2024 PROJECT PEER REVIEW

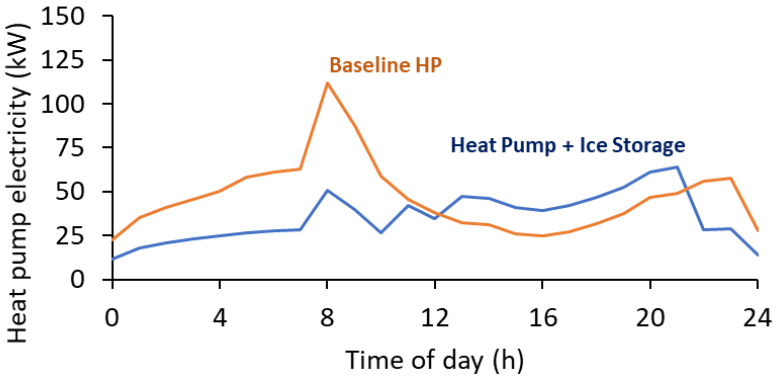
U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review: Ice storage for efficient and flexible decarbonization of hydronic space heating

Material in this presentation includes unpublished and/or preliminary data and analysis that is subject to change.



Ice storage for efficient and flexible decarbonization of hydronic space heating





NREL
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WBS 3.2.2.56

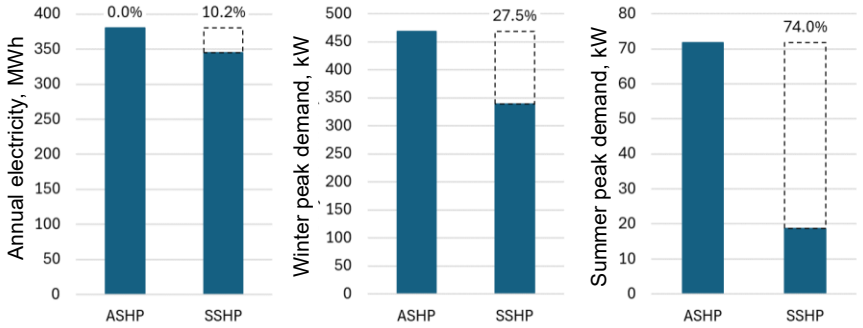
Project Summary

Preliminary results

OBJECTIVE, OUTCOME, & IMPACT

This project will develop optimal sizing and control for a storage source heat pump (SSHP), which uses ice storage for both heating and cooling. It will demonstrate the efficiency and load shifting potential with modeling and hardware-in-the-loop experiments.

The outcome will be a clear path for deploying these systems in buildings, providing low-carbon heating and cooling.



TEAM & PARTNERS

National Renewable Energy Laboratory
Trane Technologies

Advisory Group of HVAC design engineers, electric utilities, school facility managers, and community based organizations (see “Team and Advisory Group” slide in Appendix)

