

# Seminar 26 – Load Calculation Consideration for Radiant Systems

Carlos Duarte, Starr Yang,  
Paul Raftery, Stefano  
Schiavon, Fred Bauman

University of California  
Center for the Built  
Environment

[cduarte@berkeley.edu](mailto:cduarte@berkeley.edu)  
[p.raftery.berkeley.edu](mailto:p.raftery.berkeley.edu)

## Development and Demonstration of an Interactive Web-based Design Tool for High- Thermal Mass Radiant Cooling Systems

# Learning Objectives

- Understand how the difference between cooling loads for radiant cooling and all-air cooling is impacted by the heat gain characteristics, by indoor surface characteristics, and by the availability of passive cooling overnight.
- **Understand the limitations of current radiant design tools and learn how this new webtool can help HVAC designers consider innovative radiant cooling systems with high-thermal mass.**
- Understand experiments conducted to analyze differences in the cooling load of I) radiant and II) all-air systems, and rank the parameters that have impact on the difference in loads between these two systems.
- Explain the ideal load for radiant systems and understand the impact of an undersized radiant system on indoor air and surface temperatures.

*ASHRAE is a Registered Provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to ASHRAE Records for AIA members. Certificates of Completion for non-AIA members are available on request.*

This program is registered with the AIA/ASHRAE for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product. Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

# Acknowledgements

## **Funding**

California Energy Commission EPIC Program

Center for the Built Environment

Price Industries

# Outline/Agenda

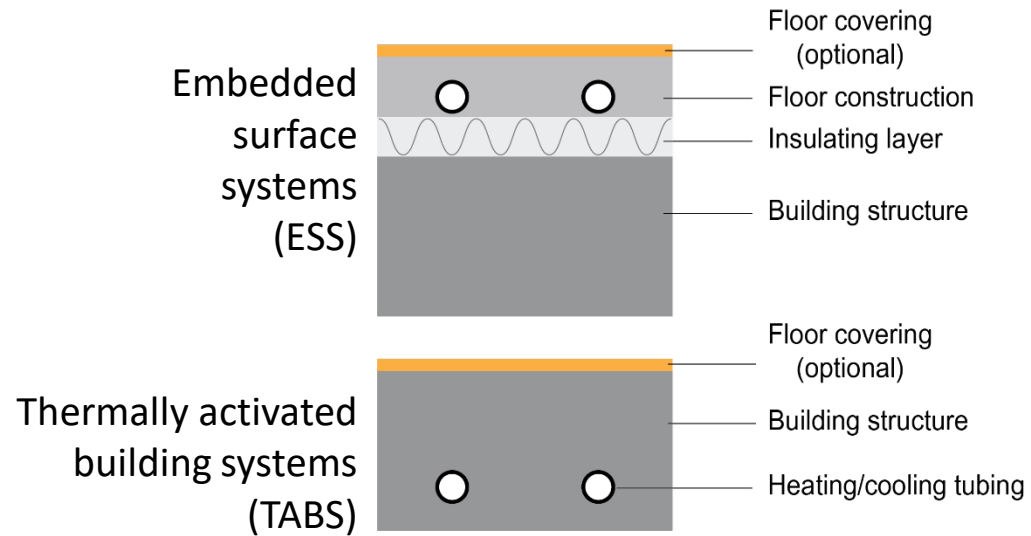
- Review types of high-thermal mass radiant system used in the web-tool
- Layout of web-tool
  - Steady-state
  - Transient
- Go through a couple examples
  - Steady-state
  - Transient



Construction workers installing high thermal mass radiant system.

# Considerations for high-thermal mass radiant systems

- Transient effects dominate
- Ability to activate/control a substantial amount of thermal mass in the room
  - Energy storage
  - Load shifting

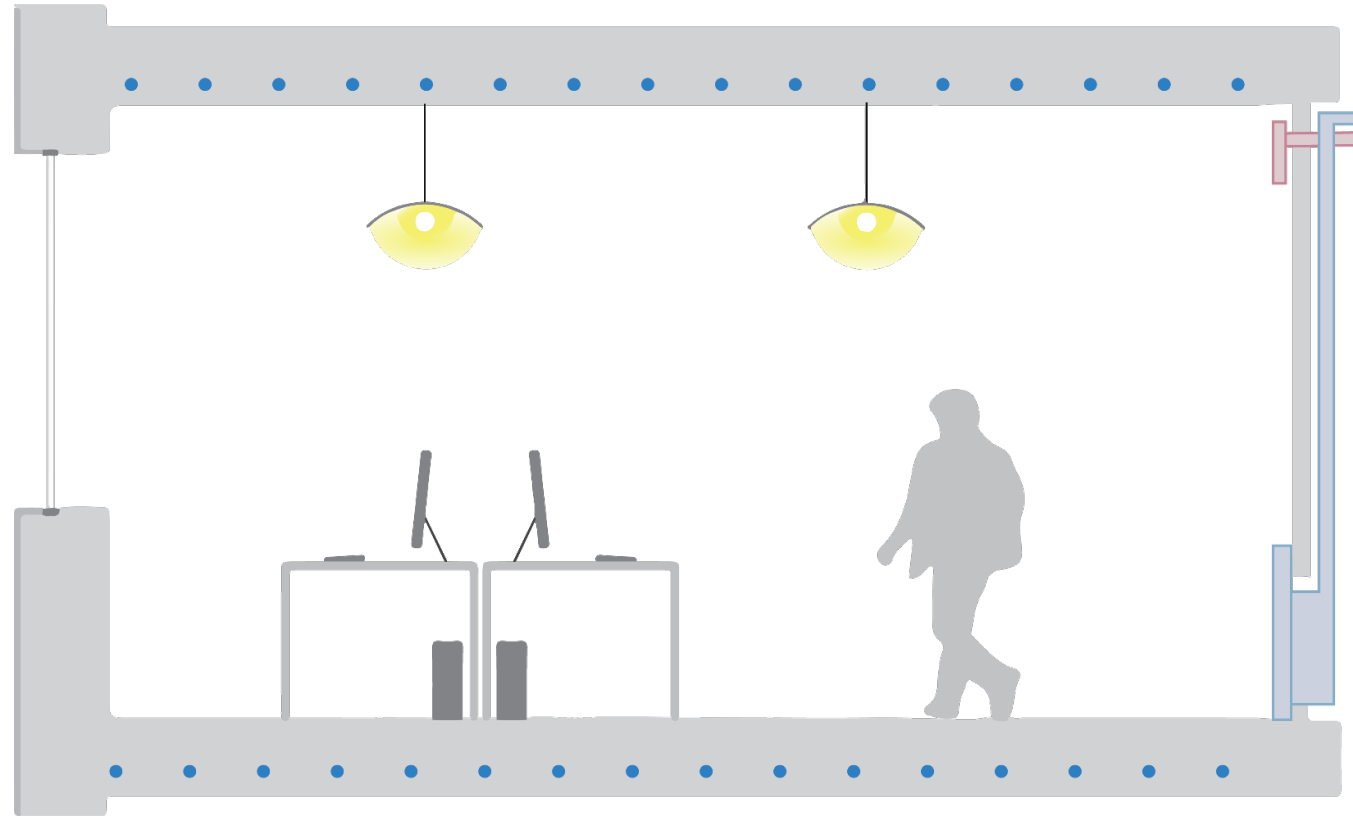


Types of high thermal mass systems incorporated in the web-tool.



