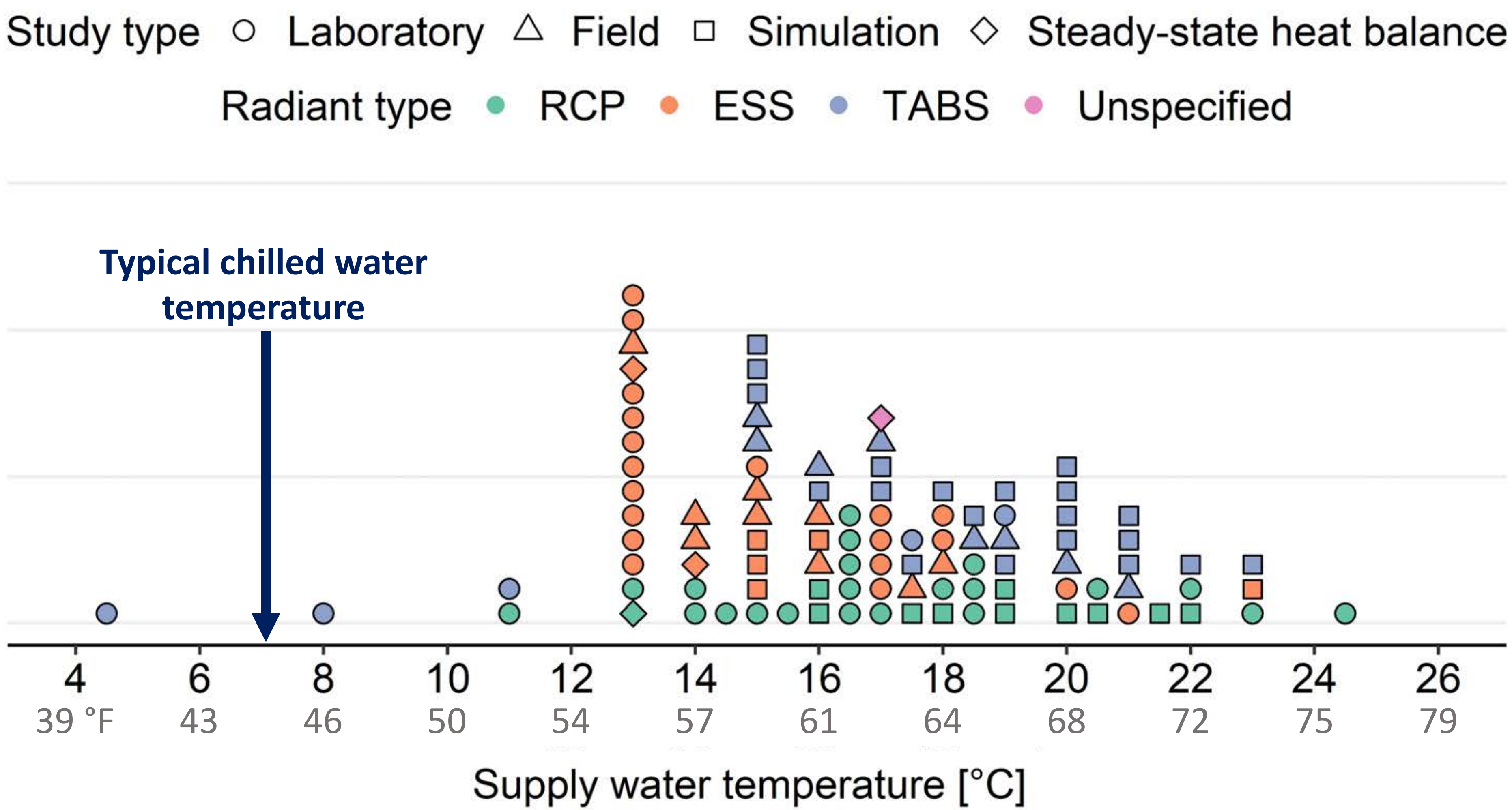




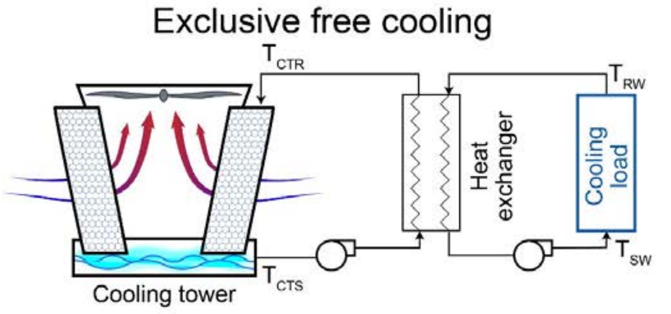
Ning, Baisong, Stefano Schiavon, and Fred S. Bauman. 2017. “A Novel Classification Scheme for Design and Control of Radiant System Based on Thermal Response Time.” *Energy and Buildings* 137 (February): 38–45. https://doi.org/10.1016/j.enbuild.2016.12.013.

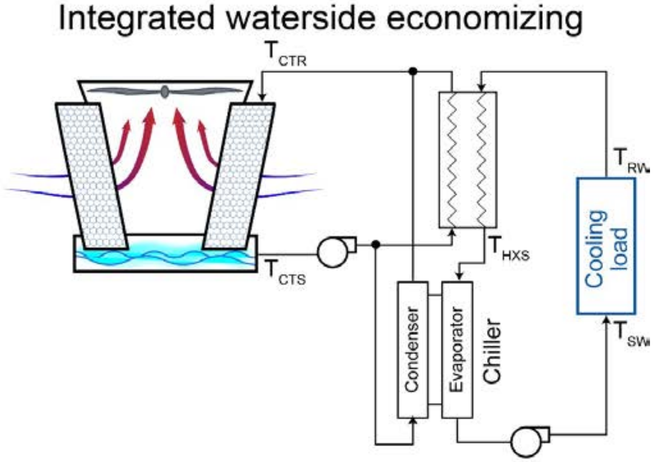
HTMR presents challenges due to its high thermal mass, yet it opens the opportunity for innovative design and control options.

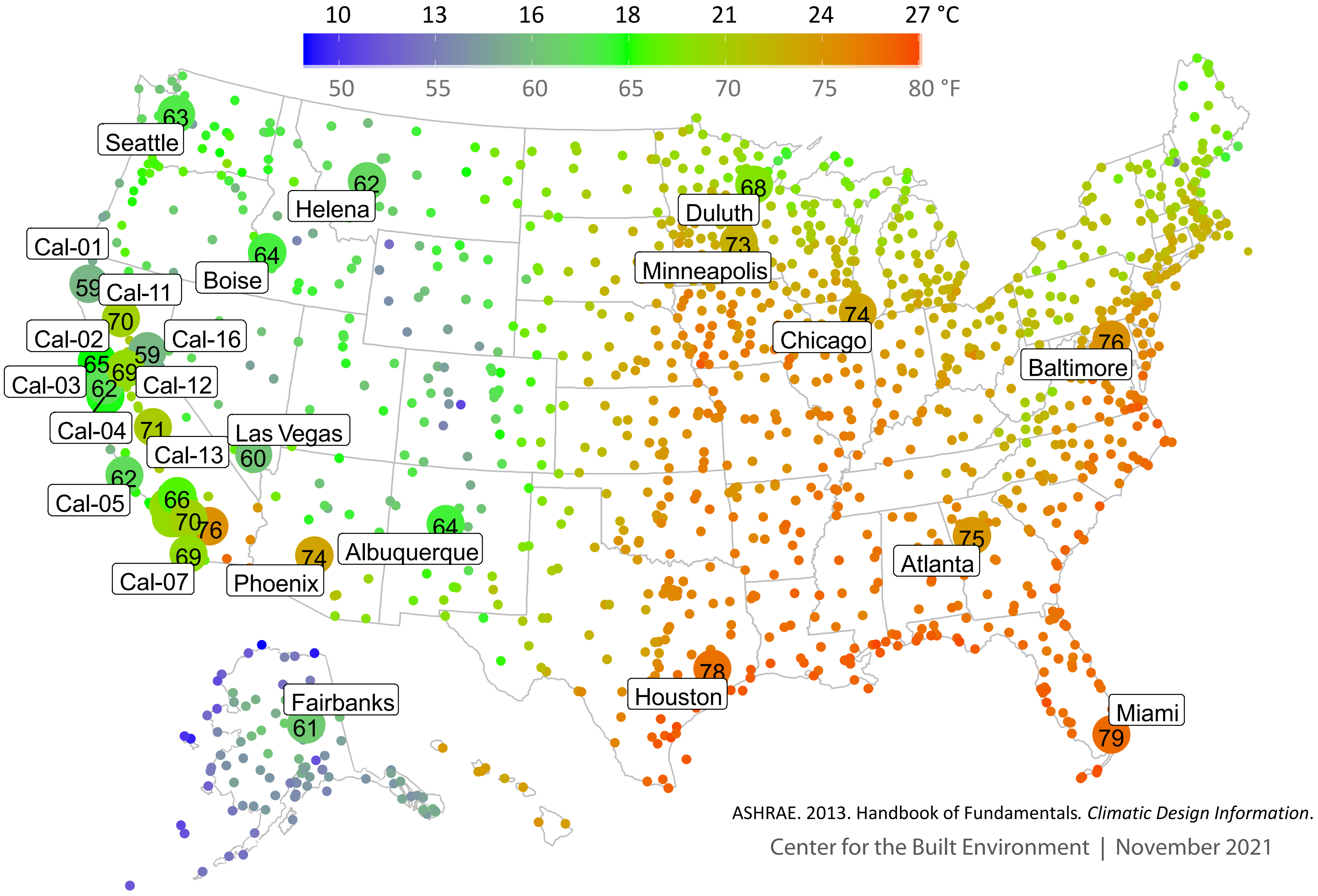
Radiant systems should use warmer water temperatures for cooling