STATS

Performance Period: 01/01/2023-12/31/2025

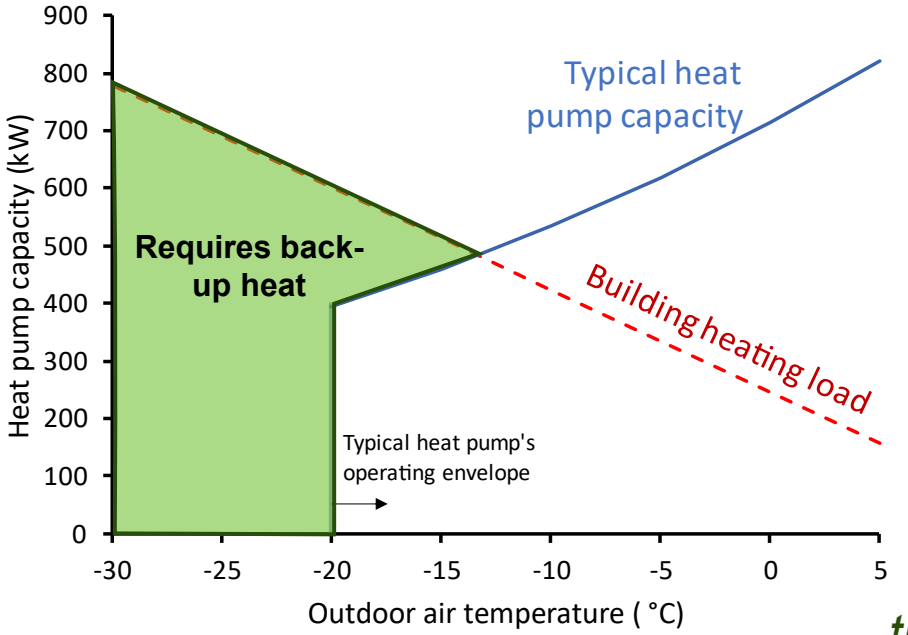
DOE budget: $1,400k, Cost Share: $150k

Milestone 1: EnergyPlus model shows 10% energy savings and 25% load reduction (prior to optimization)

Milestone 2: Optimal system size and controller operation determined for chosen use case. Target of >20% energy savings and >50% peak demand reduction

Milestone 3: Hardware-in-the-Loop experiment showing system operation and integrated supervisory controller.

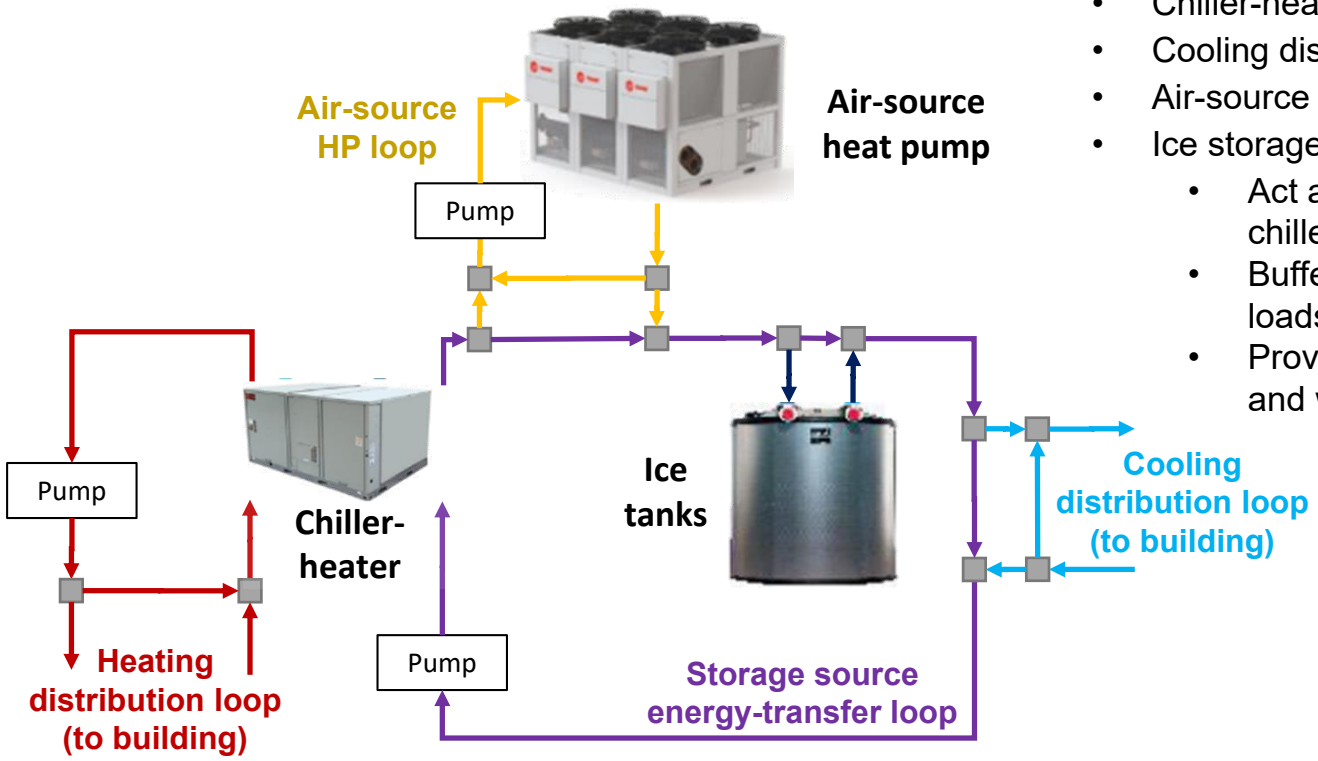
Problem: As ambient temperature drops, heating load goes up, but heat pump capacity goes down