# Considerations for high-thermal mass radiant systems

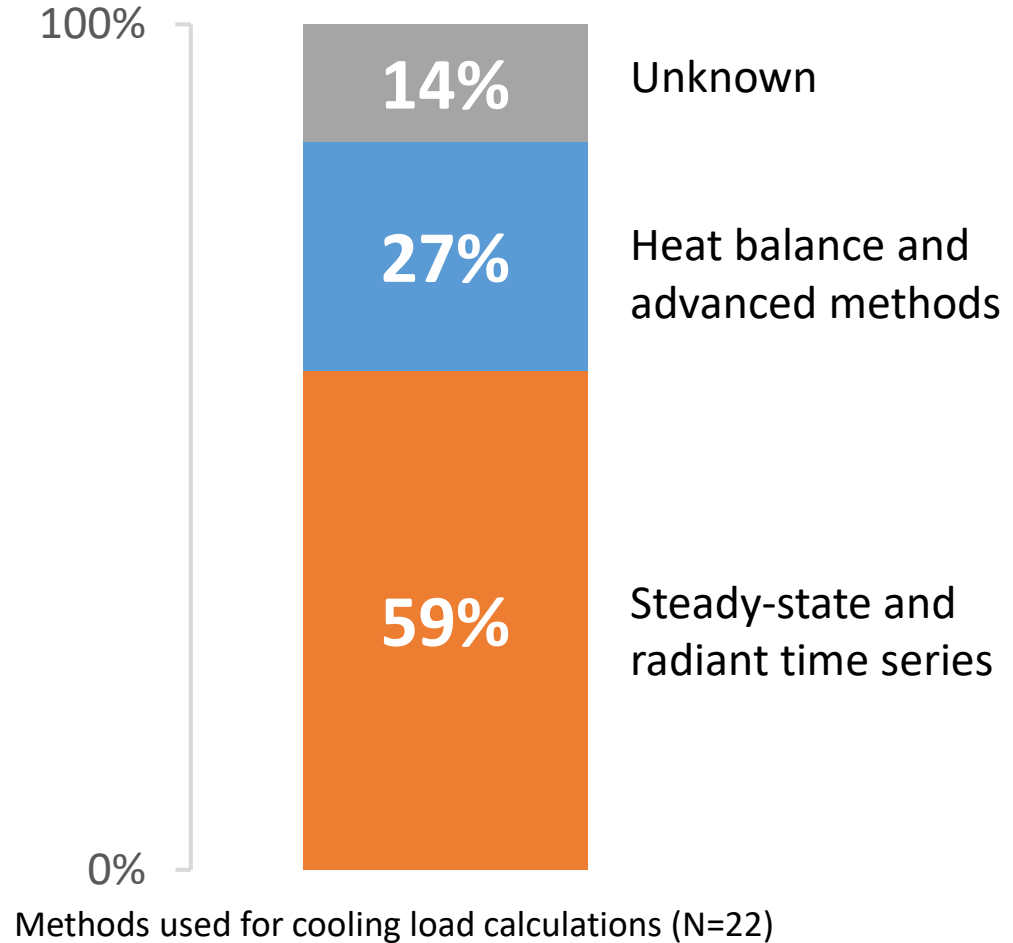
- Exposed surfaces are important!



The space's thermal mass is also important in determining a high-thermal mass radiant system. Graphic source Caroline Karmann.

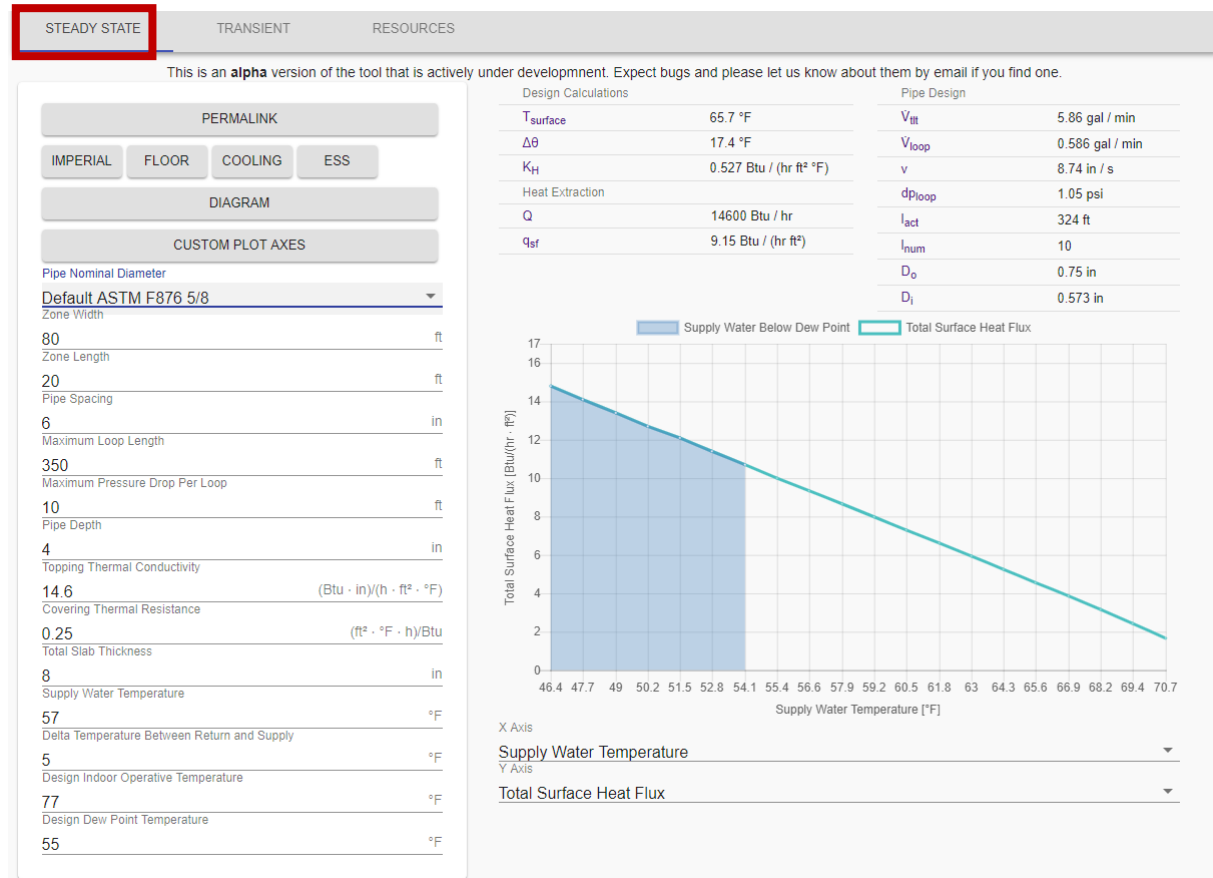
# Current state of radiant system design approach

- No consistent tool
- Same methods as for all-air systems are used for radiant systems
  - Limitations
    - Steady-state
    - Independent of control
    - Independent of HVAC system
- Detailed simulation tools are perceived as complicated, time consuming, and high cost



