Zero Energy Building with Hydronics

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ASHRAE BC
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Course description

- Hydronics offers an excellent way to address sensible heating and cooling loads in markets transitioning to a zero energy building future. This course will discuss the strengths and limitations of water-based heating and cooling systems. Considering the vast amount of buildings operating with hydronic systems today, a clearer transition path is required to adapt to the energy plants of the future.

Learning objectives

- Define zero energy building
- Why hydronics?
- Distribution efficiency
- Adaptability for future energy sources
- Radiant cooling
- Case studies

Energy jargon

Defined by the National Renewable Energy Labs (NREL):

- **Electrification** - the substitution of electricity for direct combustion of non-electricity-based fuels
- **Carbon neutral/decarbonized** - no net climate impact resulting from carbon or other greenhouse gases
- **Zero emissions** - building or community produces and uses at least as much emissions-free renewable energy as it uses from emissions-producing energy sources
- **Zero energy building (ZEB)** - a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies

Why does this matter?

- 70 million U.S. homes generate over 560 million tons of CO_2 each year—**roughly 20 percent of our nation's total emissions**. According to the American Council for an Energy-Efficient Economy (ACEEE), if U.S. residential buildings were a country, it would be the sixth-highest emitter of greenhouse gasses in the world.

- "On average, more than half (51% in 2015) of a household's annual energy consumption is for just two energy end uses: **space heating and air conditioning.**" (U.S. Energy Information Administration)

- Space heating/cooling accounts for ~10% of the annual U.S. energy consumption

The easiest path to ZEB is a small heating/cooling load

- Option A

- Reality

Why hydronics for zero energy building?

- Electrification friendly
- Decarbonization friendly
- No point-source pollution
- No products of combustion or gas lines in the mechanical room
- Higher energy prices will reduce system ROI

Not us vs. them anymore

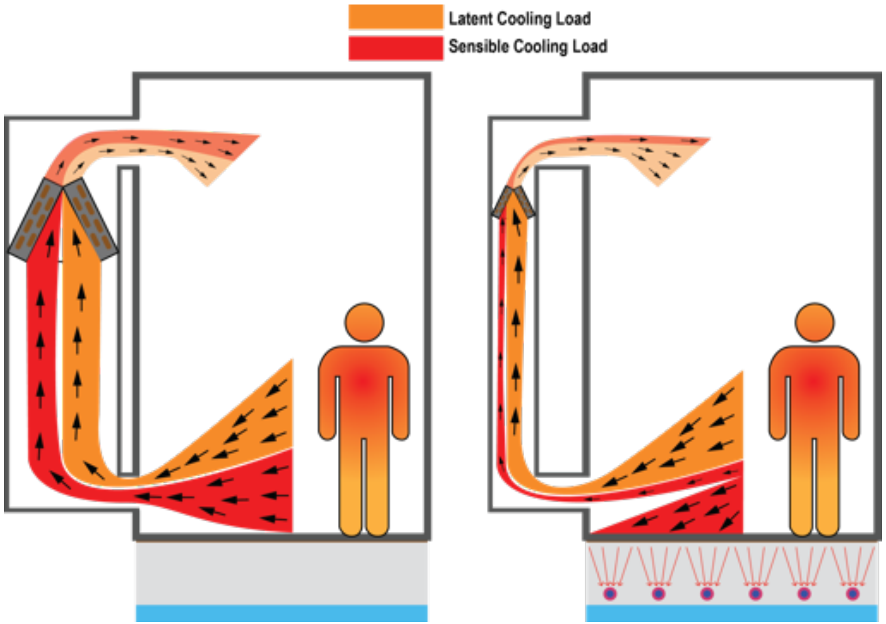
- Radiant heat, especially in homes, was often targeted as a direct replacement for forced-air systems
- Modern buildings are too tight to omit ventilation and use hydronics only
- People need cooling, it isn’t a luxury item anymore
- Warm floors aren’t the deliverable anymore
- The refrigeration cycle is an important way to boost system efficiency

- **Hybrid systems with hydronics and mechanical ventilation are an excellent way to balance ASHRAE Standards 90.1, 55 and 62.1/62.2**

Hybrid system example – radiant cooling

Air-based system

- Cooling coil sized for 100% of the sensible and latent loads
- Larger equipment may be required

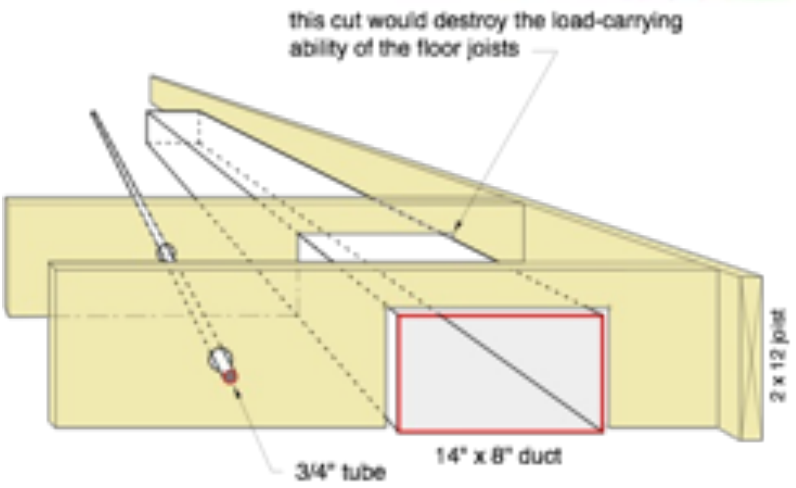


Radiant cooling hybrid system

- Transfer more of the sensible load to the radiant surface
- Air-side coil may be downsized, because it is responsible for the latent load and a small fraction, or none of the sensible load

Why hydronics?