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

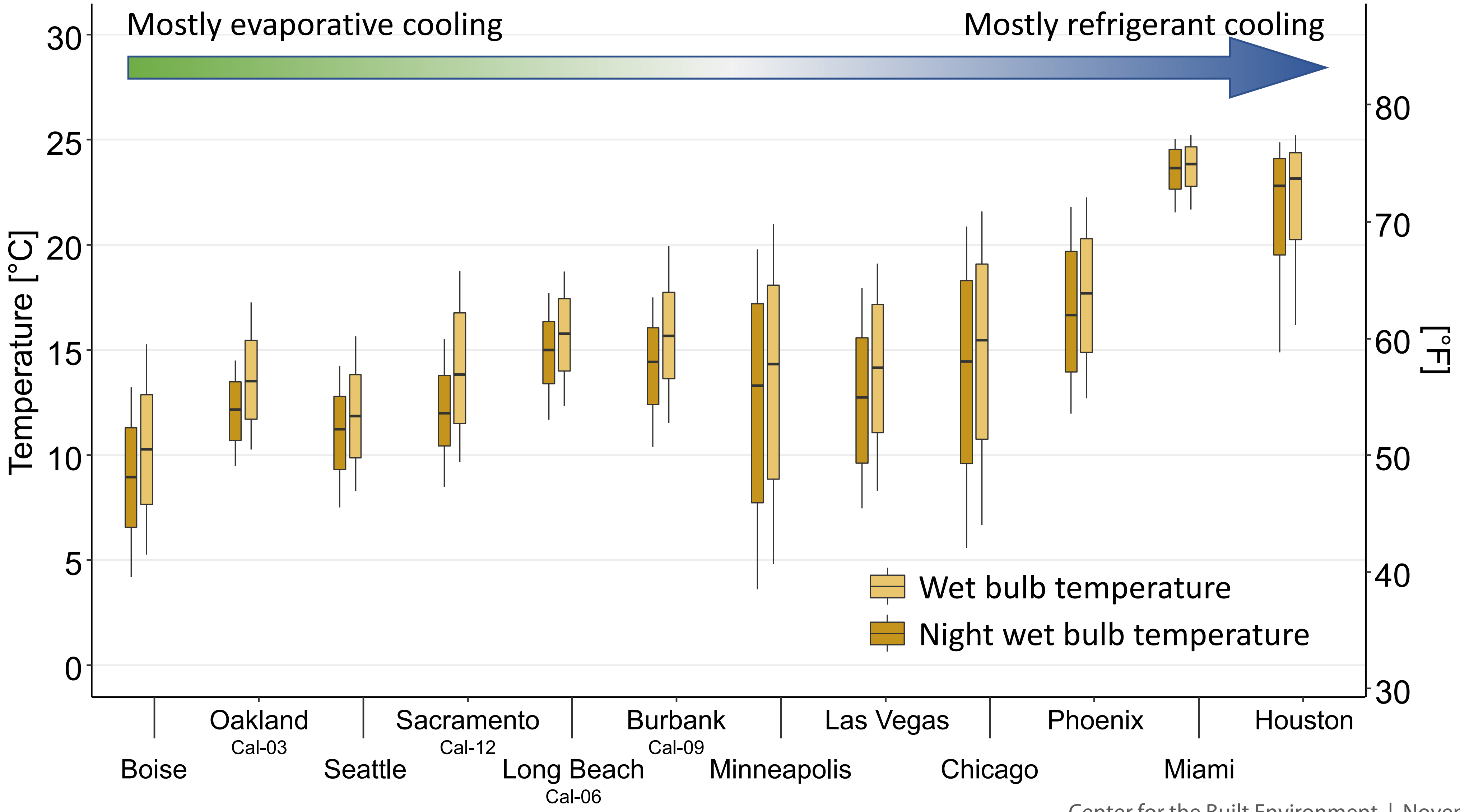




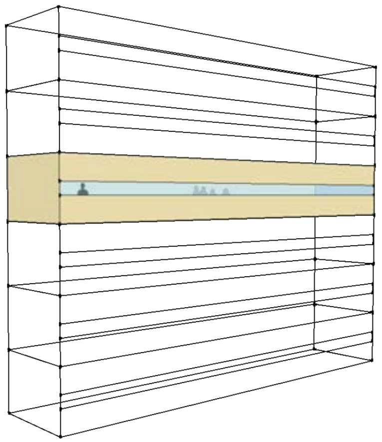


ASHRAE. 2013. Handbook of Fundamentals. *Climatic Design Information*.

Evaporative cooling feasibility increases with lower wet bulb temperatures

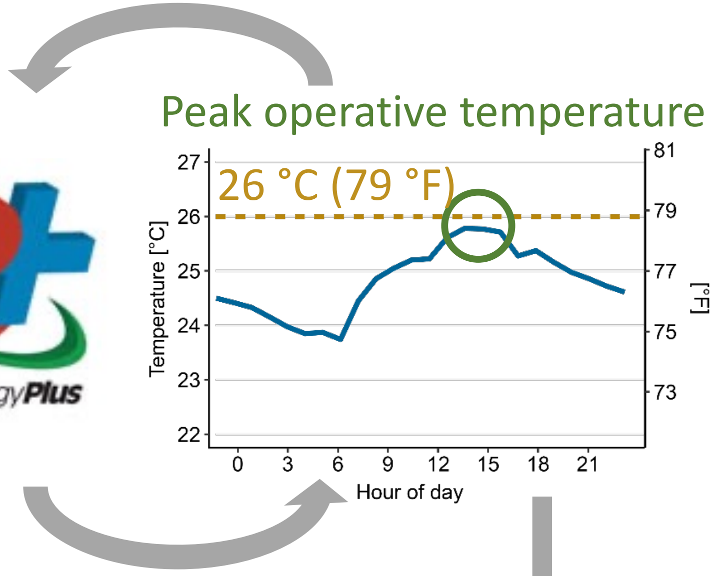


Simulation procedure to find the warmest supply water temperature



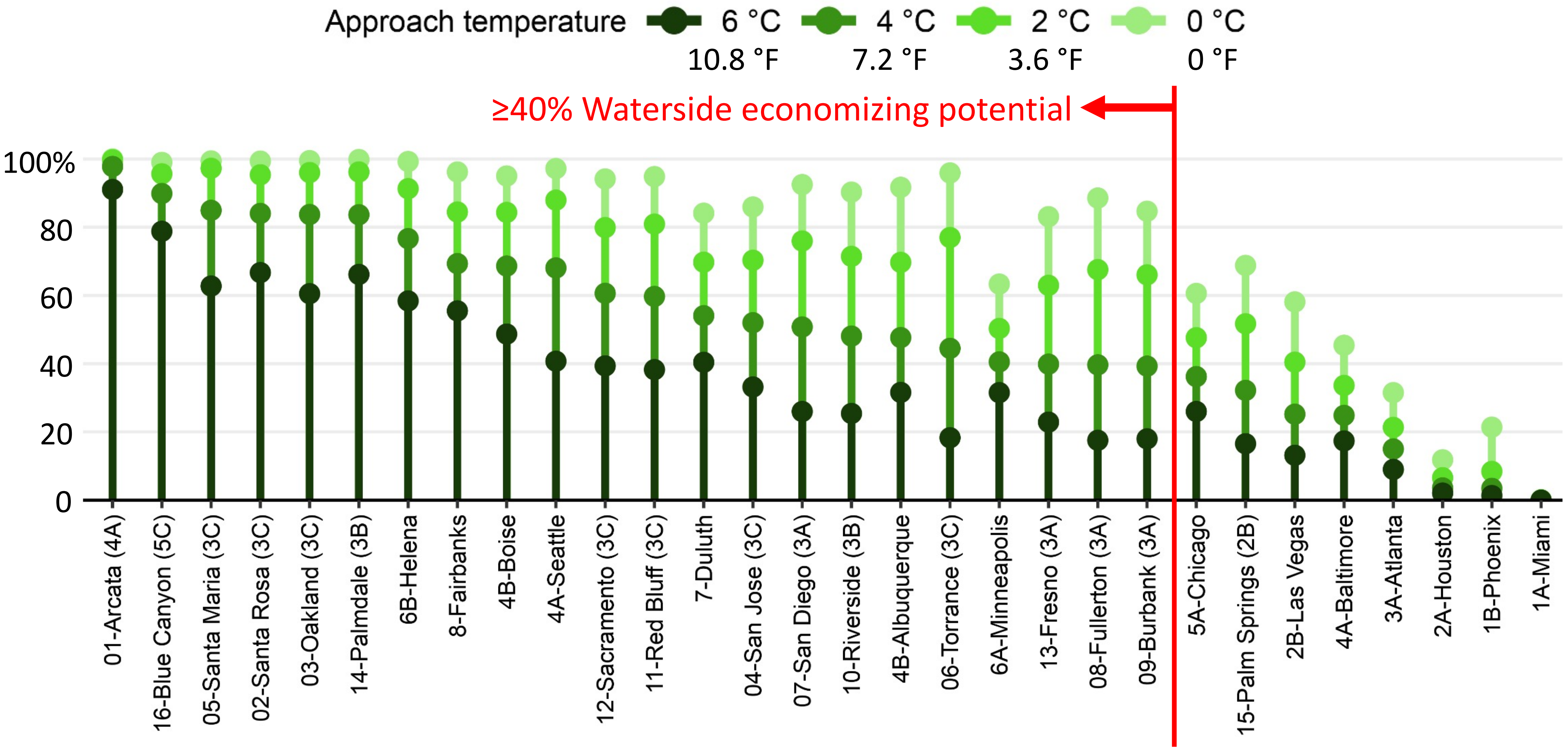
Middle floor of commercial office building

- 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



Collect final supply water temperature

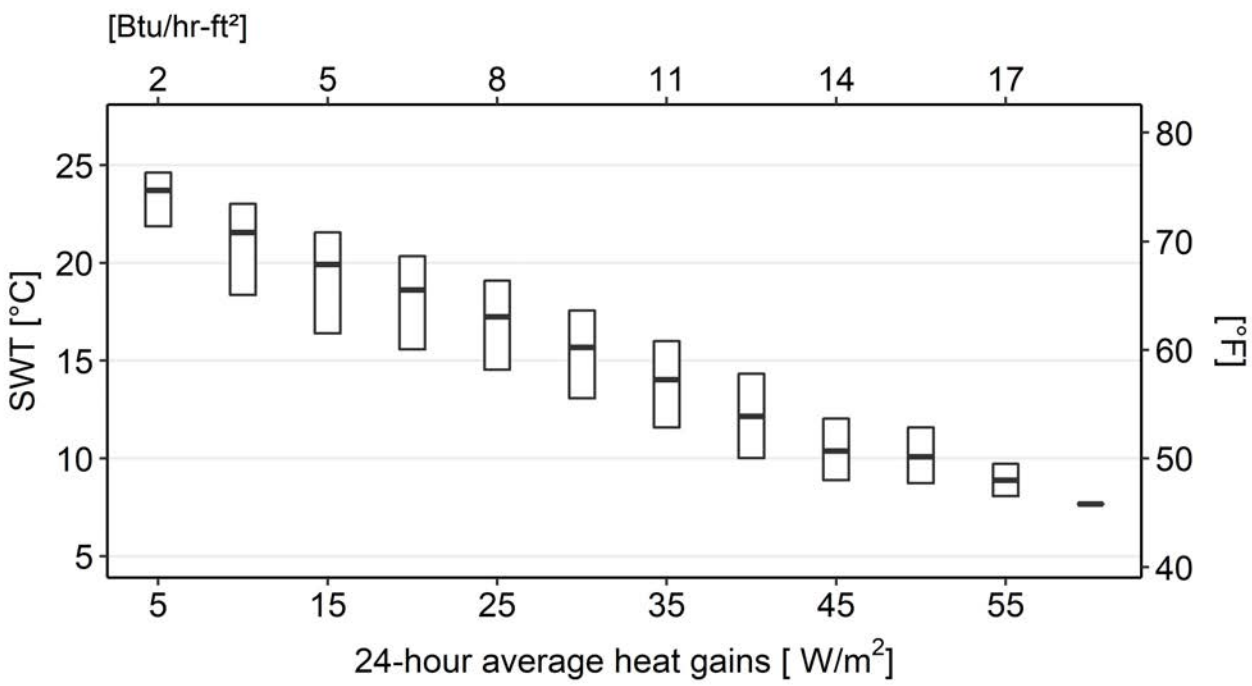
Median percentage of waterside economizing operation



Climate zone number-representative climate zone city (ASHRAE climate zone)

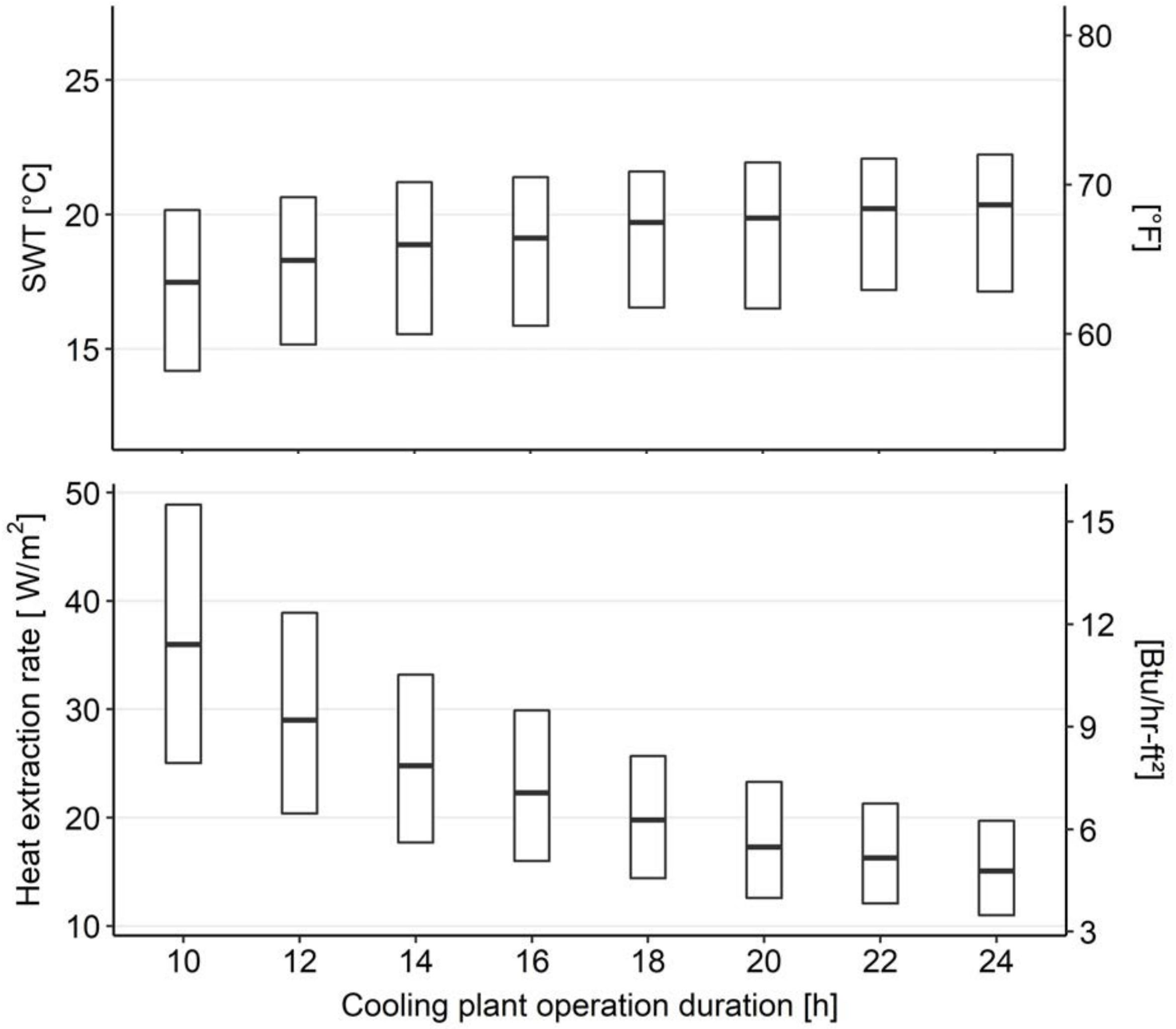
Managing zone heat gains improves high-temperature cooling