# Layout of the webtool: Steady-state

- Calculation type
  - Steady-state
  - ISO 11855 standard

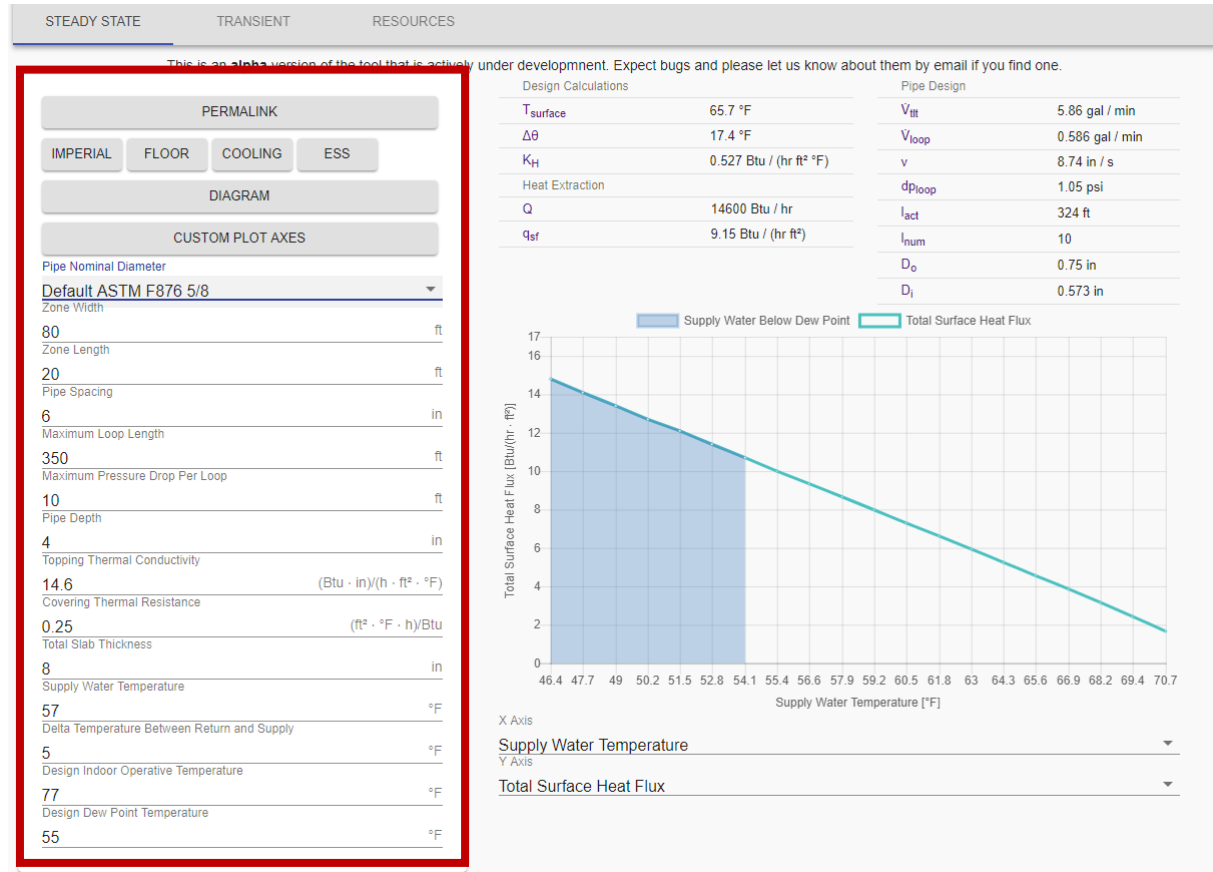


Screenshot of web-tool for the early design of high-thermal mass radiant systems.



# Layout of the webtool: Steady-state

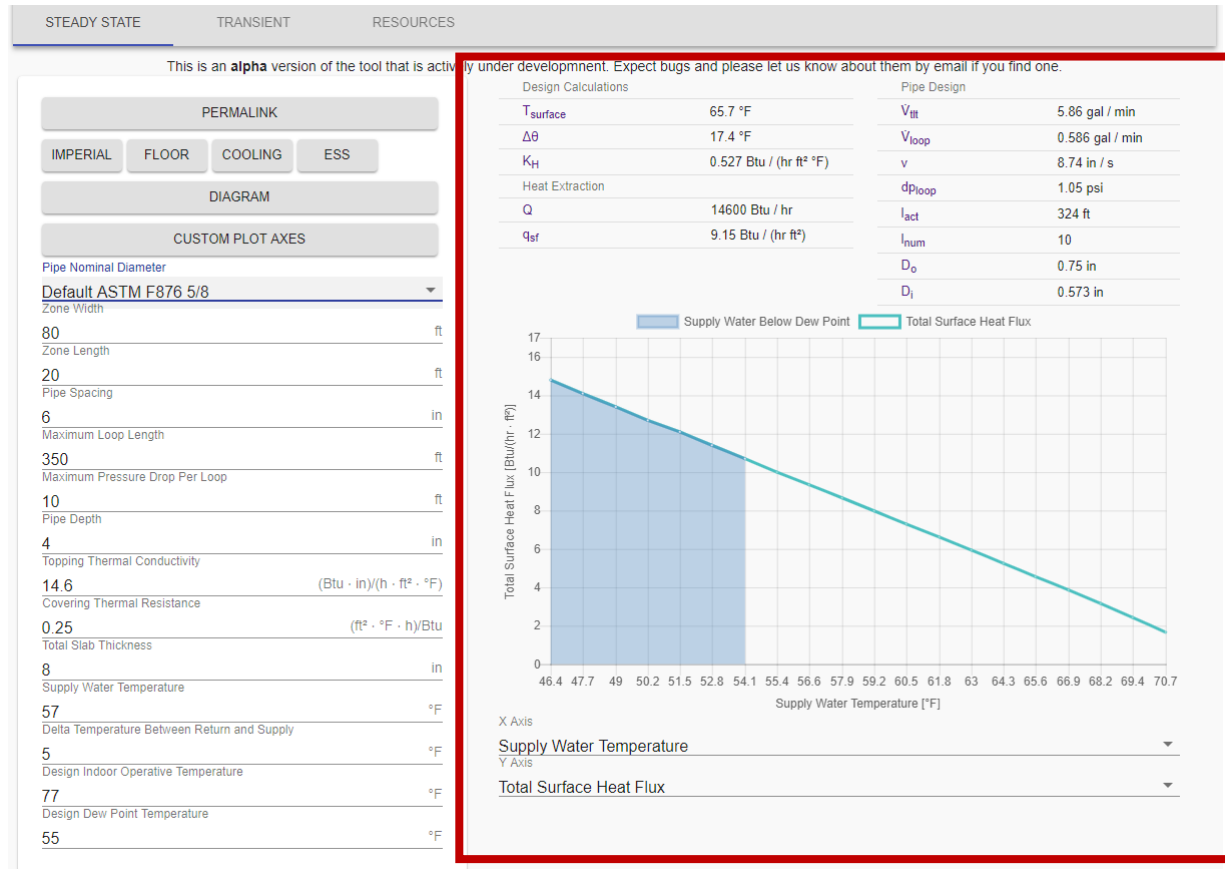
- Calculation type
  - Steady-state
  - ISO 11855 standard
- Inputs
  - Radiant system type
  - Design parameters
  - Metric/Imperial units



Screenshot of web-tool for the early design of high-thermal mass radiant systems.