- This mismatch means we use inefficient electric resistance heat, with higher emissions, grid impact, and utility costs.
- We can avoid this problem by not absorbing heat from outdoor air:
  - Option 1: Ground-source heat pump (use the ground as the heat source, which is warmer than the air)
  - **Option 2: Storage-source heat pump** (use previously stored heat as the heat source, which is warmer than the air)

this project

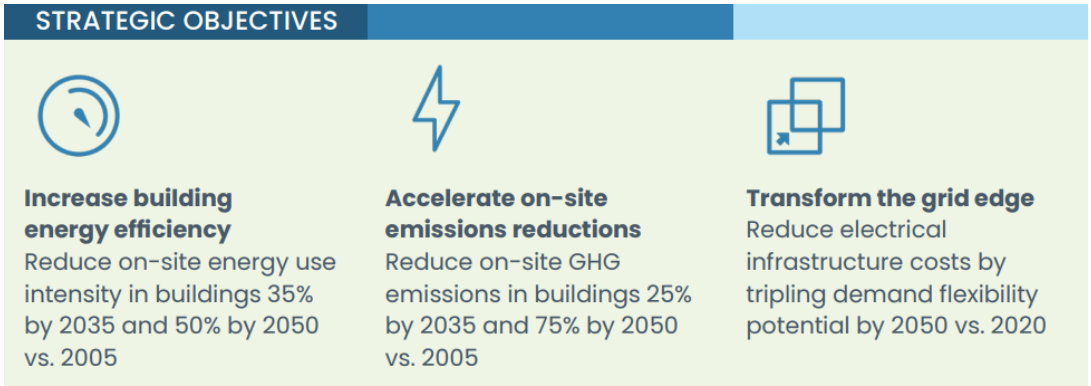
What is a storage-source heat pump?



Storage source loop connects to:

- Chiller-heater (heat sink)
- Cooling distribution loop (heat source)
- Air-source heat pump (heat source/sink)
- Ice storage tanks, which:
  - Act as an energy source for the chiller heater evaporator
  - Buffer between heating and cooling loads, increasing energy recovery
  - Provide load shifting for both summer and winter

Alignment and Impact

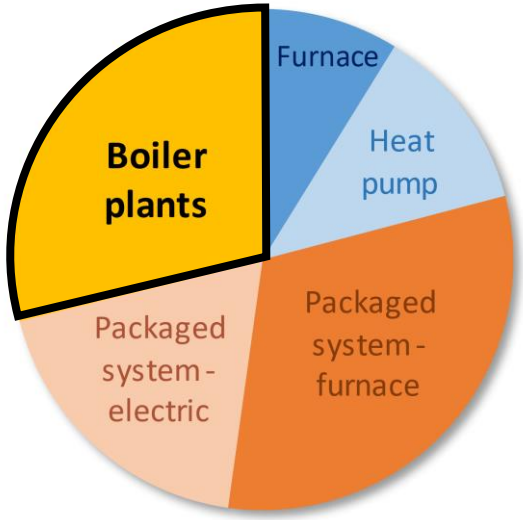


Storage enables flexibility
(**Goal: 50% peak shaving**)