- Best way to address **sensible loads**
- Water is an excellent conveyor belt for heat
- Potential to downsize air-side components
- A given volume of water can absorb almost 3,500 times as much heat as the same volume of air, when both undergo the same temperature change



$$\frac{62.4 \ \text{Btu/ft}^3/°\text{F}}{0.018 \ \text{Btu/ft}^3/°\text{F}} = 3467_x \approx 3500_x$$

Material	Specific heat (Btu/lb/°F)	Density* (lb/ft³)	Heat capacity (Btu/ft³/°F)
Water	1.00	62.4	62.4
Concrete	0.21	140	29.4
Steel	0.12	489	58.7
Wood (fir)	0.65	27	17.6
Ice	0.49	57.5	28.2
Air	0.24	0.074	0.018
Gypsum	0.26	78	20.3
Sand	0.1	94.6	9.5
Alcohol	0.68	49.3	33.5

Distribution efficiency – baseline hydronics

- Example: Consider a system that delivers 120,000 Btu/hr at design load conditions using four circulators operating at 85 watts each.
- Each watt of electrical power supplied to the distribution system delivers 353 Btu/hr from the heat source to where it's needed in the building.
- High efficiency hydronic heating systems should minimize fuel usage as well as the electrical energy needed for heat distribution.

$$\text{distribution efficiency} = \frac{120{,}000\ \text{Btu/hr}}{340\ \text{watts}} = 353\ \frac{\text{Btu/hr}}{\text{watt}}$$

$$\text{distribution efficiency} = \frac{\text{rate of heat delivery}}{\text{rate of energy use by distribution equipment}}$$

Distribution efficiency – baseline forced-air

- So is a distribution efficiency of 353 Btu/hr/watt good or bad?
- The previously assumed hydronic system had a distribution efficiency almost four times higher than the forced air system.
- With modern hydronic hardware and design methods (panel radiators, variable speed ECM circulator, homerun distribution system) the distribution efficiency has the potential to be much higher.

$$\text{distribution efficiency} = \frac{80{,}000 \text{ Btu/hr}}{850 \text{ watts}} = 94 \ \frac{\text{Btu/hr}}{\text{watt}}$$

$$\text{distribution efficiency} = \frac{\text{rate of heat delivery}}{\text{rate of energy use by distribution equipment}}$$

Distribution efficiency – modern hydronics

- With good design and modern hardware it's possible to design a homerun distribution system for panel radiators that can supply 30,800 Btu/hr design load using only 8.6 watts of electrical power input to circulator!
- Baseline forced-air was 94 Btu/hr/watt

$$\text{distribution efficiency} = \frac{30{,}800\,\frac{Btu}{hr}}{8.6\,watt} = 3581\,\frac{Btu/hr}{watt}$$

$$\text{distribution efficiency} = \frac{\text{rate of heat delivery}}{\text{rate of energy use by distribution equipment}}$$

Low-temperature hydronic systems are adaptable

Potential timeline:

- Today: non-condensing boiler, high-temperature baseboard
- Tomorrow: air/water heat pump added, original non-condensing boiler still in service, add low-temp panel radiators or fan coils
- Best case, incorporate renewables: electric boiler with solar PV, high-efficiency wood pellet boiler, water/water heat pump, etc.

Bridge the gap between energy sources, while maximizing renewable options

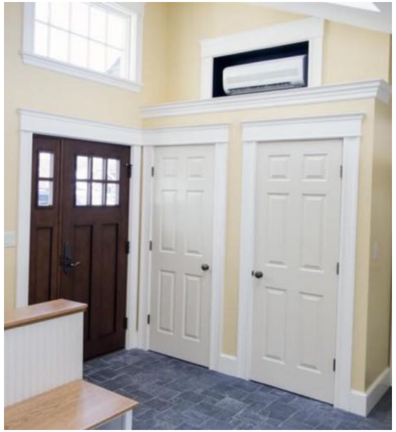
What do we do with existing hydronics systems?

- Abandon them and add mini-splits to every room
- Repurpose them with low-temperature energy sources
- Break the 180°F supply temp. expectation
- Evaluate upgrading the heat emitters
- Consider radiant cooling in commercial new construction projects

Pro Trade CRAFT For Residential Construction Pros (/)