# Layout of the webtool: Steady-state

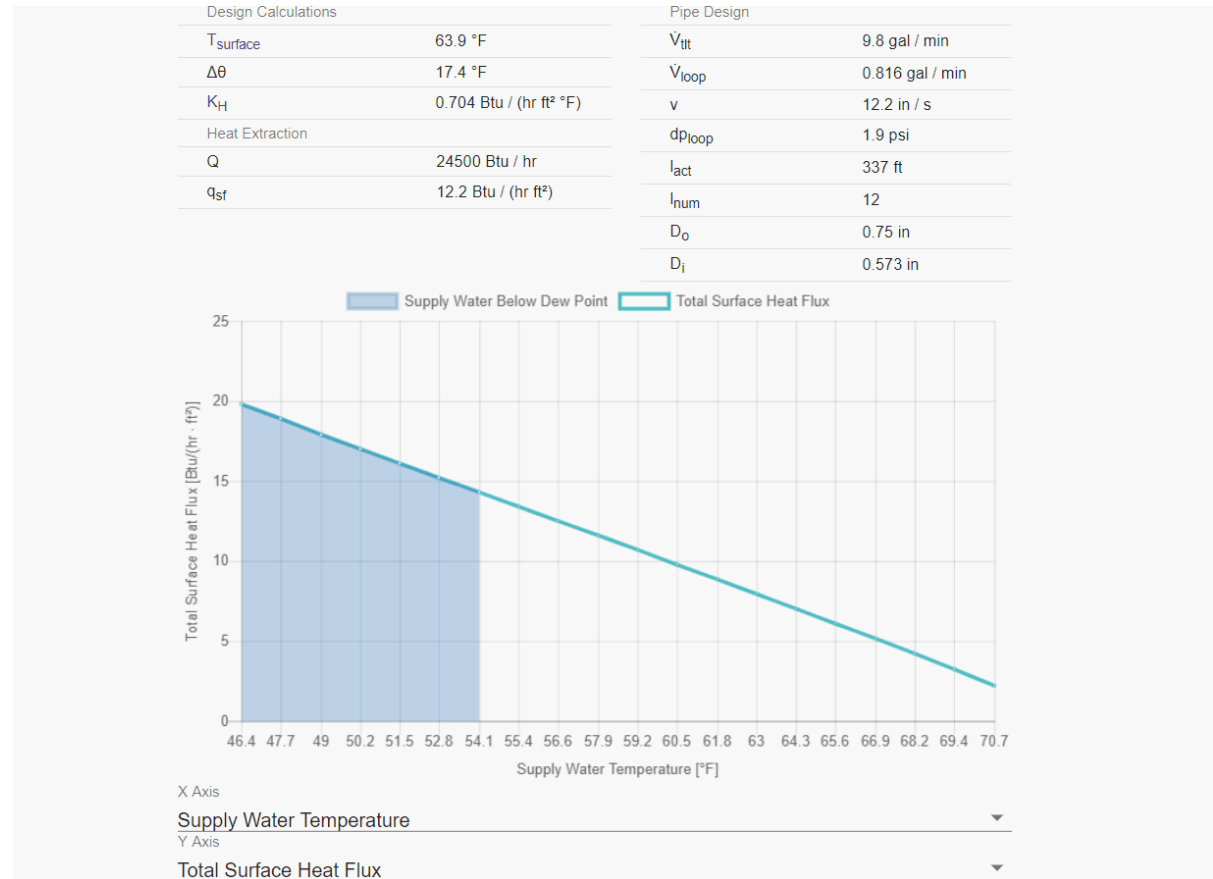
- Calculation type
  - Steady-state
  - ISO 11855 standard
- Inputs
  - Radiant system type
  - Design parameters
  - Metric/Imperial units
- Outputs
  - Design values
    - Surface heat flux
    - Hydronic heat capacity
    - Waterflow rate
    - Pipe design
    - Surface temperature
  - Visualization of the design space



Screenshot of web-tool for the early design of high-thermal mass radiant systems.

# Layout of the webtool: Steady-state

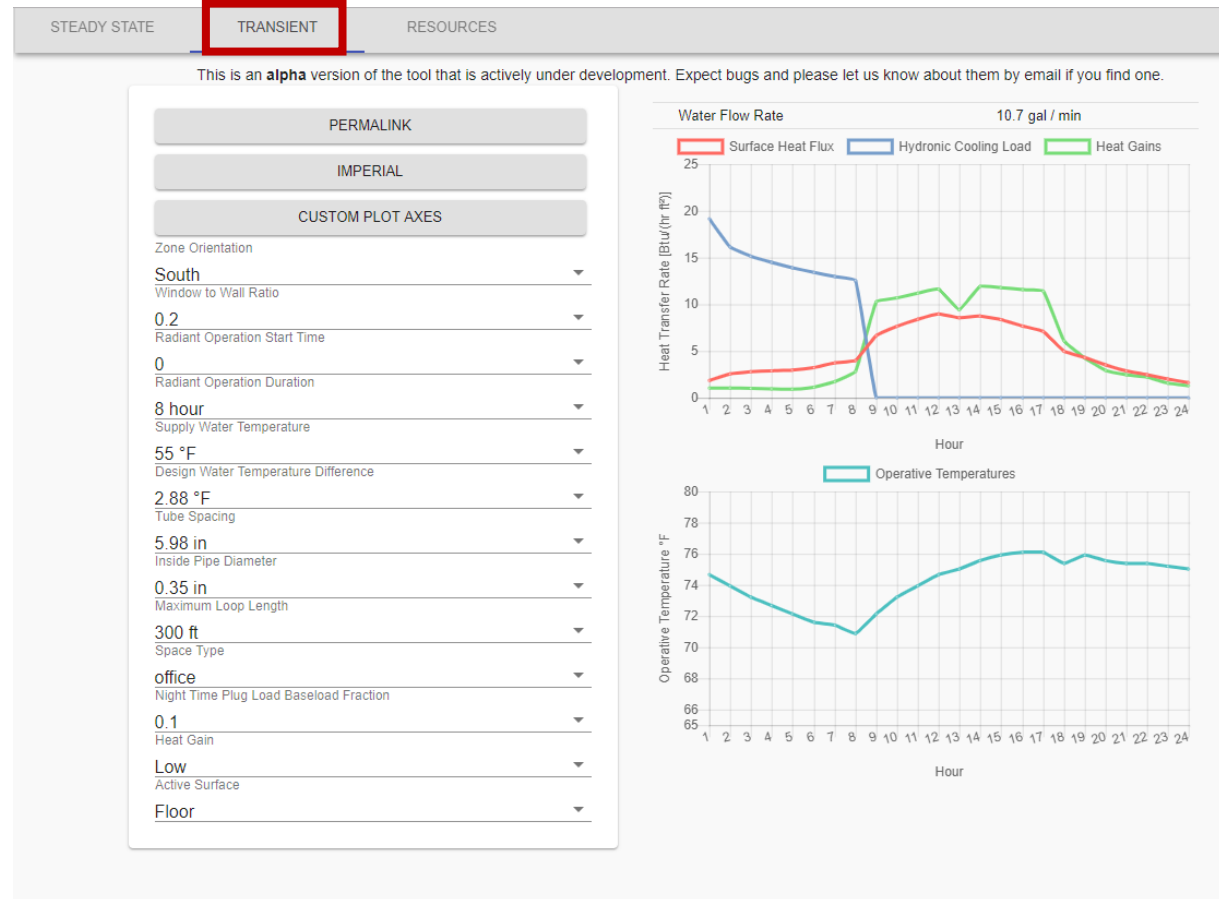
- Calculation type
  - Steady-state
  - ISO 11855 standard
- Inputs
  - Radiant system type
  - Design parameters
  - Metric/Imperial units
- Outputs
  - Design values
    - Surface heat flux
    - Hydronic heat capacity
    - Waterflow rate
    - Pipe design
    - Surface temperature
  - Visualization of the design space



Screenshot of web-tool for the early design of high-thermal mass radiant systems.