- 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/m^2 (8 Btu/hr-ft^2) enables supply water temperatures greater than 15°C (59°F)



Increasing plant operation duration facilitates high-temperature cooling

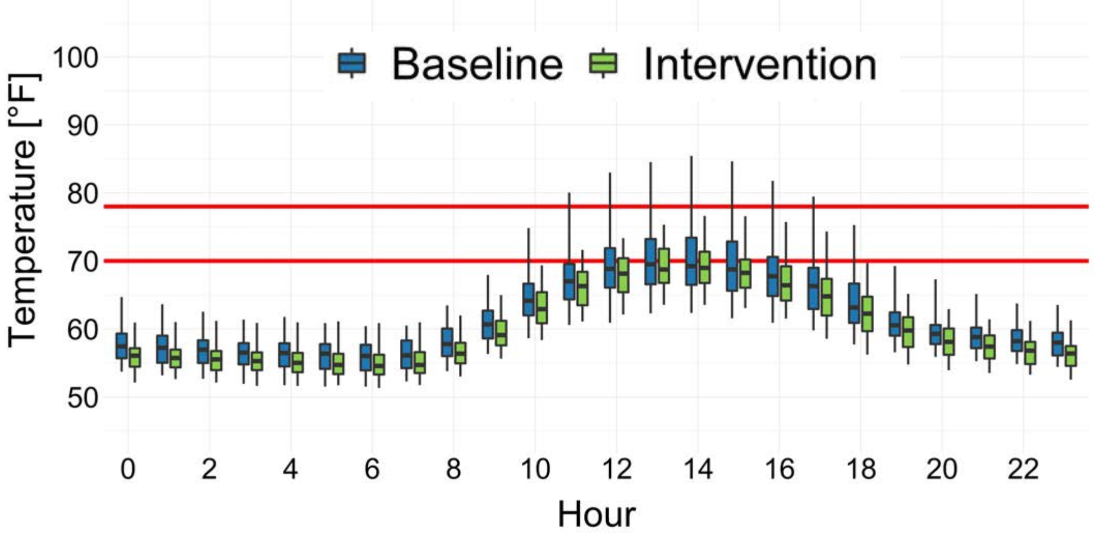
- Increasing operation duration from 10 to 18 hours:
  - Increases required SWT by **~3°C (5°F)**
  - Reduces cooling plant size by **43%**
- Still avoid unfavorable operation hours
  - High electricity prices
  - High greenhouse gas emission rates
  - Peak outdoor conditions
- Benefits include:
  - 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 ft^2 (3.9K m^2) 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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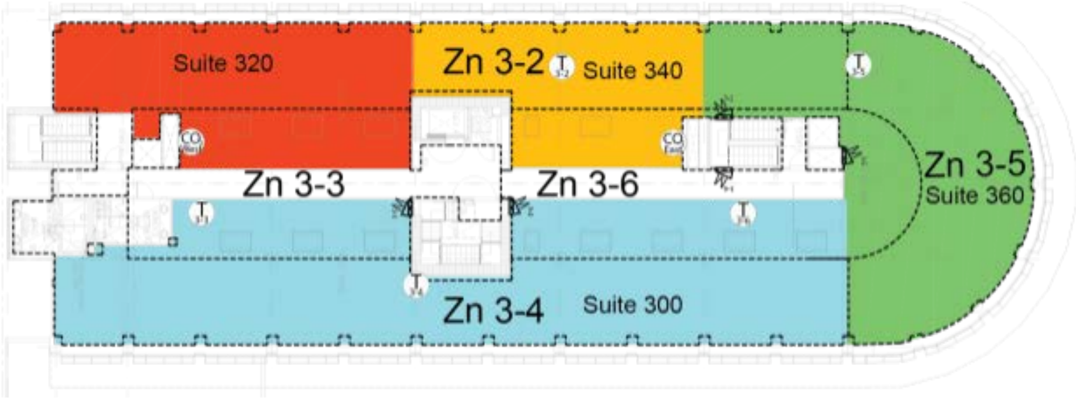
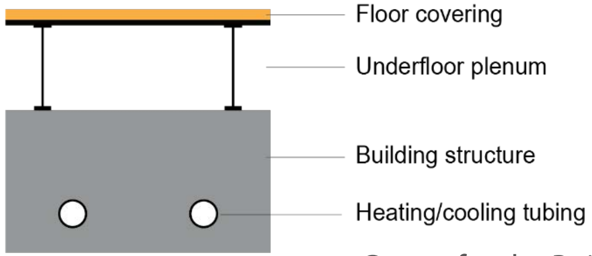
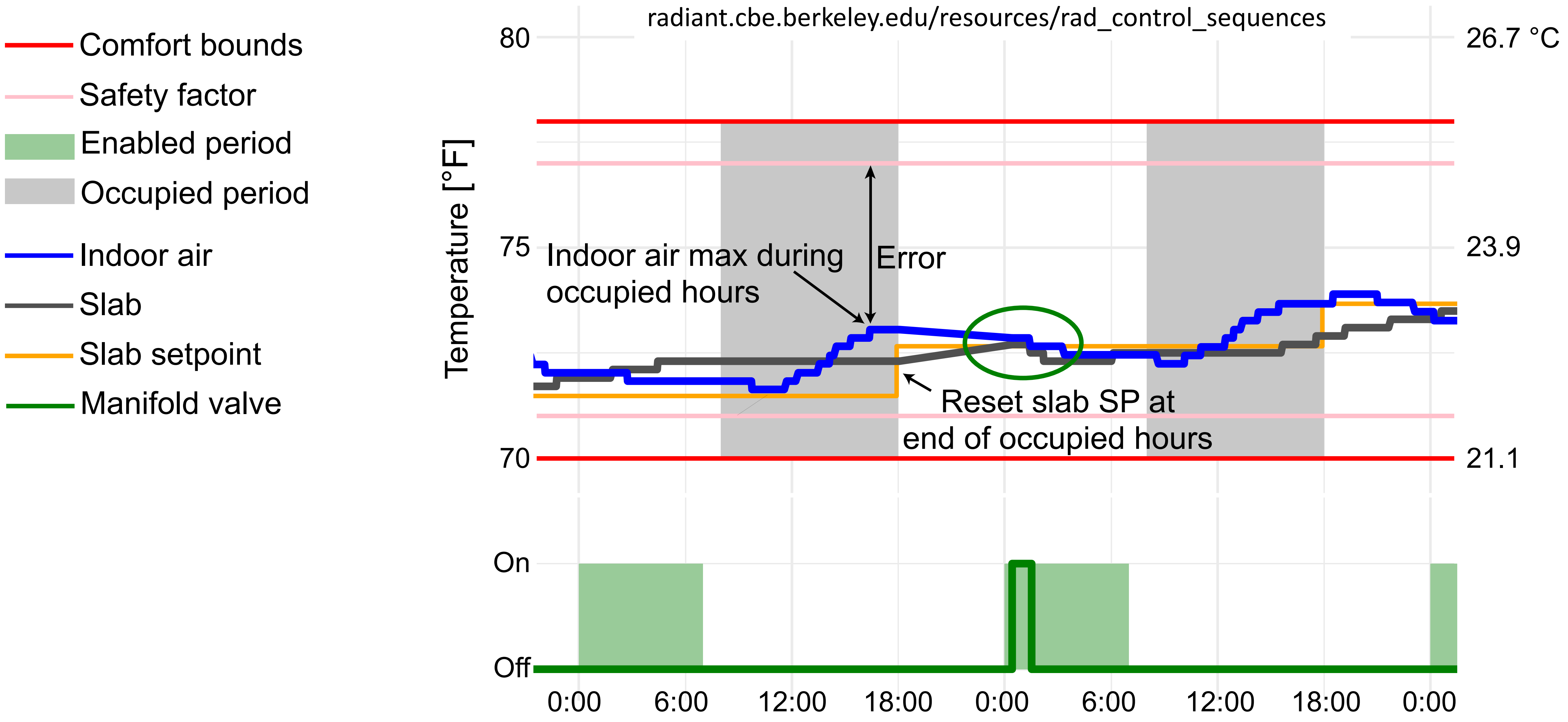


- Cooling tower only
  - Two position valves
- UFAD ventilation
- 2-pipe system for whole building
- Whole building tested