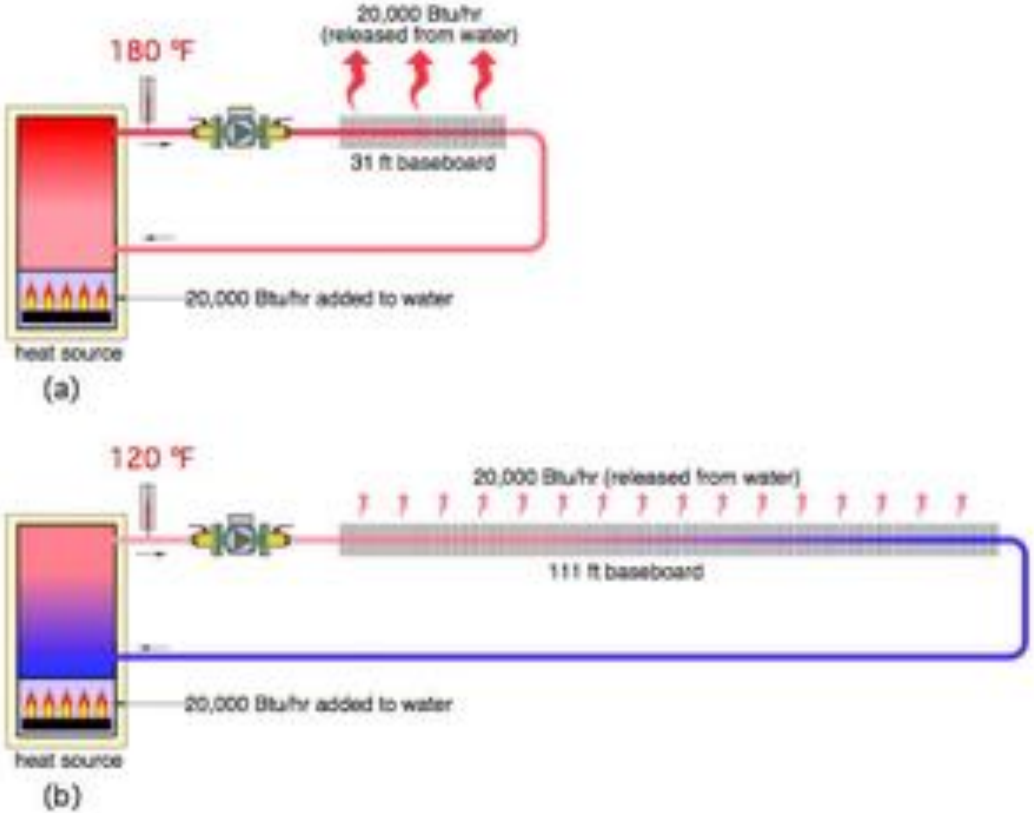
9 Ways to Hide a Minisplit

December 20, 2019



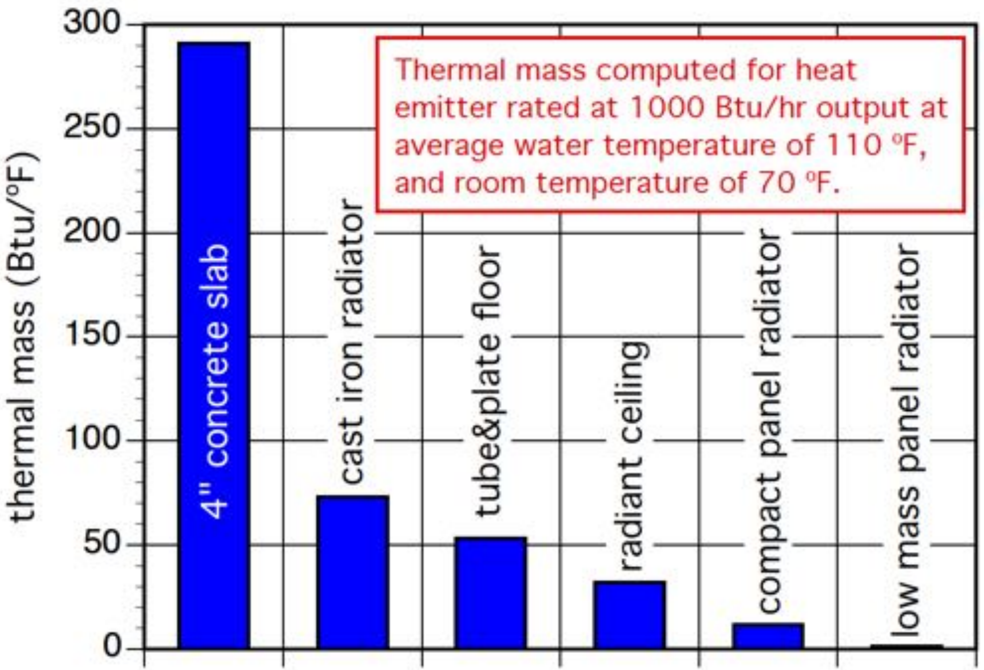
Surface area is key

- Multiple paths to a thermal equilibrium



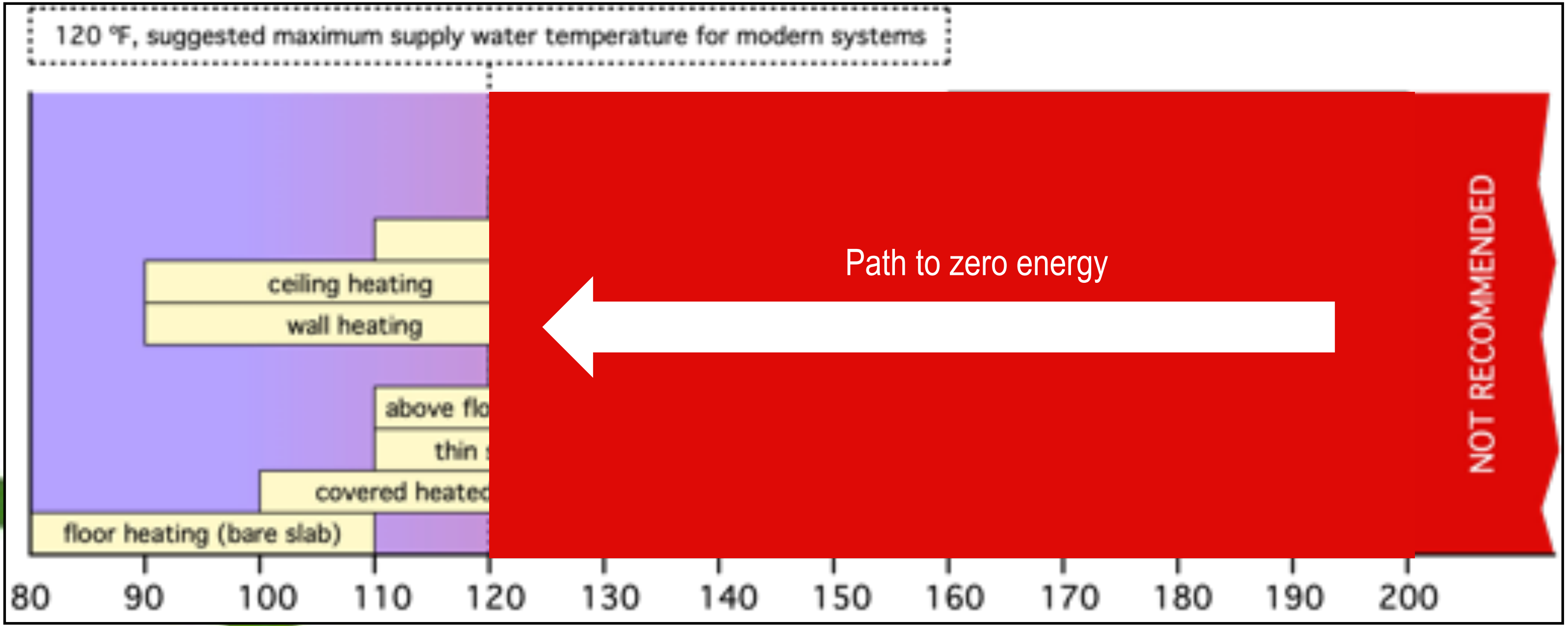
Thermal mass options

- Hydronics doesn't mean high mass
- A comparison of thermal mass for several heat emitters: All heat emitters sized to provide 1,000 Btu/hr at 110ºF average water temperature, and 70ºF room temperature:
- Low thermal mass heat emitters are generally preferred in low load buildings - **due to fast response characteristic**