# Layout of the webtool: Transient

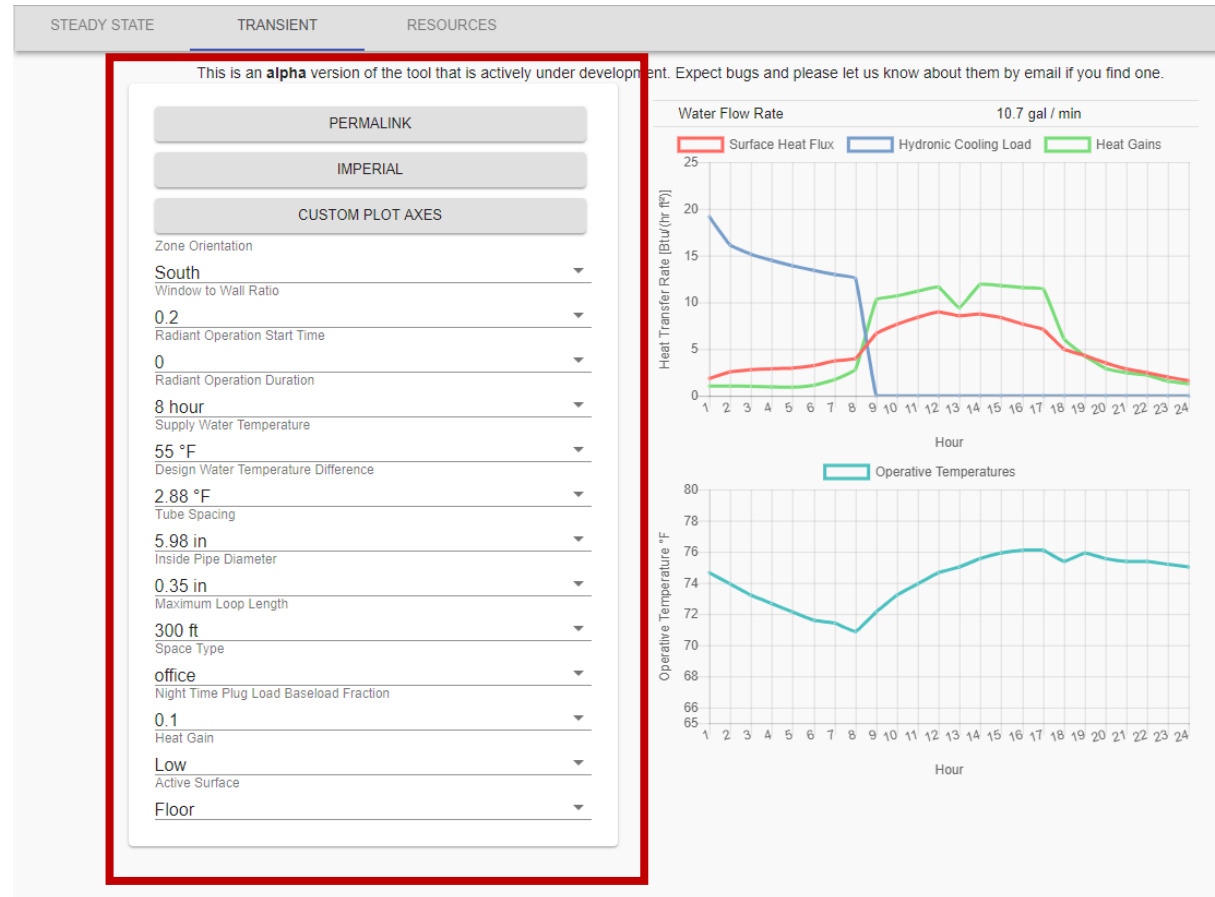
- Calculation type
  - Transient
  - Over 2.5 million EnergyPlus simulations



Screenshot of web-tool for the early design of high-thermal mass radiant systems.

# Layout of the webtool: Transient

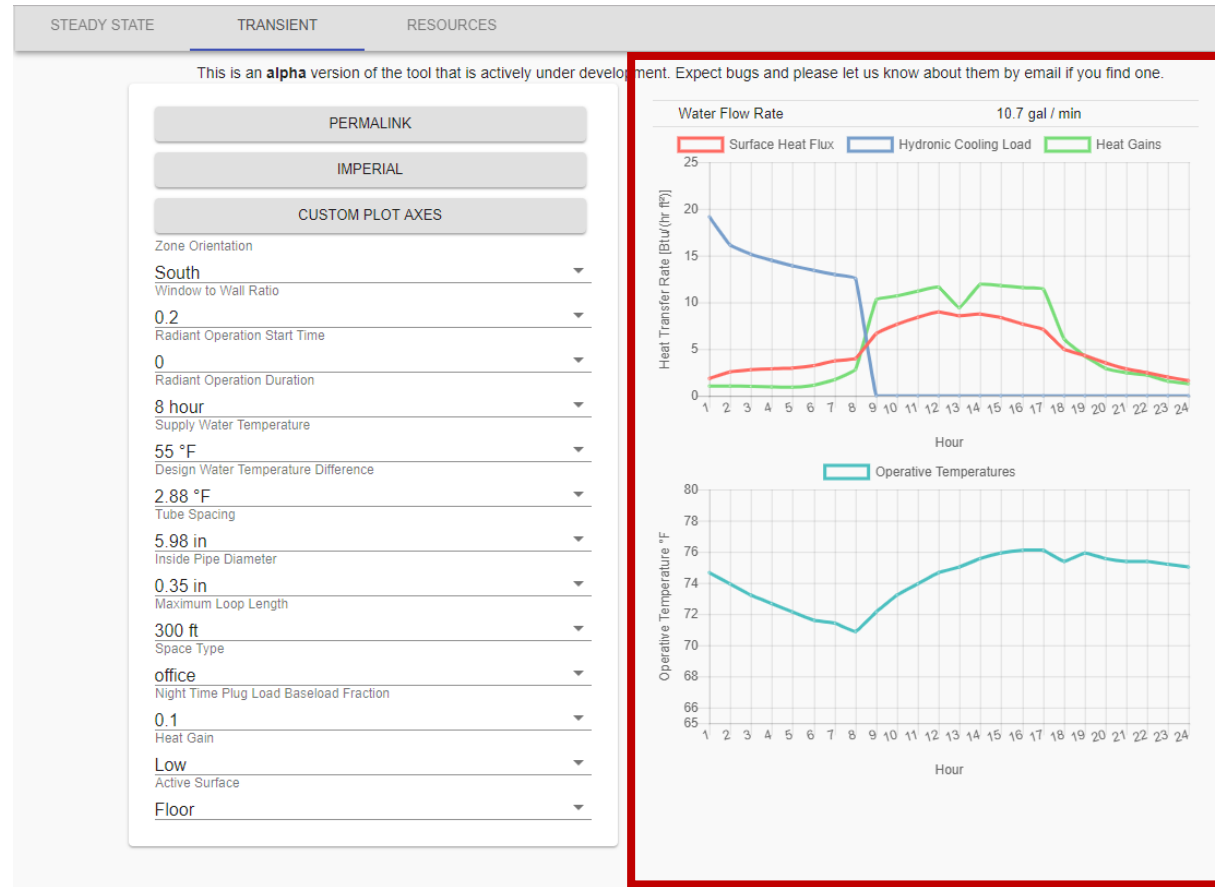
- Calculation type
  - Transient
  - Over 2.5 million EnergyPlus simulations
- Inputs
  - Design parameters
  - Time



Screenshot of web-tool for the early design of high-thermal mass radiant systems.