CBE control sequences for high thermal mass radiant system

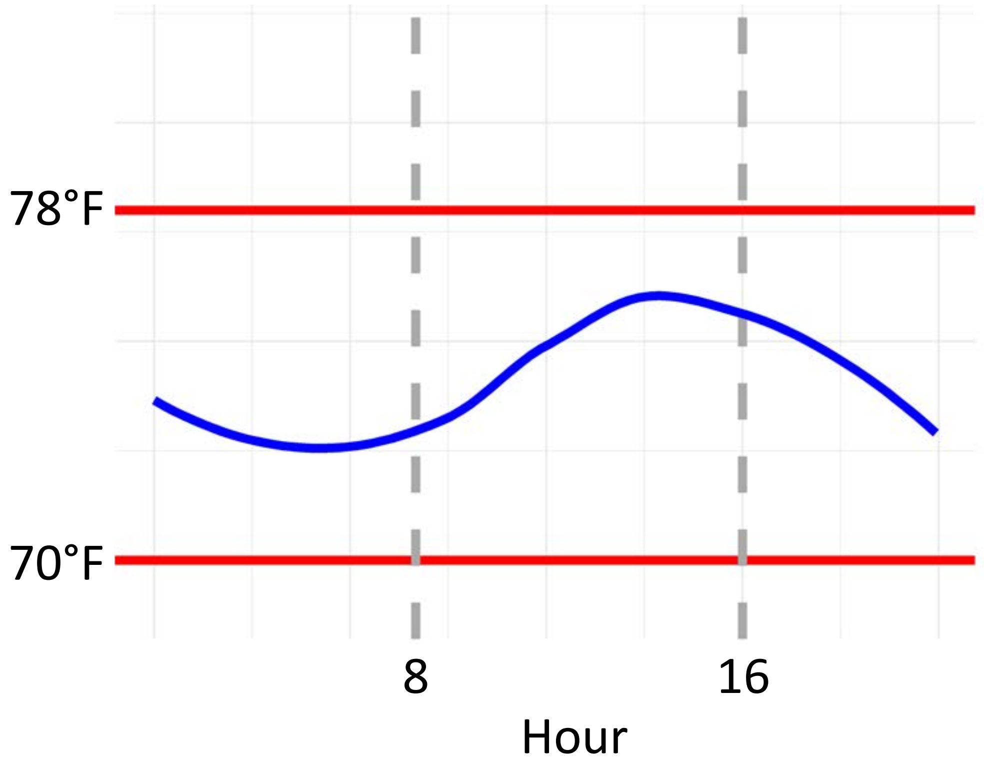


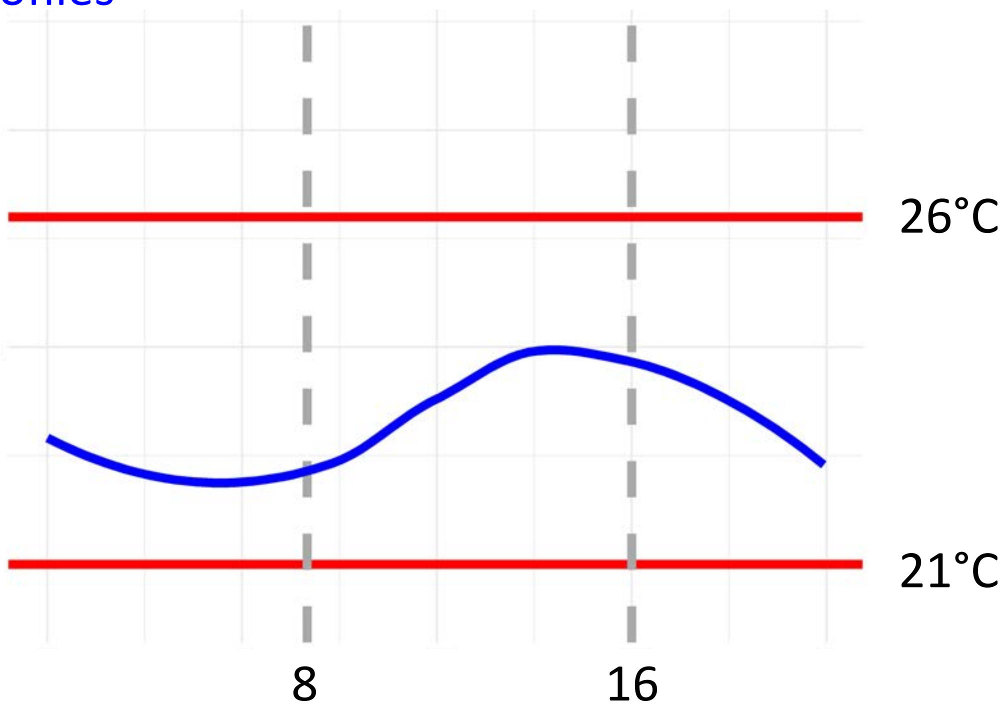
B-1 radiant system thermal comfort performance in **one** zone