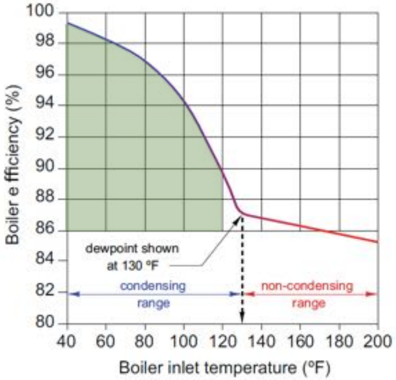


Supply temperature and heat emitters

- Hydronics is adaptable to existing heat emitters
- High-temperatures won't do the job for zero energy targets

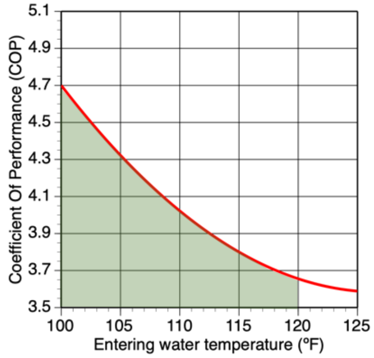


Low-temperature heat emitters maximize benefit

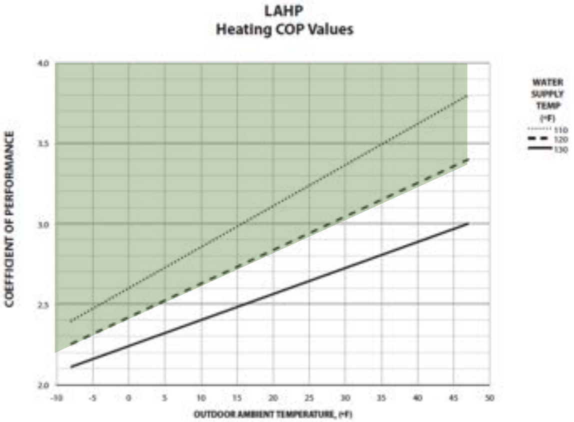


- Condensing boilers

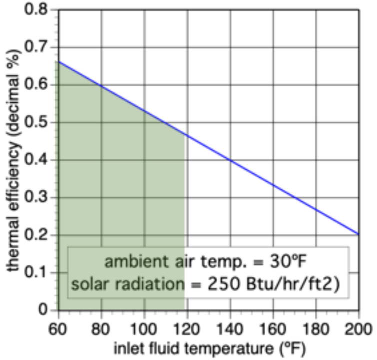
- Water/water heat pumps



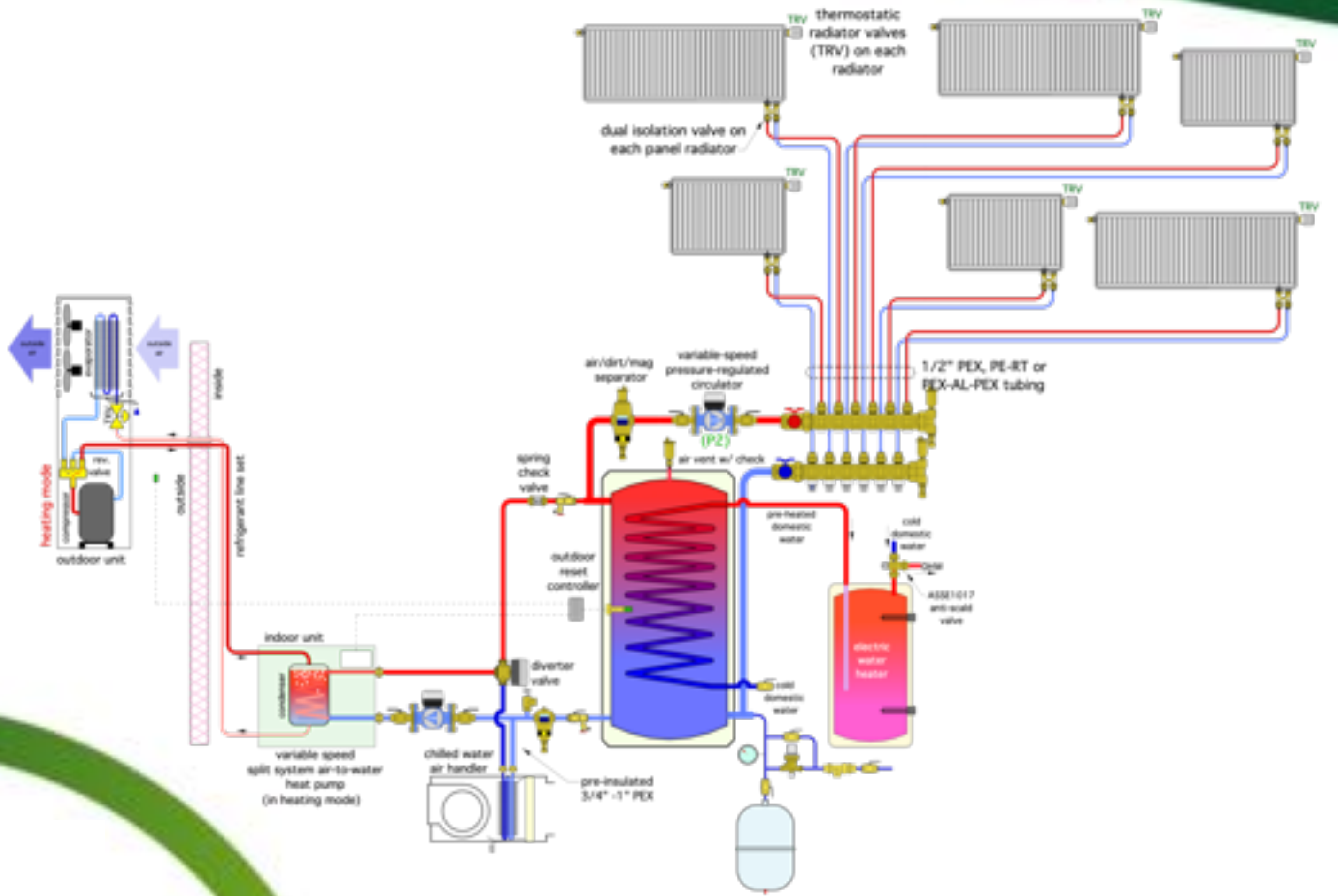
- Air/water heat pumps



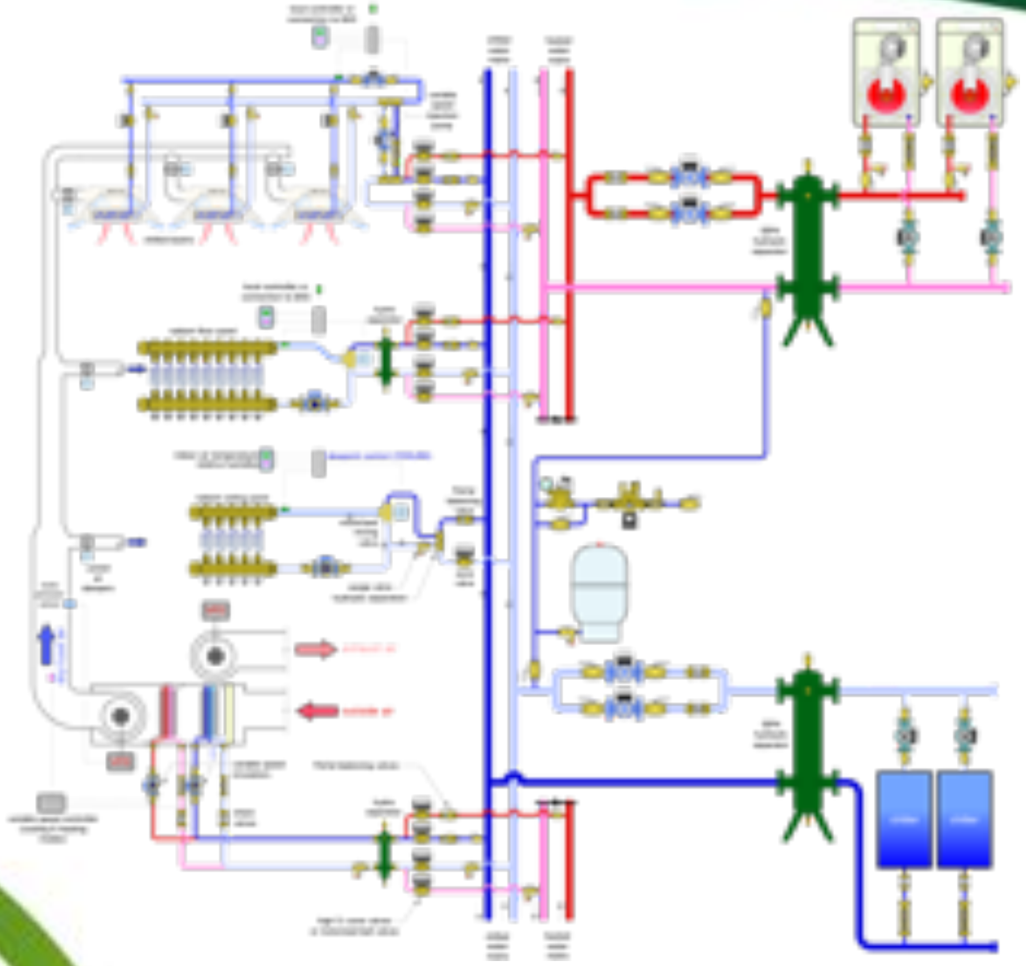
- Solar thermal



Conceptual residential design



Conceptual commercial design



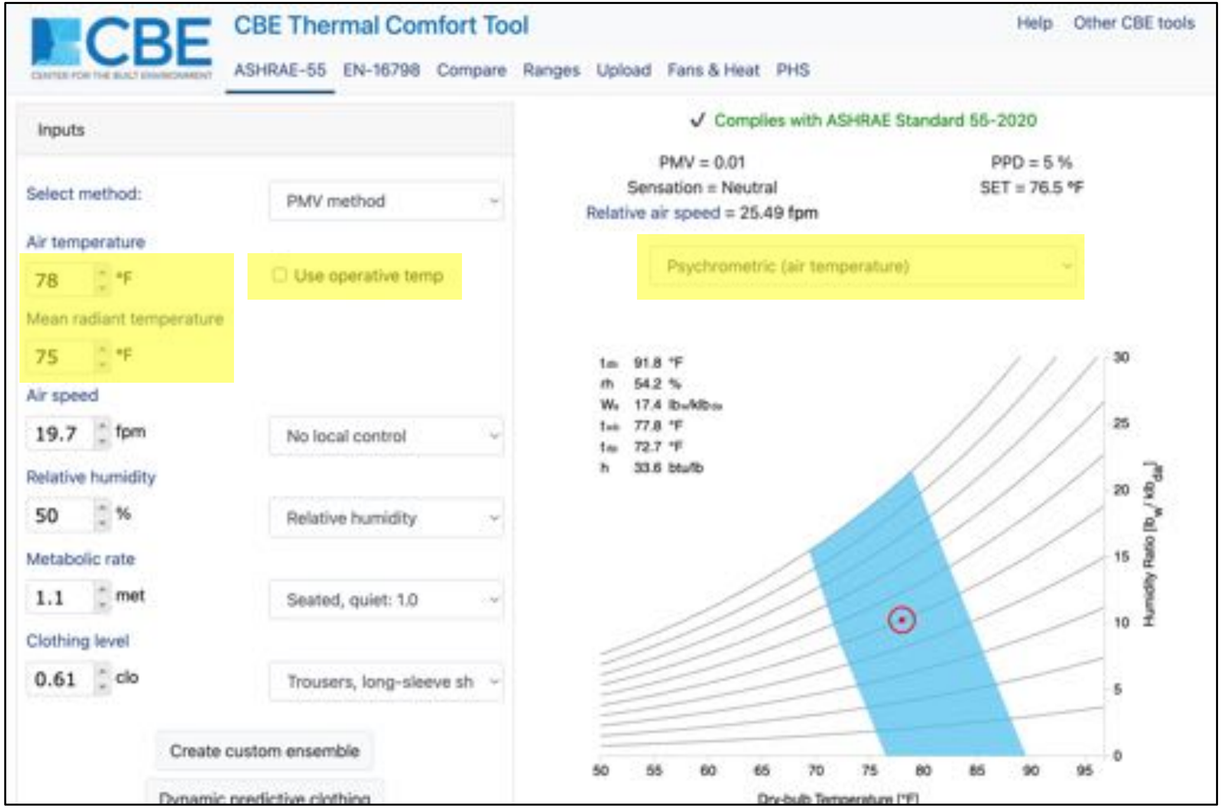
Energy efficiency studies

- A New Buildings Institute research study of site energy use in 23 radiant buildings found: **Radiant buildings are more energy efficient than 90% of comparable buildings**, with two-thirds receiving an EnergyStar score of 90 or above.
- "The study noted that two independent study datasets found the **majority of zero net energy buildings use radiant systems**, which suggests that leading designers have identified radiant systems as a part of their solution to get to low-energy results."
- Radiant buildings used 32% less energy than the EIA 2012 Commercial Buildings Energy Consumption Survey average.