# Layout of the webtool: Transient

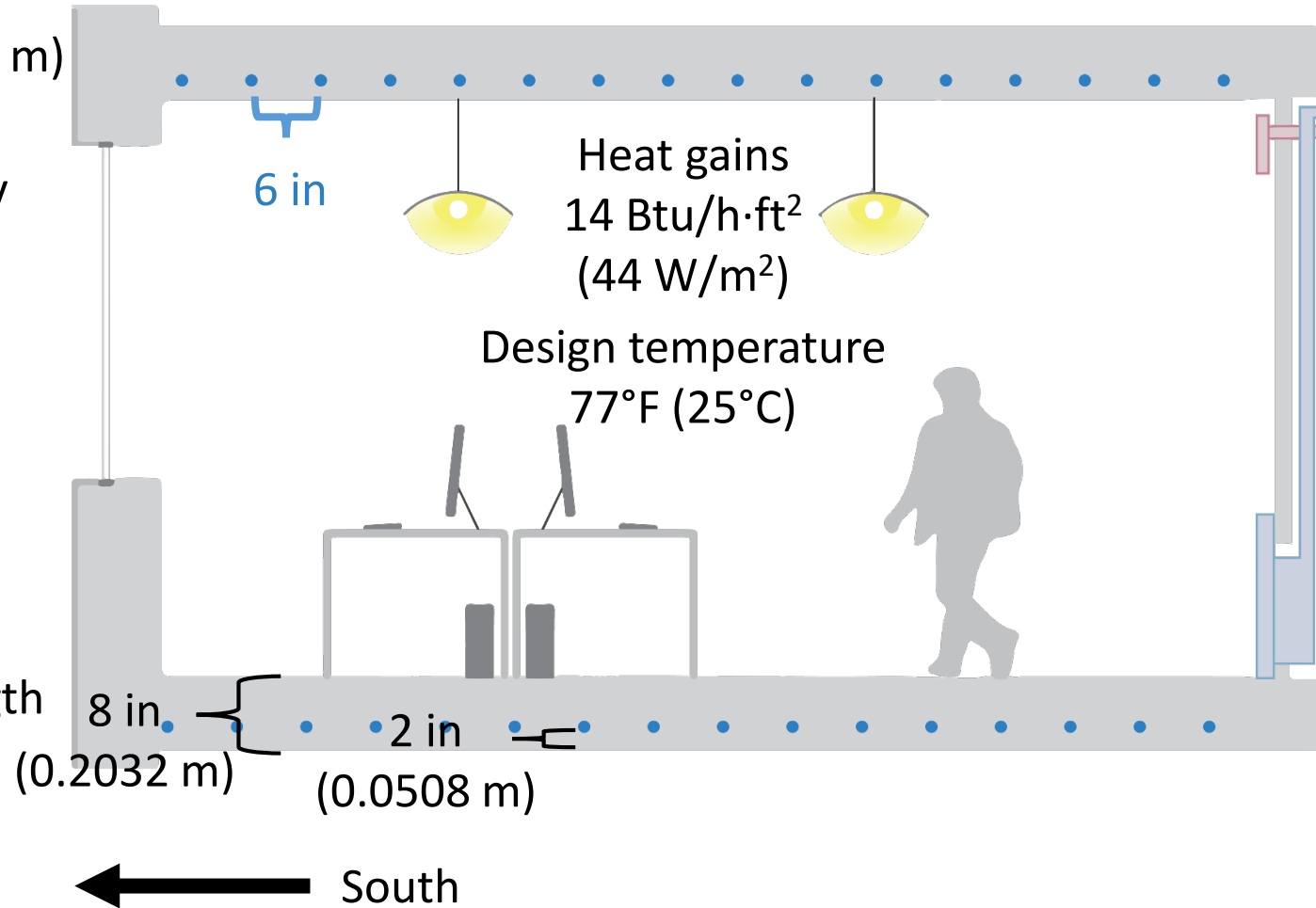
- Calculation type
  - Transient
  - Over 2.5 million EnergyPlus simulations
- Inputs
  - Design parameters
  - Time
- Outputs
  - 24-hour cooling day design values
    - Surface heat flux
    - Hydronic heat capacity
    - Operative temperature



Screenshot of web-tool for the early design of high-thermal mass radiant systems.

# Example: Verify that system parameters meet the required load

- 100 x 20 ft (30.5 x 6 m) office zone
- 57°F (13.9°C) supply water temperature
- 5°F (2.8°C) supply/return difference
- 55°F (12.8°C) dew point temperature
- 350 ft (107 m) maximum loop length





# Demo: Steady-state example

Surface heat flux =  $12.2 \text{ Btu/h}\cdot\text{ft}^2$  ( $38.5 \text{ W/m}^2$ )

Initial design does not meet the required heat gain load of  $14 \text{ Btu/h}\cdot\text{ft}^2$  ( $44 \text{ W/m}^2$ )!

STEADY STATE    TRANSIENT    RESOURCES

This is an **alpha** version of the tool that is actively under development. Expect bugs and please let us know about them by email if you find one.

PERMALINK

IMPERIAL    CEILING COOLING    TABS

DIAGRAM

CUSTOM PLOT AXES

Pipe Nominal Diameter  
Default ASTM F876 5/8

Zone Width 100 ft

Zone Length 20 ft

Pipe Spacing 6 in

Maximum Loop Length 350 ft

Maximum Pressure Drop Per Loop 10 ft

Pipe Depth 2 in

Topping Thermal Conductivity 14.6  $(\text{Btu}\cdot\text{in})/(\text{h}\cdot\text{ft}^2\cdot^\circ\text{F})$

Covering Thermal Resistance 0  $(\text{ft}^2\cdot^\circ\text{F}\cdot\text{h})/\text{Btu}$