Baseline

Intervention

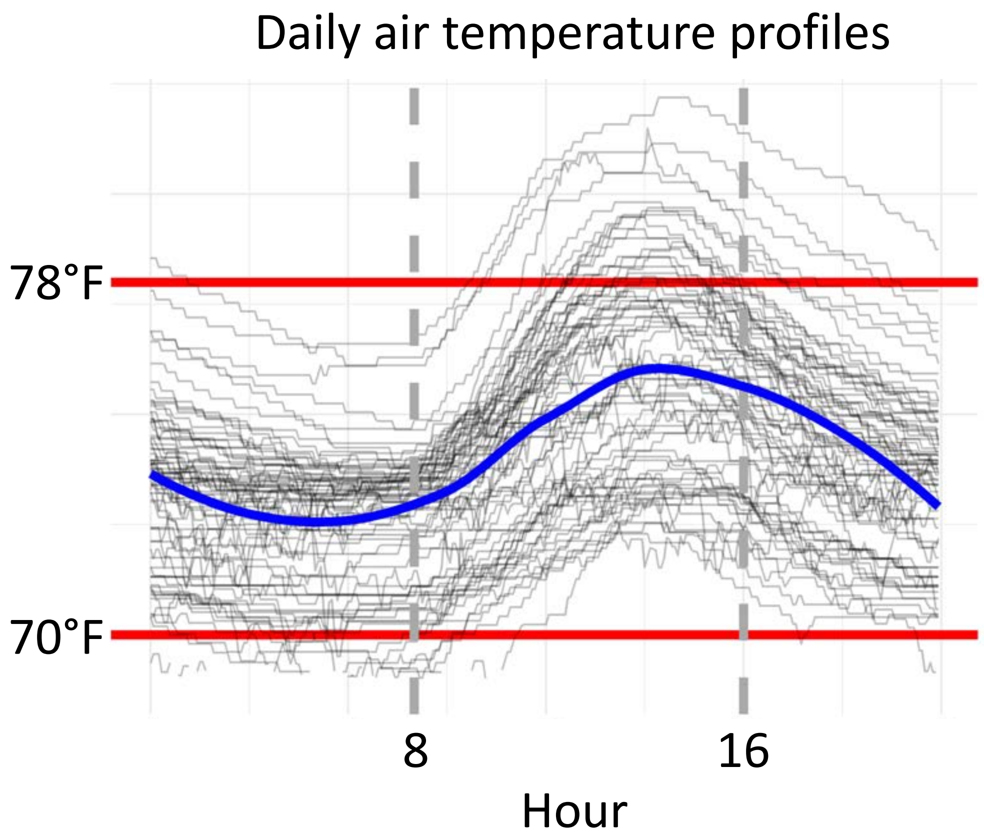
Mean air temperature profiles



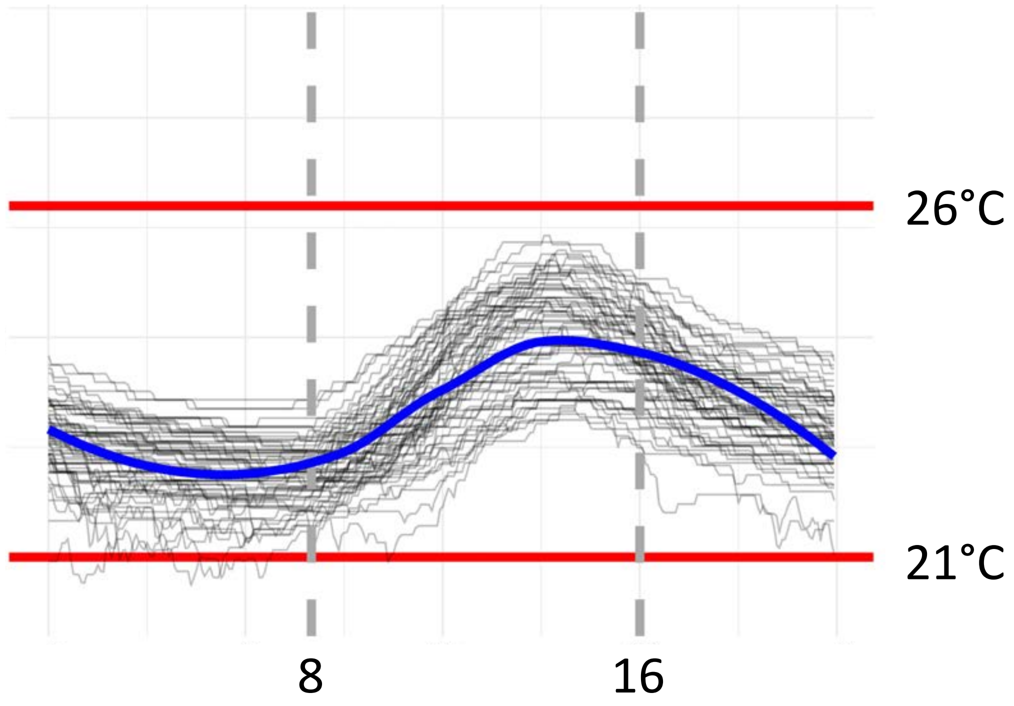


B-1 radiant system thermal comfort performance in **one** zone

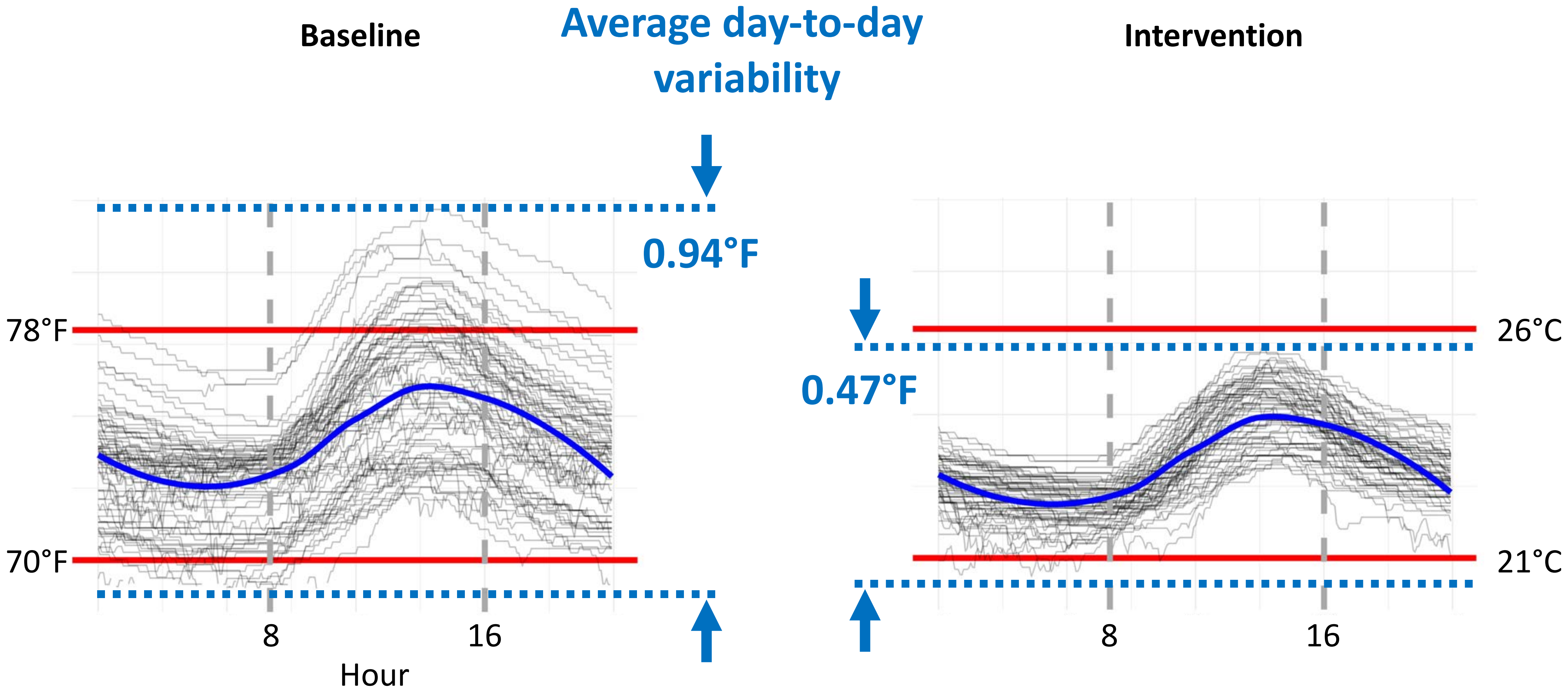
Baseline



Intervention

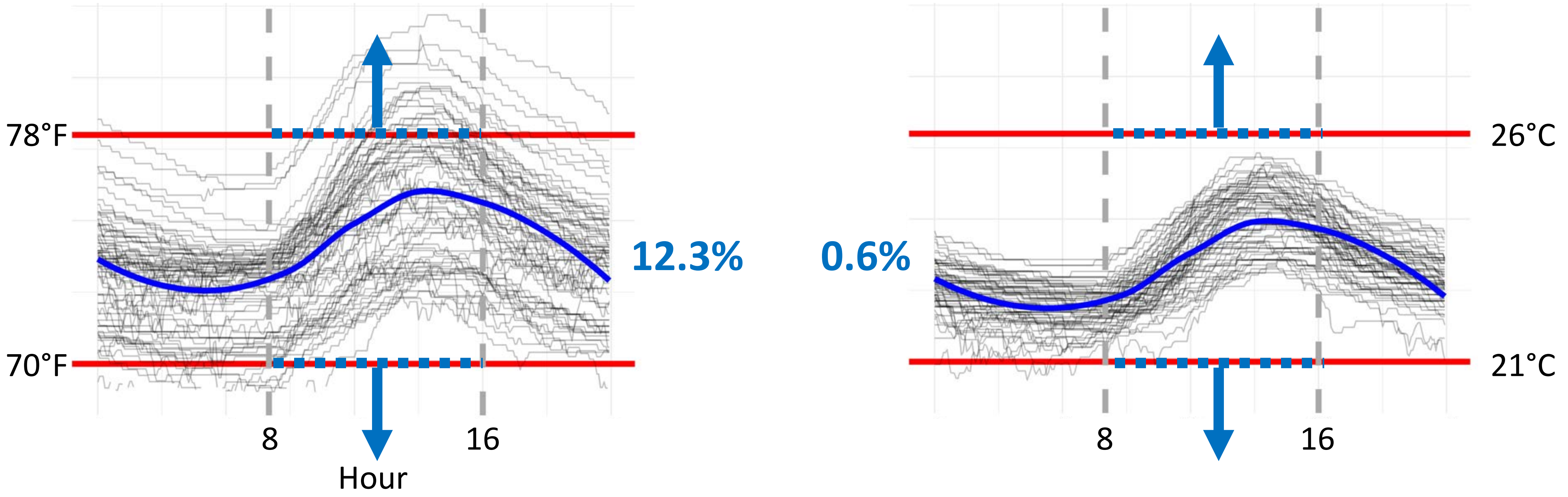


B-1 radiant system thermal comfort performance in **one** zone

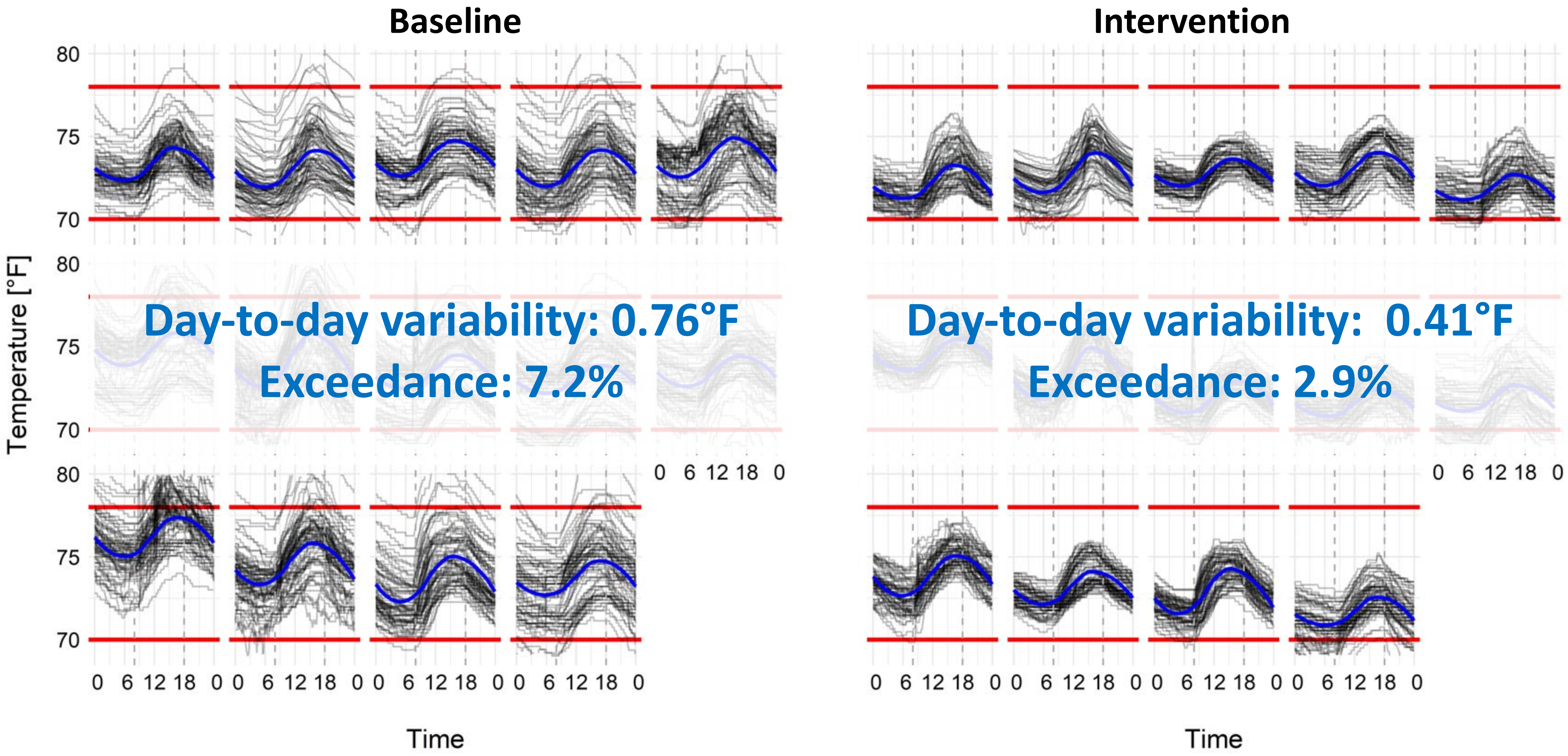


B-1 radiant system thermal comfort performance in **one** zone

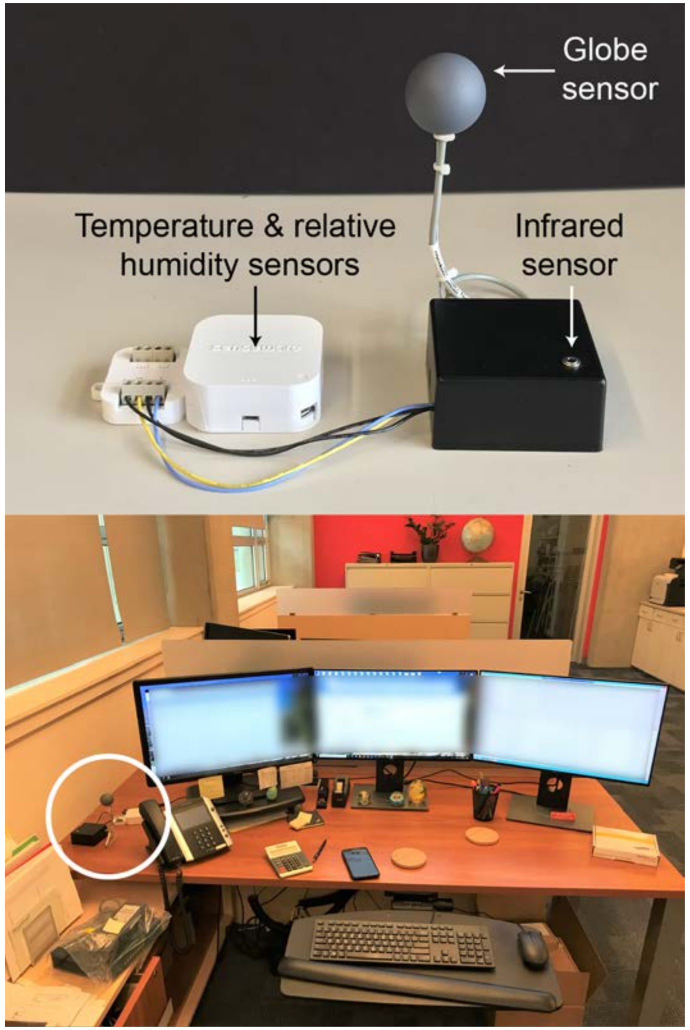
Baseline **Exceedance percentage of total occupied hours** **Intervention**



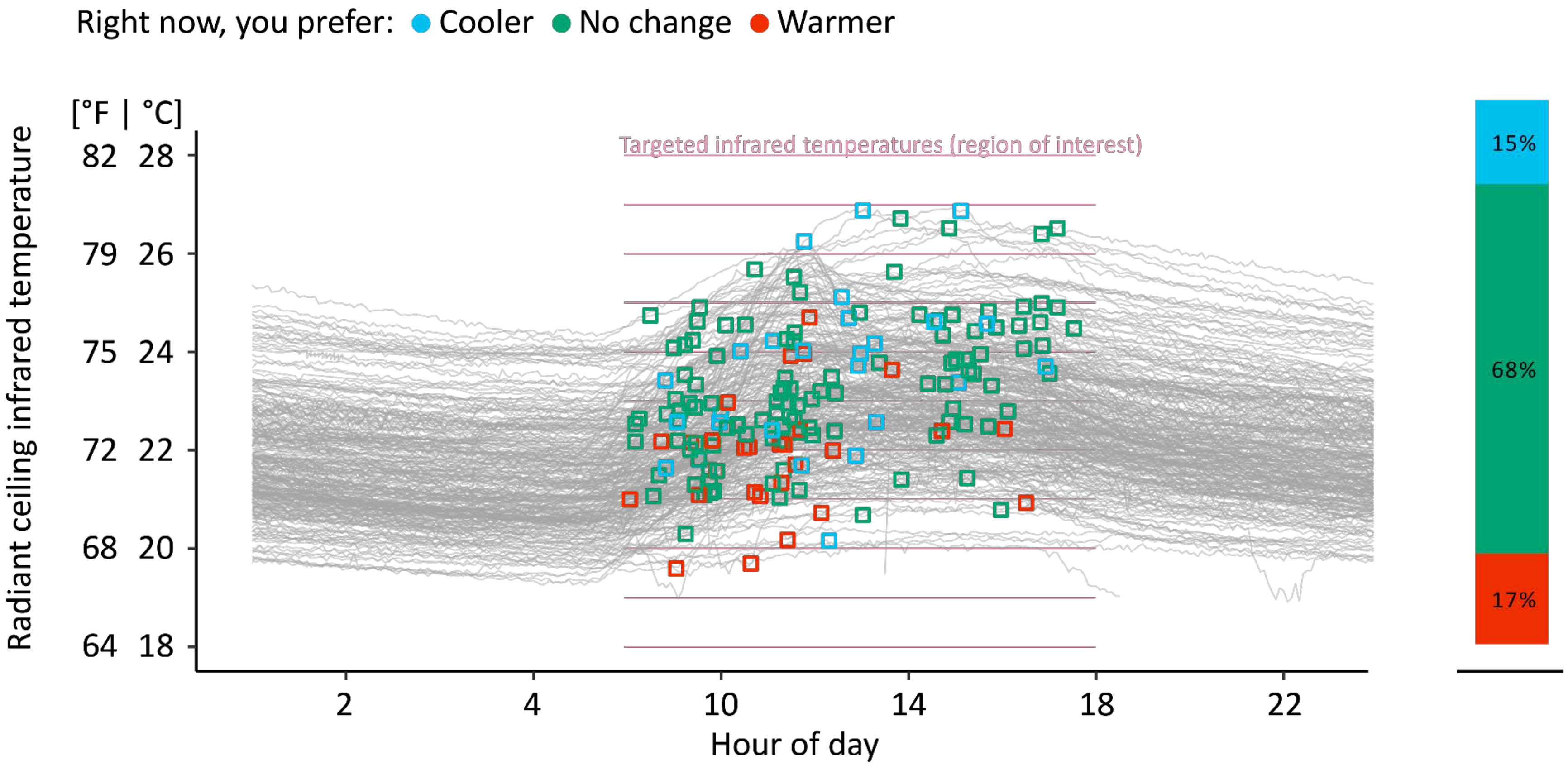
B-1 radiant system thermal comfort performance in **all** zones