-Energy Use, Occupant Surveys and Case Study Summary: Radiant Cooling and Heating in Commercial Buildings, New Buildings Institute and Center for the Built Environment, 2017

Center for the Built Environment ASHRAE 55 calculator

- https://comfort.cbe.berkeley.edu/
- The six primary factors for thermal comfort according to ASHRAE Standard 55:
  - Metabolic rate
  - Clothing insulation
  - Air temperature
  - Air speed
  - Humidity
  - Radiant temperature

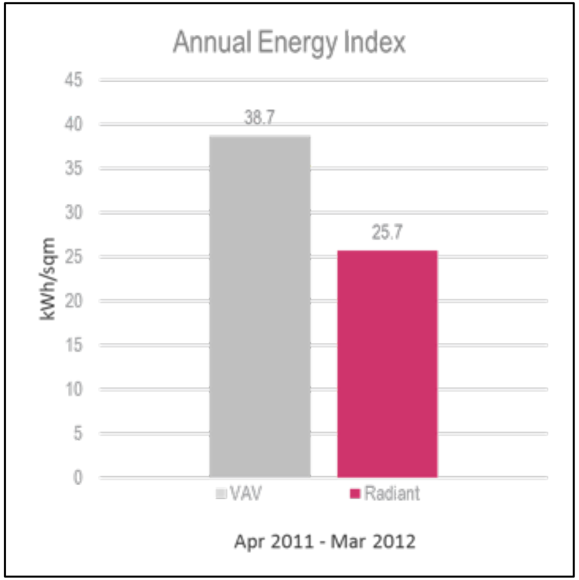


Project profiles

Radiant cooling with hybrid radiant/ventilation systems

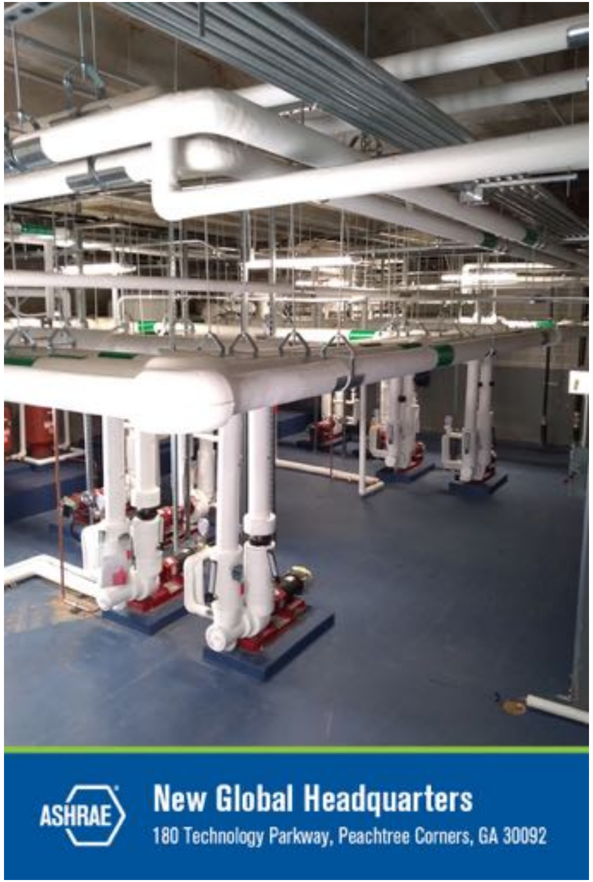
- Radiant cooling panels address the sensible loads well
- DOAS systems address latent loads well
- ASHRAE Standards 55 and 62.1 set ideal boundaries for temperature and indoor air quality to maximize the benefit of radiant cooling, **without fear of condensation**

Infosys SDB1
“The radiant cooling system was 33% lower in energy consumption compared to the conventional air-conditioning system.”
-ASHRAE Journal, May 2014