Total Slab Thickness 8 in

Supply Water Temperature 57  $^\circ\text{F}$

Delta Temperature Between Return and Supply 5  $^\circ\text{F}$

Design Indoor Operative Temperature 77  $^\circ\text{F}$

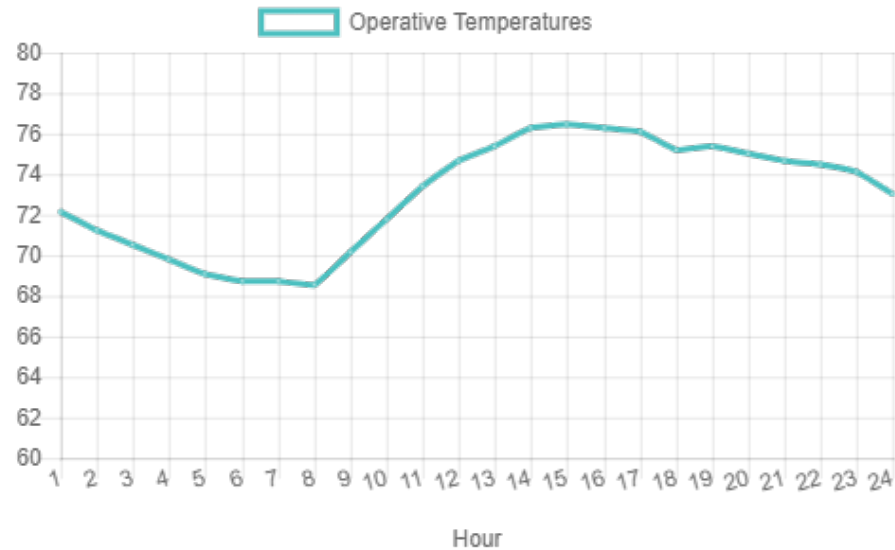
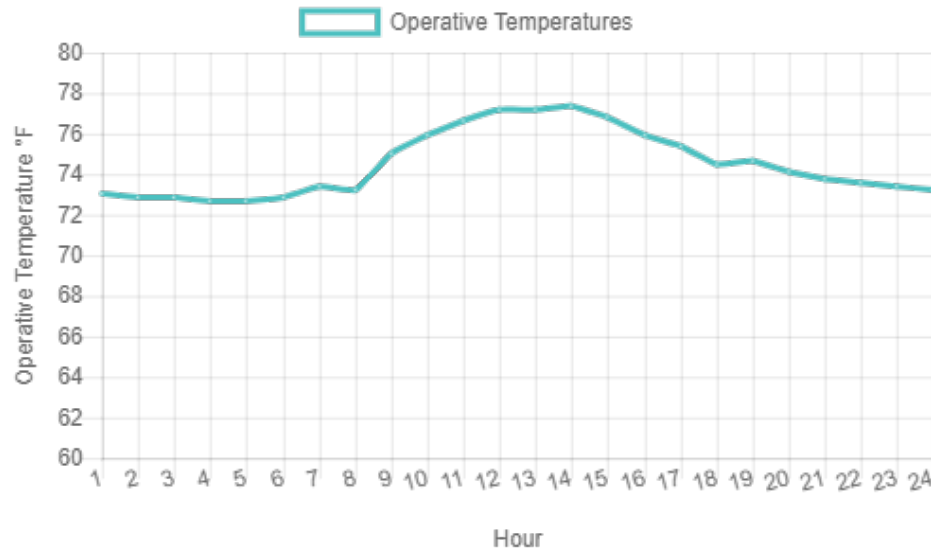
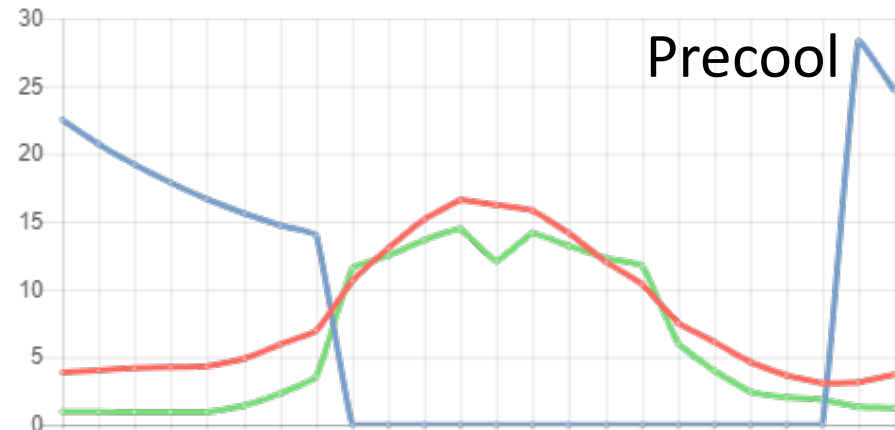
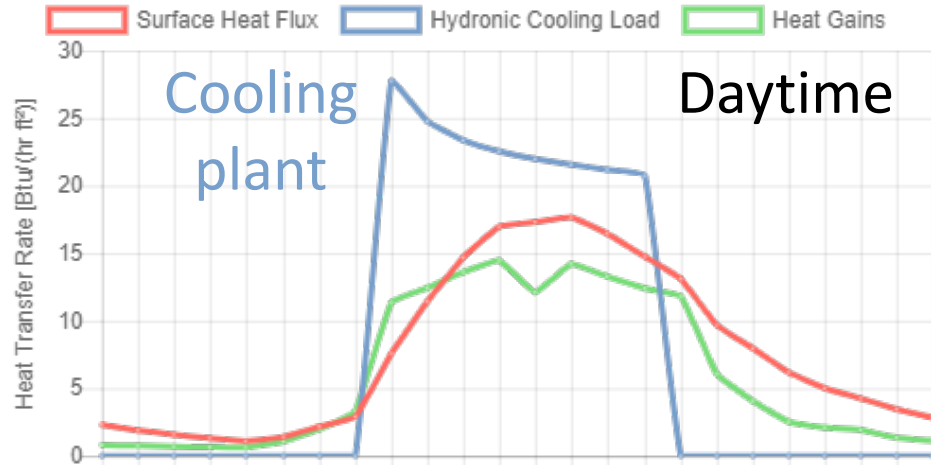
Design Dew Point Temperature 55  $^\circ\text{F}$

Design Calculations		Pipe Design	
$T_{\text{surface}}$	63.9 $^\circ\text{F}$	$V_{\text{lit}}$	9.8 gal / min
$\Delta\theta$	17.4 $^\circ\text{F}$	$V_{\text{loop}}$	0.816 gal / min
$K_H$	0.704 Btu / (hr ft $^2$ $^\circ\text{F}$ )	$v$	12.2 in / s
Heat Extraction			
$Q$	24588 Btu / hr	$d_{\text{loop}}$	1.9 psi
$q_{\text{sf}}$	12.2 Btu / (hr ft $^2$ )	$l_{\text{act}}$	337 ft
		$l_{\text{num}}$	12
		$D_o$	0.75 in
		$D_i$	0.573 in