Testing the TOS platform in a pilot study



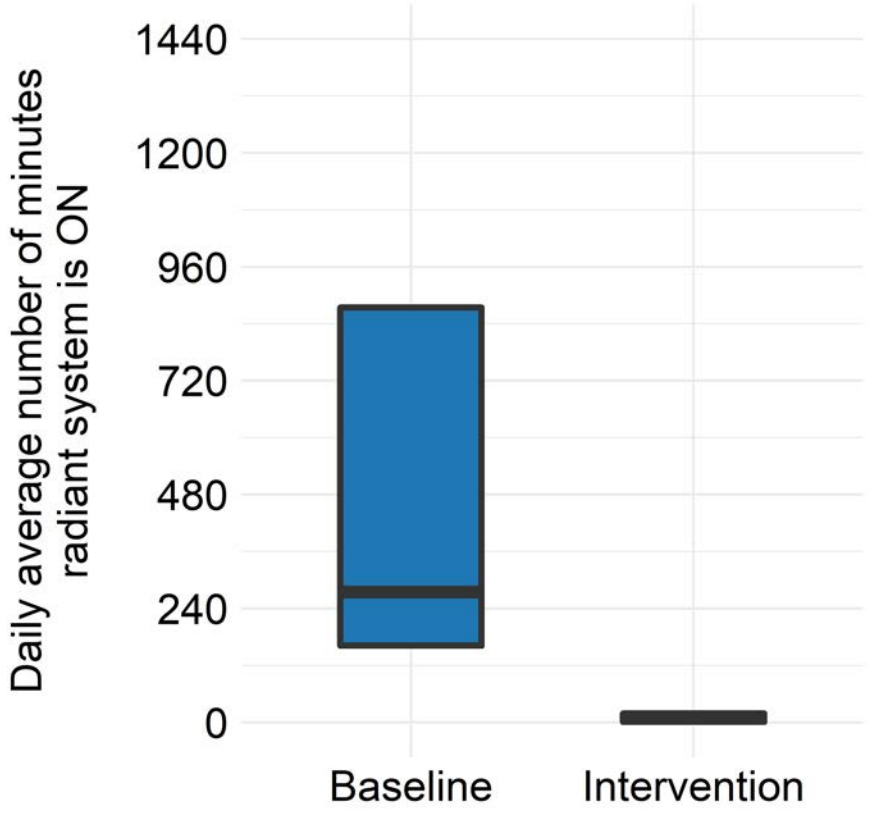
Recruited 11 occupants and placed small sensor on their desk.



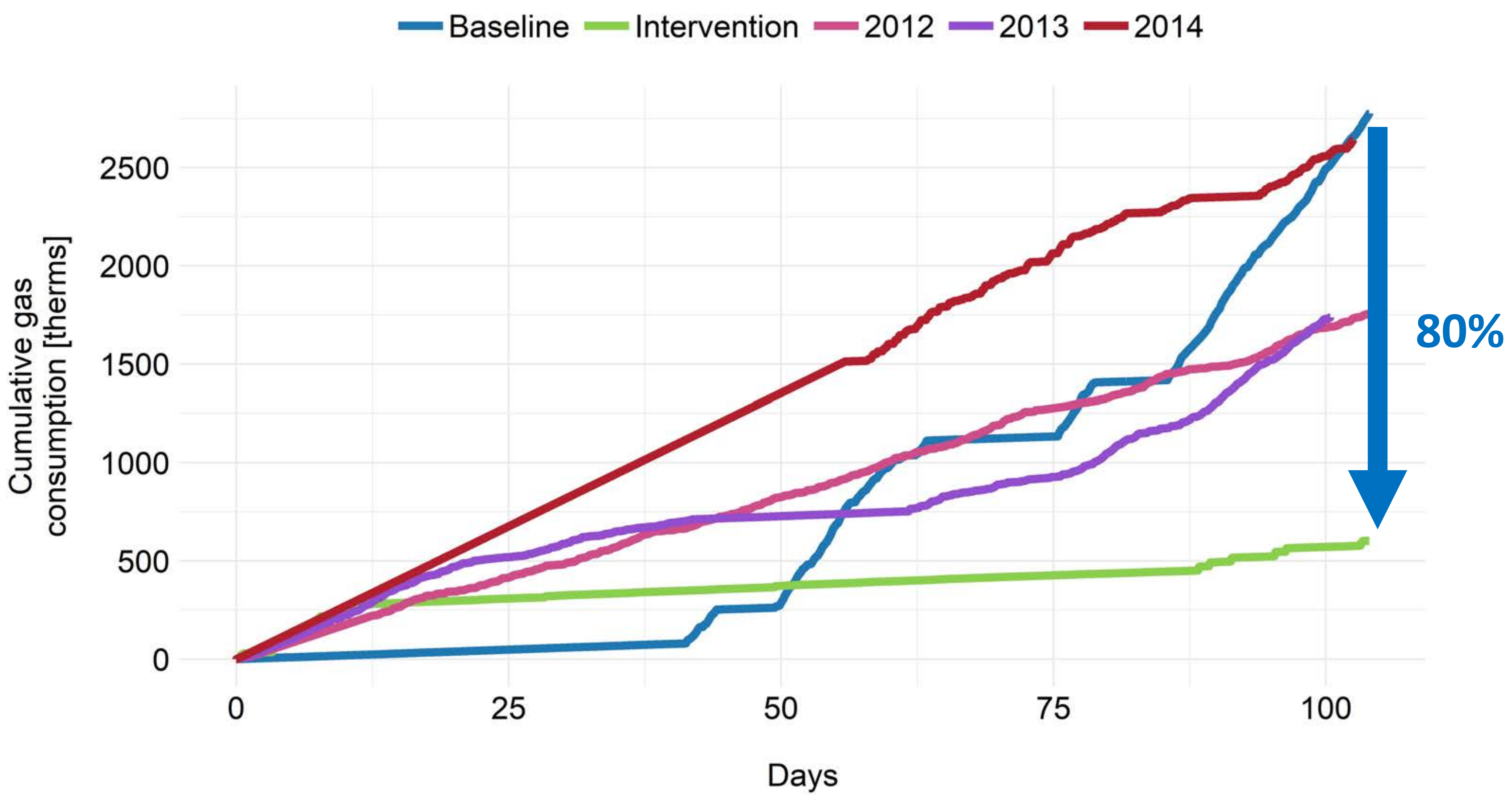
B-1 radiant system zone performance

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

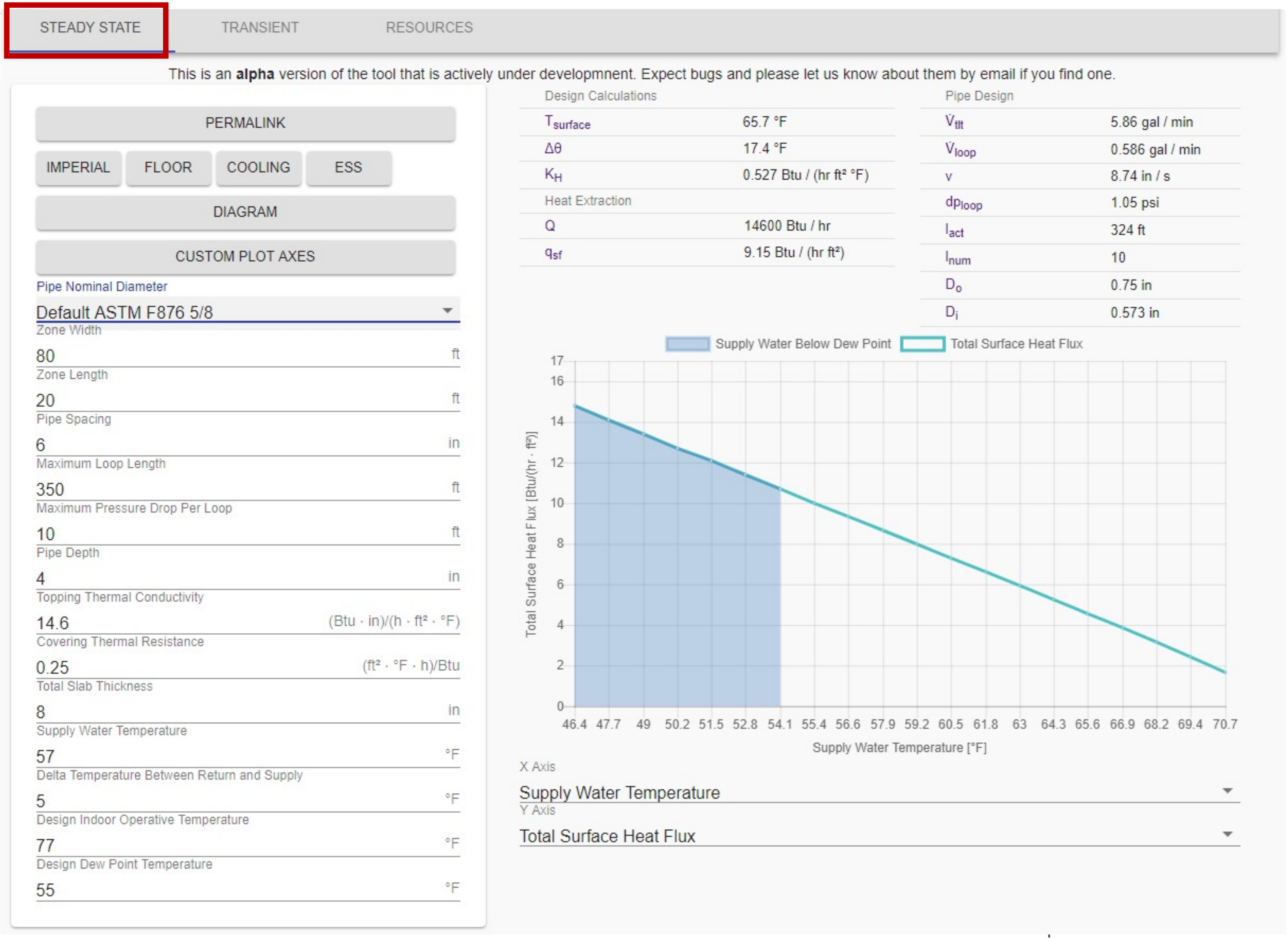


CBE Rad Tool

Layout of the webtool: Steady-state (radiant.cbe.berkeley.edu)

Calculation type

- Steady-state
- ISO 11855 standard



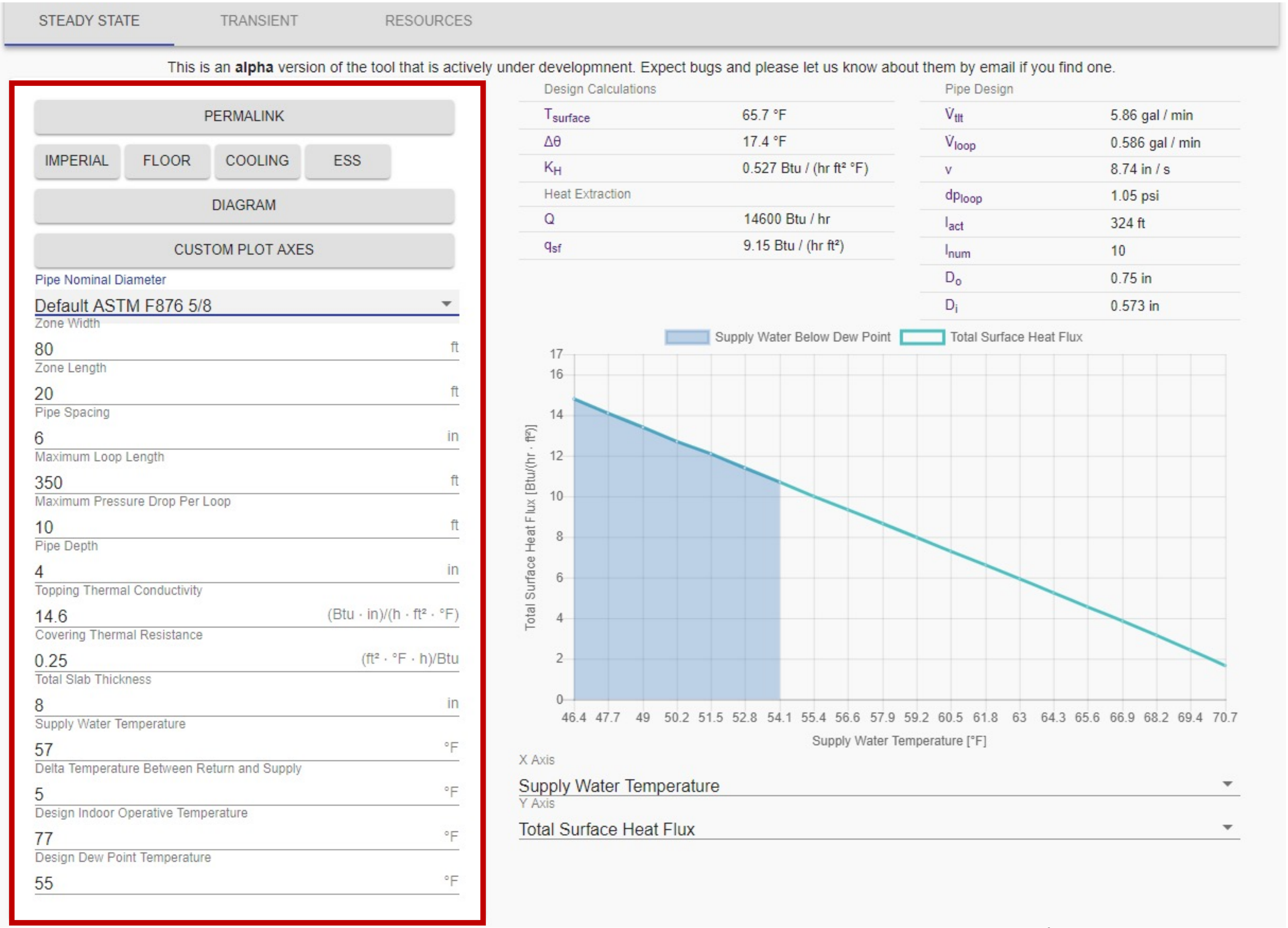
Layout of the webtool: Steady-state (radiant.cbe.berkeley.edu)