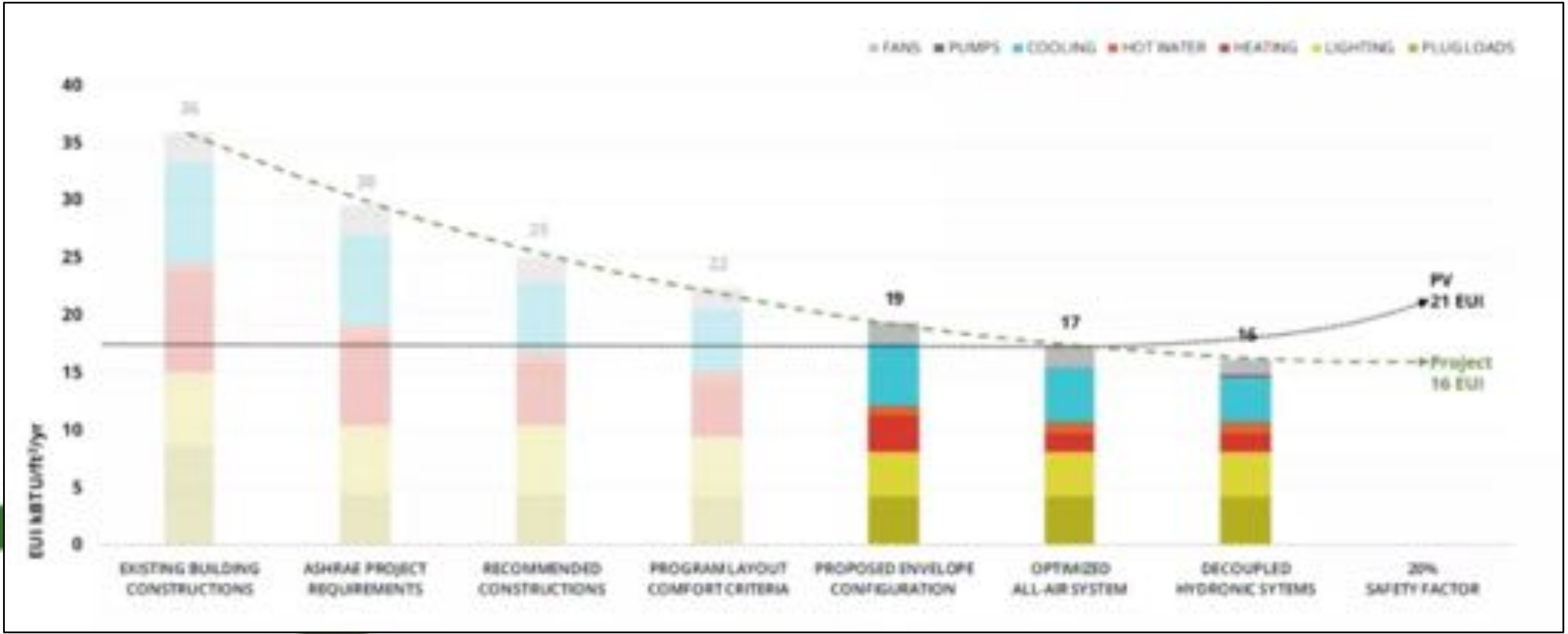
Case study – ASHRAE HQ

- Constructed during COVID-19
- Reached net-zero status with addition of solar PV in 2021
- Retrofit, originally constructed in 1978
- https://www.ashrae.org/about/the-building-project



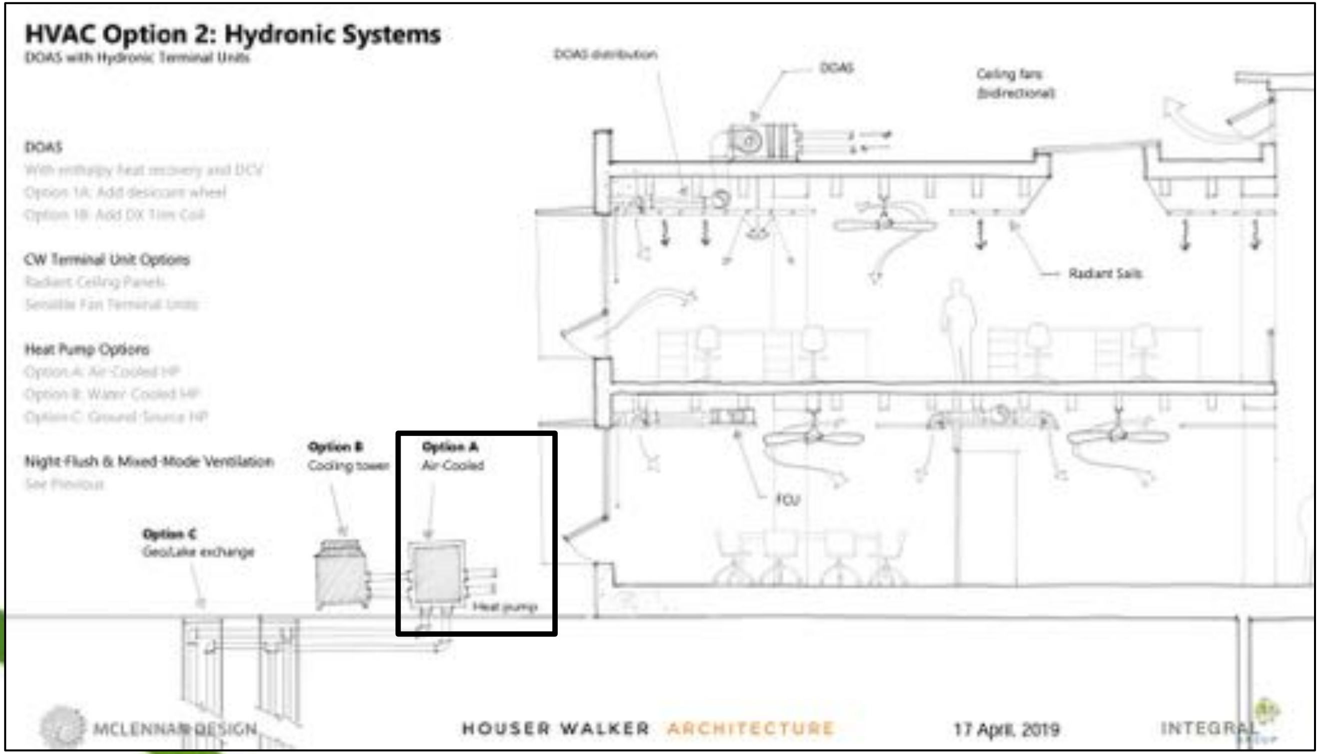
Energy modeling

- Many options evaluated, eleven modeled
- Two system types were finalists: An all-air, thermodynamically zoned air source heat pump, and a hydronic with radiant cooling