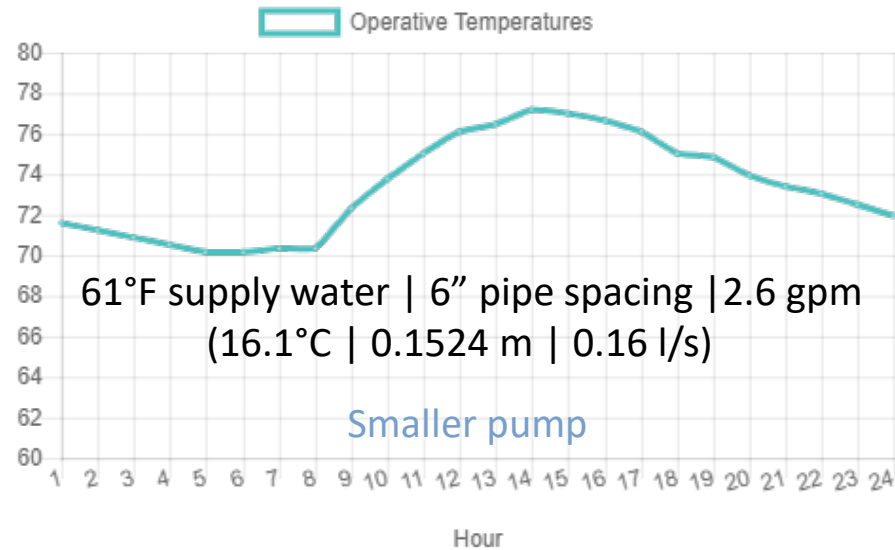
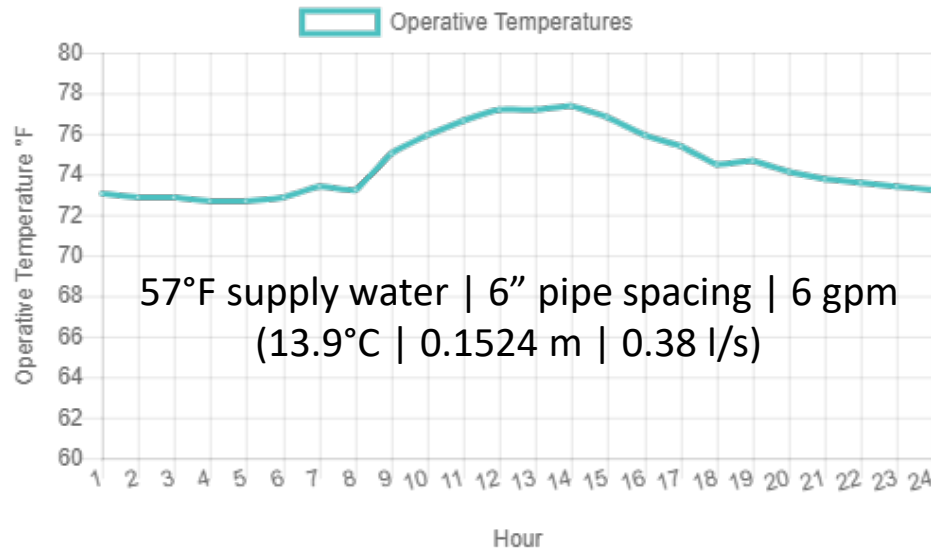
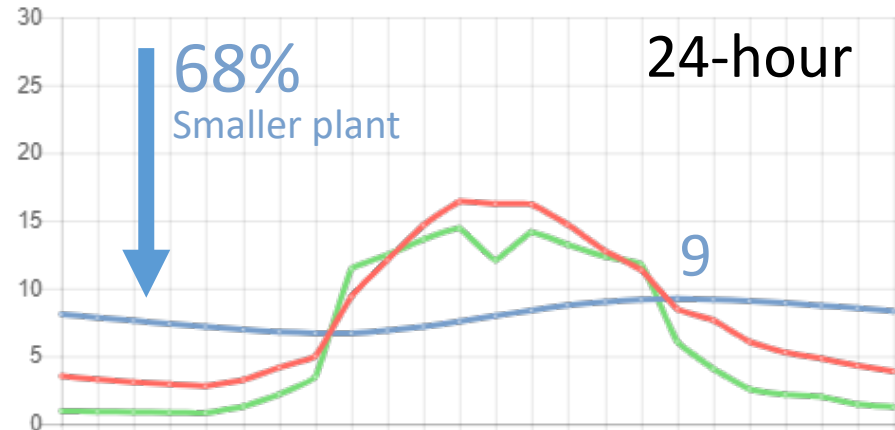
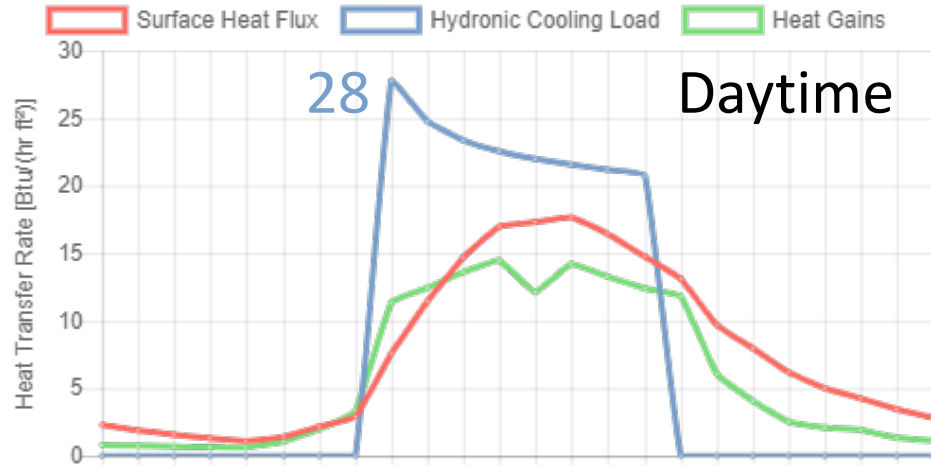
Supply Water Temperature

Total Surface Heat Flux

# Demo: Transient example

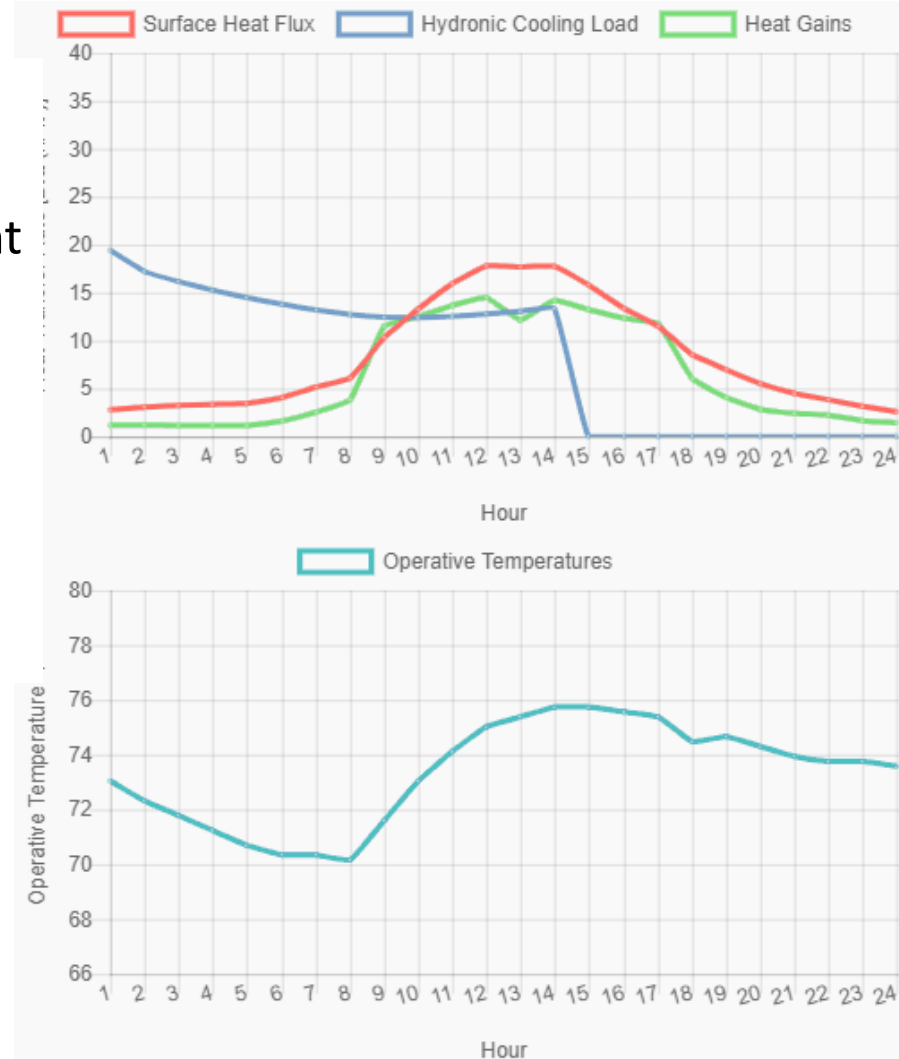


# Demo: Transient example



# Conclusion

- Tool facilitates existing steady-state calculations
- High thermal mass systems need transient tools
- Transient tool allows designers to explore ways to reduce:
  - Energy consumption
  - Cooling plant size
  - Electricity costs



Output example from transient calculations.

# Next steps

- Continue development
- Resources
  - User's guide documentation
  - Sequences of operation for radiant control
  - EnergyPlus example models that includes control sequences



Infrared picture of ceiling with high-thermal mass radiant system.

# Bibliography

- **Feng, J. (Dove), F. Bauman, S. Schiavon. 2014. Critical review of water based radiant cooling system design methods. Proceedings of Indoor Air 2014.**
- **Raftery, P., C. Duarte, S. Schiavon, F. Bauman. 2017. CBE Rad Tool. [radiant.cbe.berkeley.edu](http://radiant.cbe.berkeley.edu)**

# Questions?

Carlos Duarte  
cduarte@berkeley.edu

Paul Raftery  
p.raftery.berkeley.edu