Calculation type

- Steady-state
- ISO 11855 standard

Inputs

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



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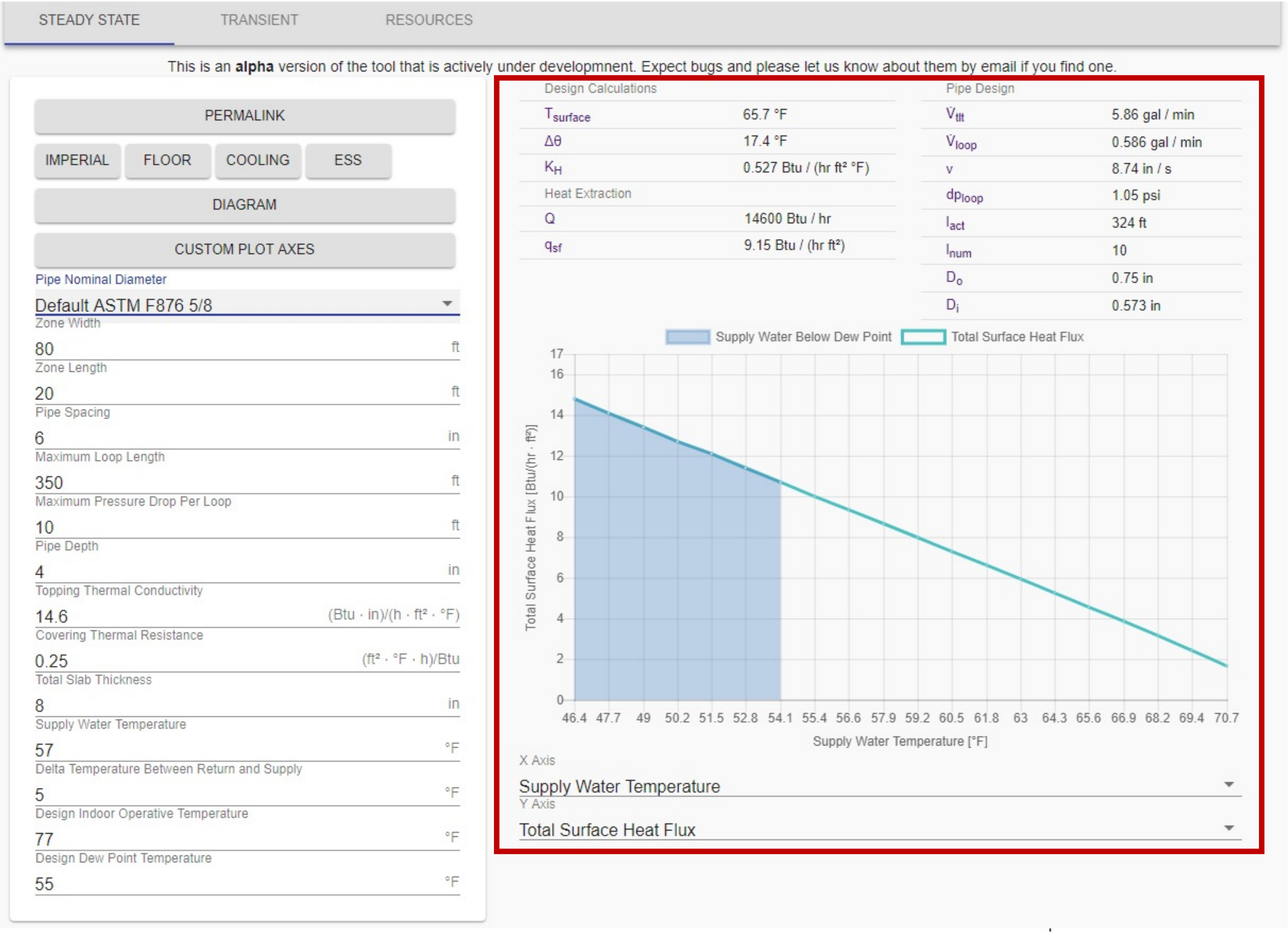
Outputs

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



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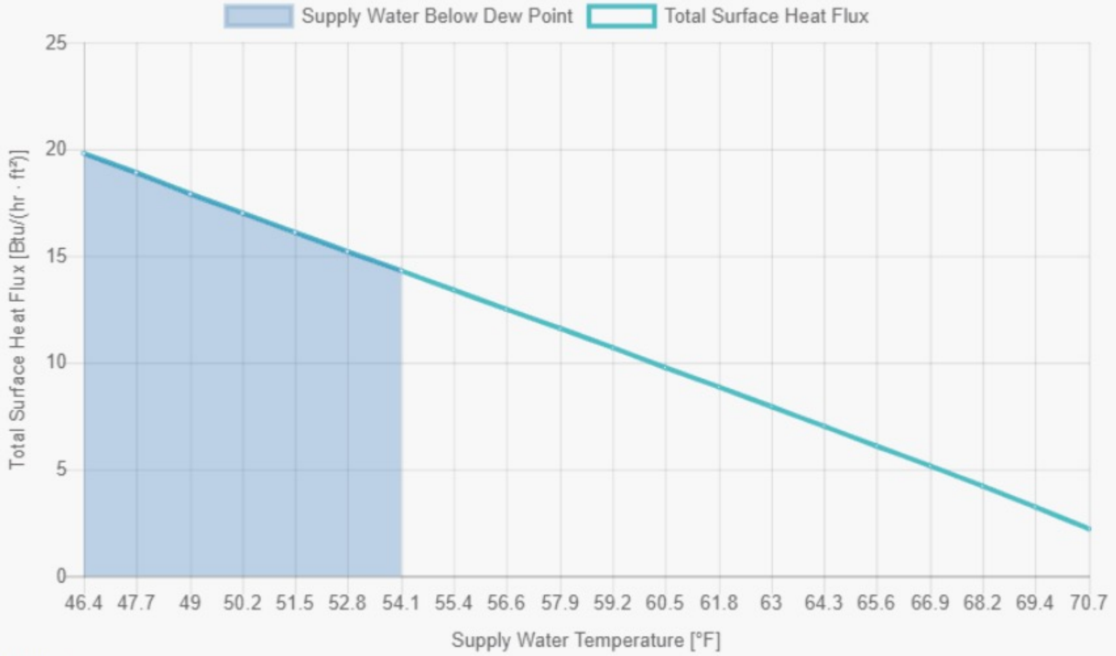
Design Calculations	
$T_{surface}$	63.9 °F
$\Delta\theta$	17.4 °F
K_H	0.704 Btu / (hr ft² °F)
Heat Extraction	
Q	24500 Btu / hr
q_{sf}	12.2 Btu / (hr ft²)

Pipe Design	
$\dot{V}_{tlt}$	9.8 gal / min
$\dot{V}_{loop}$	0.816 gal / min
v	12.2 in / s
dp_{loop}	1.9 psi
l_{act}	337 ft
l_{num}	12
D_o	0.75 in
D_i	0.573 in



X Axis

Supply Water Temperature

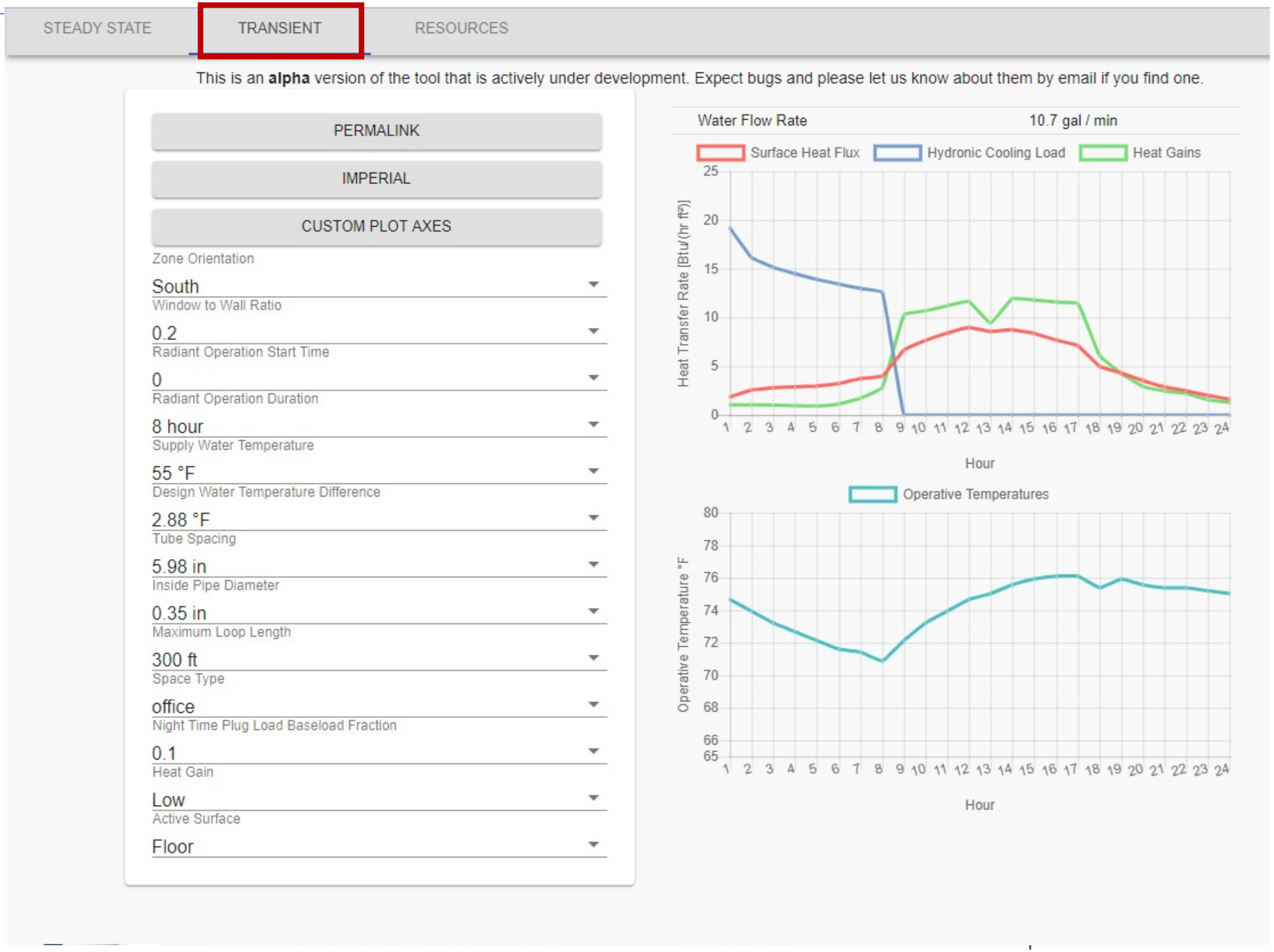
Y Axis

Total Surface Heat Flux

Layout of the webtool: Transient (radiant.cbe.berkeley.edu)