Hydronic system concepts

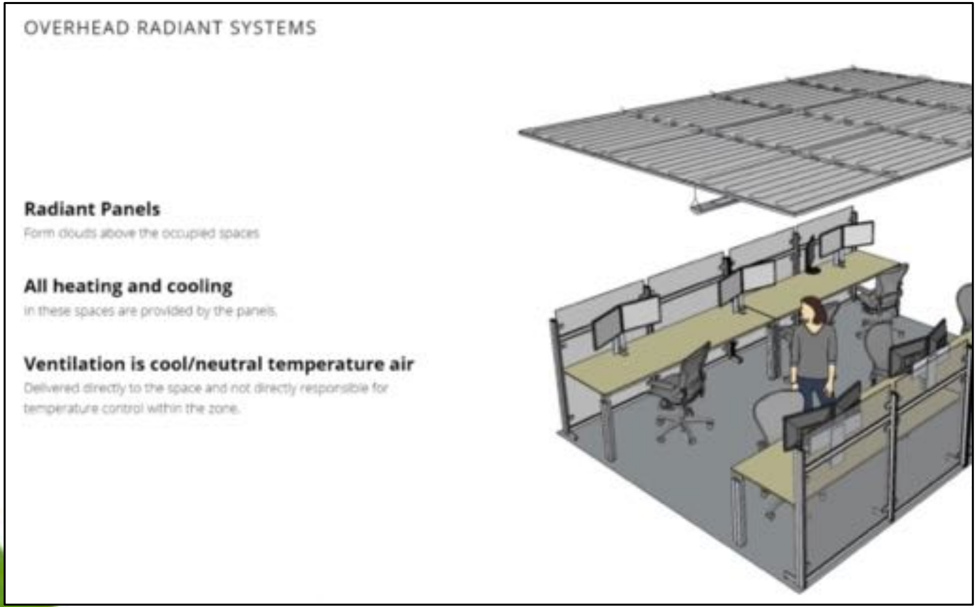
- Air cooled heat pump chiller
- Radiant ceiling panels



Hydronic system concepts

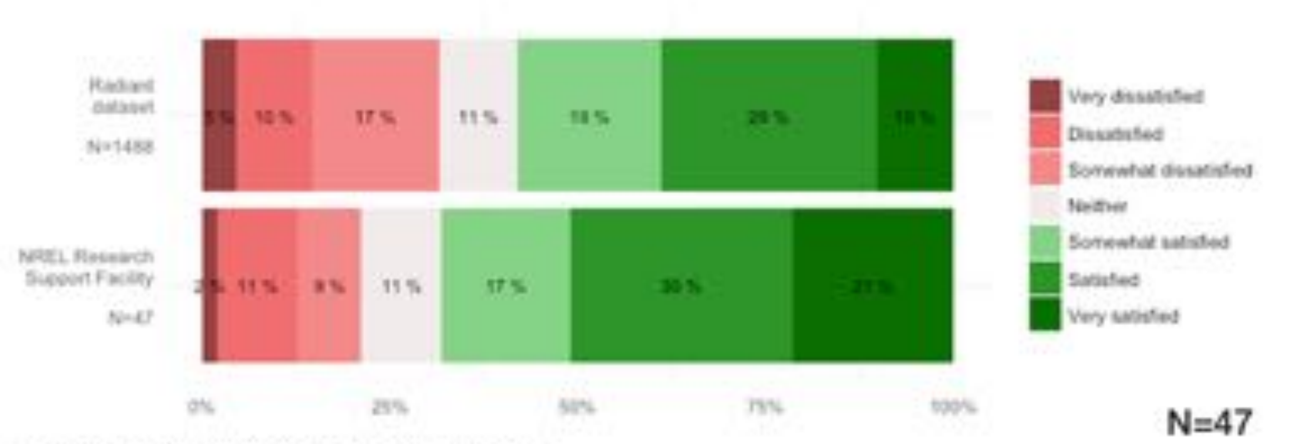
Stanton Stafford, Managing Principal, Integral (Introba) Group

- Radiant was more expensive
- "ASHRAE made the decision that they wanted to show a forward thinking approach to the industry, showing that we could put in a different system type, an unconventional system type for the US market, perfectly viable, something we could use in warm, humid climate."



National Renewable Energy Laboratory (NREL)

- 222,000 square feet in Golden, CO (ASHRAE climate zone 5B)
- TABS radiant heating and cooling covering over 75% of the conditioned floor area
- Natural ventilation and a DOAS for latent loads
- EUI of 36
- https://newbuildings.org/wp-content/uploads/2017/09/Radiant_NREL_FINAL.pdf



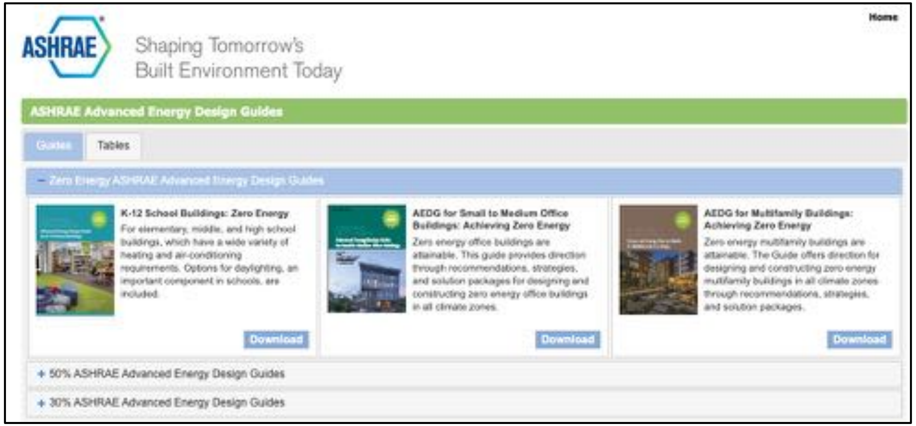
Occupant thermal comfort feedback for the RSF

Whisper Valley Planned Community

- 7,500 net-zero ready homes in phased development outside Austin, TX
- 237 geoexchange vertical ground loops, connecting a network of homes. Each residence has a water/air heat pump and is solar PV ready.
- Provide homeowners a tax credit of 26%, claim to reduce heating and cooling costs by more than 50%
- https://www.whispervalleyaustin.com/

Resources

- *ASHRAE*, Zero Energy AEDG Free Download:
https://www.ashrae.org/technical-resources/aedgs/zero-energy-aedg-free-download
- *New Buildings Institute*, Radiant Solutions: Energy Findings from the Largest Study of Commercial Buildings with Radiant Cooling and Heating System:
https://newbuildings.org/resource/energy-findings-from-the-largest-study-of-commercial-buildings-with-radiant-cooling-and-heating/
- *Center for the Built Environment*: ASHRAE-55 Thermal Comfort Tool
https://comfort.cbe.berkeley.edu/



Summary

- Define zero energy building
- Why hydronics?
- Distribution efficiency
- Adaptability for future energy sources
- Radiant cooling
- Case studies

Questions?

THANK YOU

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