Calculation type

- Transient
- Over 2.5 million EnergyPlus simulations



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Calculation type

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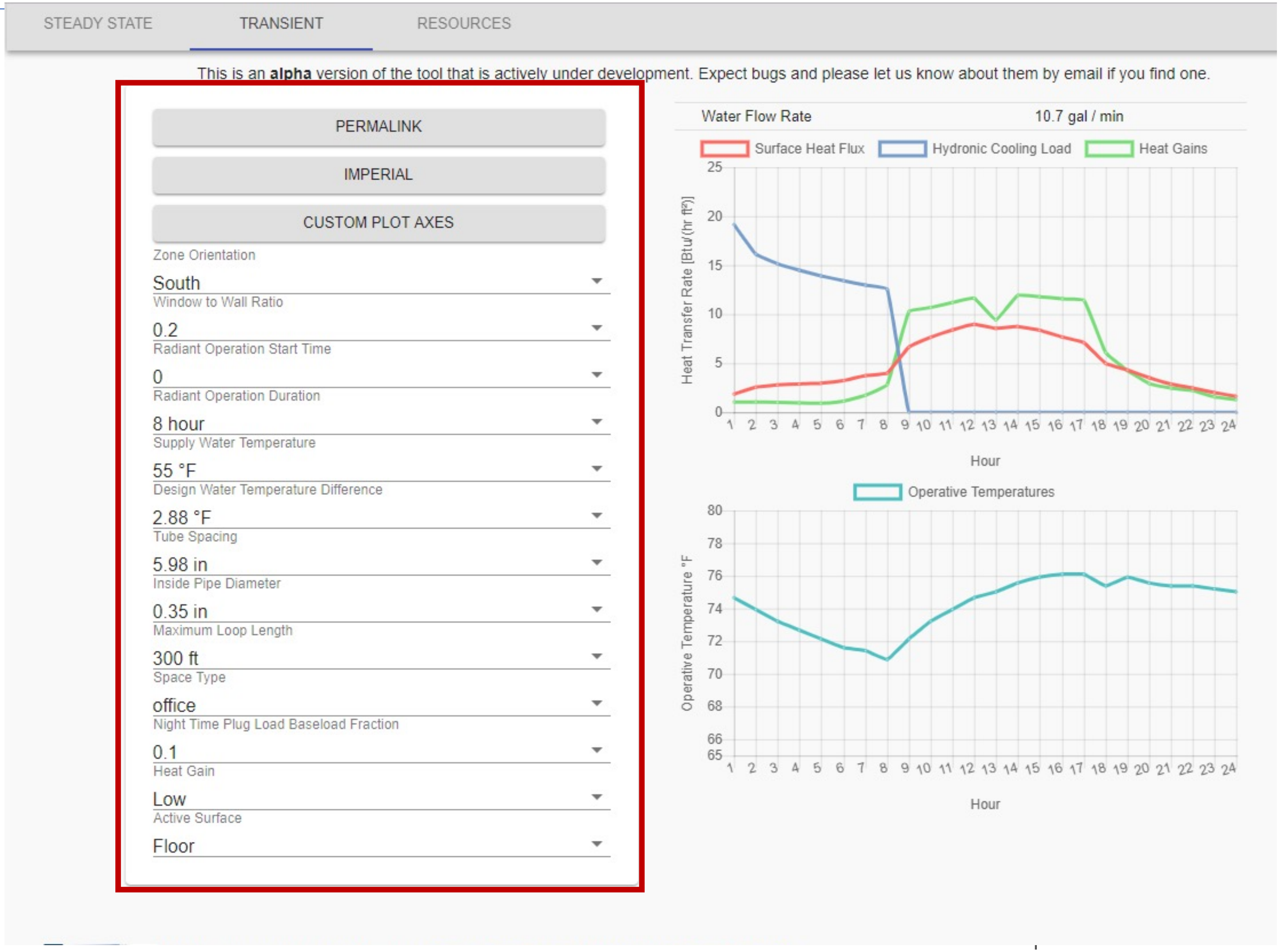
- Over 2.5 million EnergyPlus simulations

Inputs

- Design parameters
- Time



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Calculation type

- Transient
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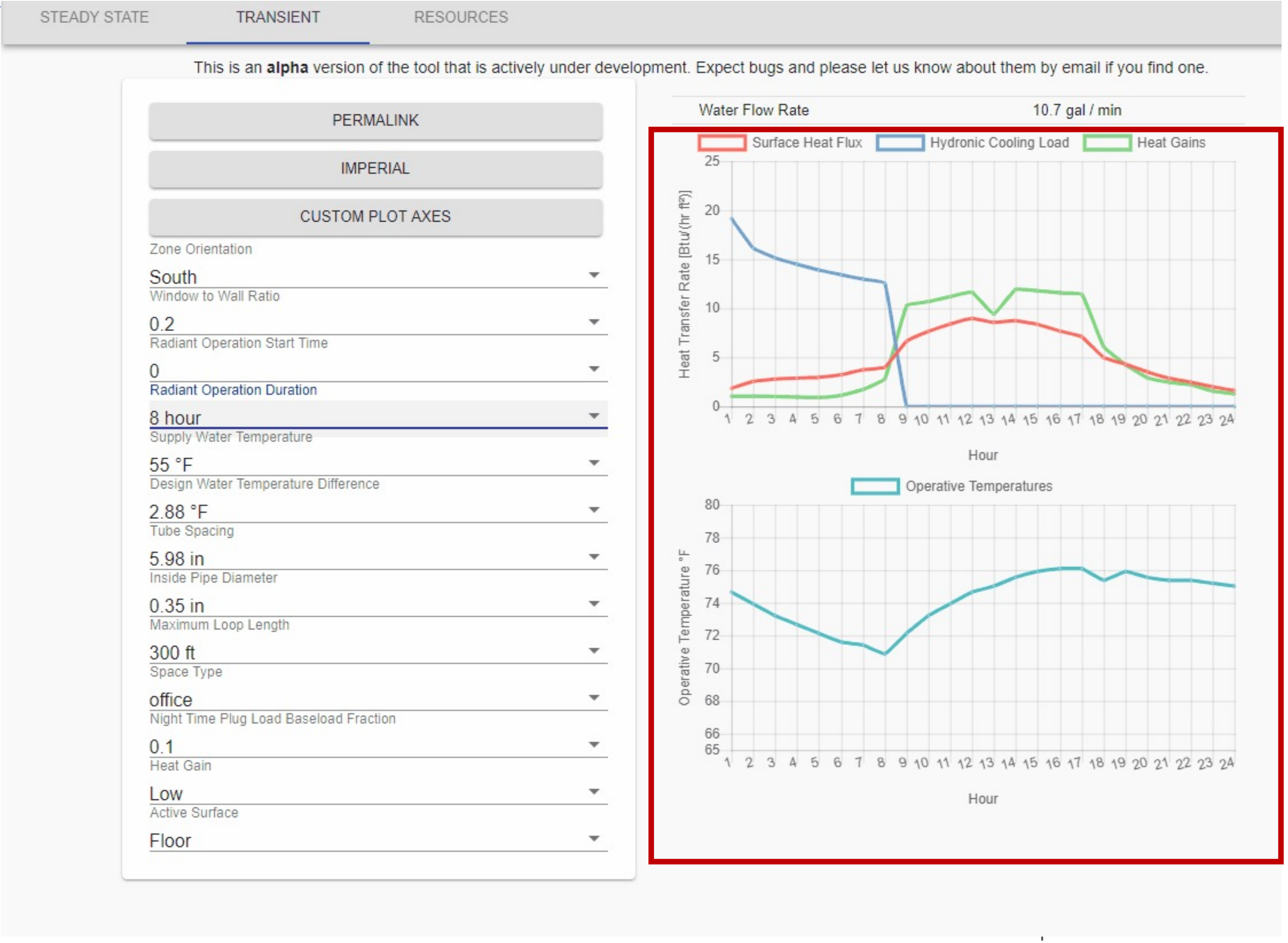
Inputs

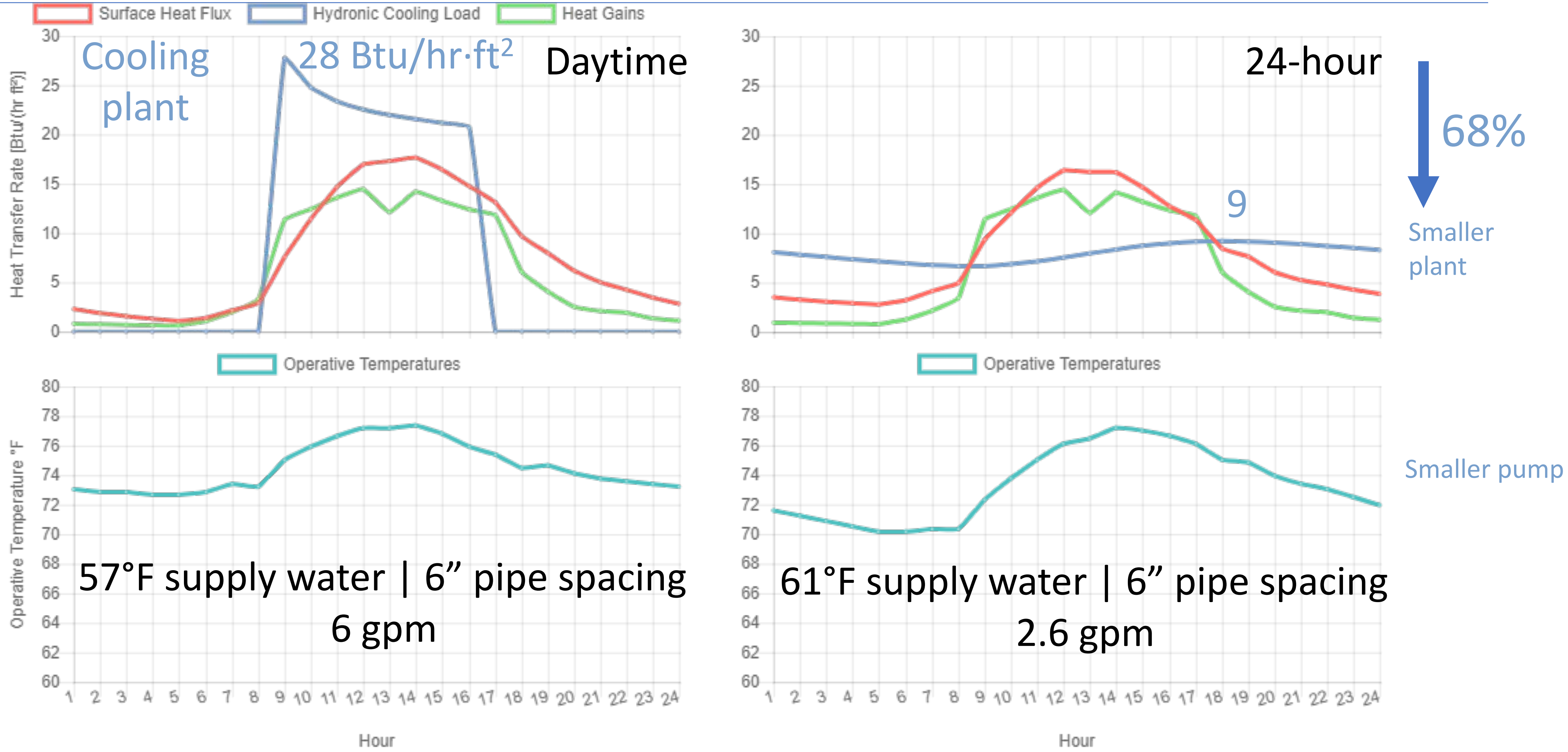
- Design parameters
- Time

Outputs

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



24-hour transient profiles for different scenarios



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 ≤ 25 W/m^2 (8 $Btu/hr\text{-}ft^2$)
- 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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