Supports electrification by mitigating challenges of heat pumps in cold climates
(**Goal: system's cost of ownership is less than a gas boiler**)

Reducing the use of electric resistance heat, and increasing energy recovery will improve efficiency
(**Goal: 20% lower electricity use**)

Alignment and Impact



U.S. commercial building heating system by floor area

- 30% of commercial-building floorspace is heated with a boiler, most often natural gas. This solution is applicable to these situations.
- In this project, we are focused on secondary schools, which are common across all communities.

https://www.eia.gov/consumption/commercial/data/2018/

Approach

Outcome 1: A design and optimal control strategy for this heating and cooling plant with ice storage

Outcome 2: Demonstrated efficiency, load shifting potential, and optimal controls with real equipment and supervisory controller

Develop modeling platform for ice storage for heating and cooling

- Create new model in EnergyPlus for a heating and cooling plant with ice storage
- Leverage Python user-defined components

Develop optimal control

- Develop a model-predictive control (MPC) algorithm to find the optimal dispatch for ice-storage heating and cooling central plant

Perform hardware-in-the-loop experiments

- Demonstrate load flexibility and efficiency in both heating and cooling operation, and validate modeling
- Demonstrate supervisory control using MPC

Building energy modeling



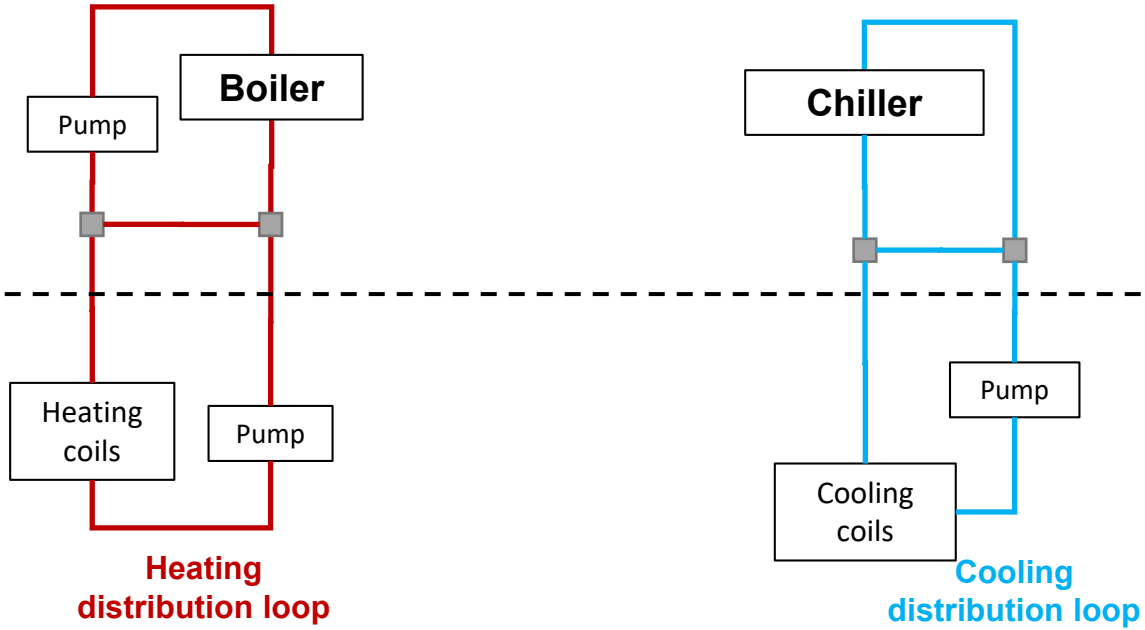
In this project, we are creating a digital representation of the system in EnergyPlus, which we can use to optimize the design and and controls.

Developing this in EnergyPlus will allow Trane and other stakeholders to model and evaluate this technology for different buildings, utility rates, and climates.

Typical EnergyPlus plant loop configuration

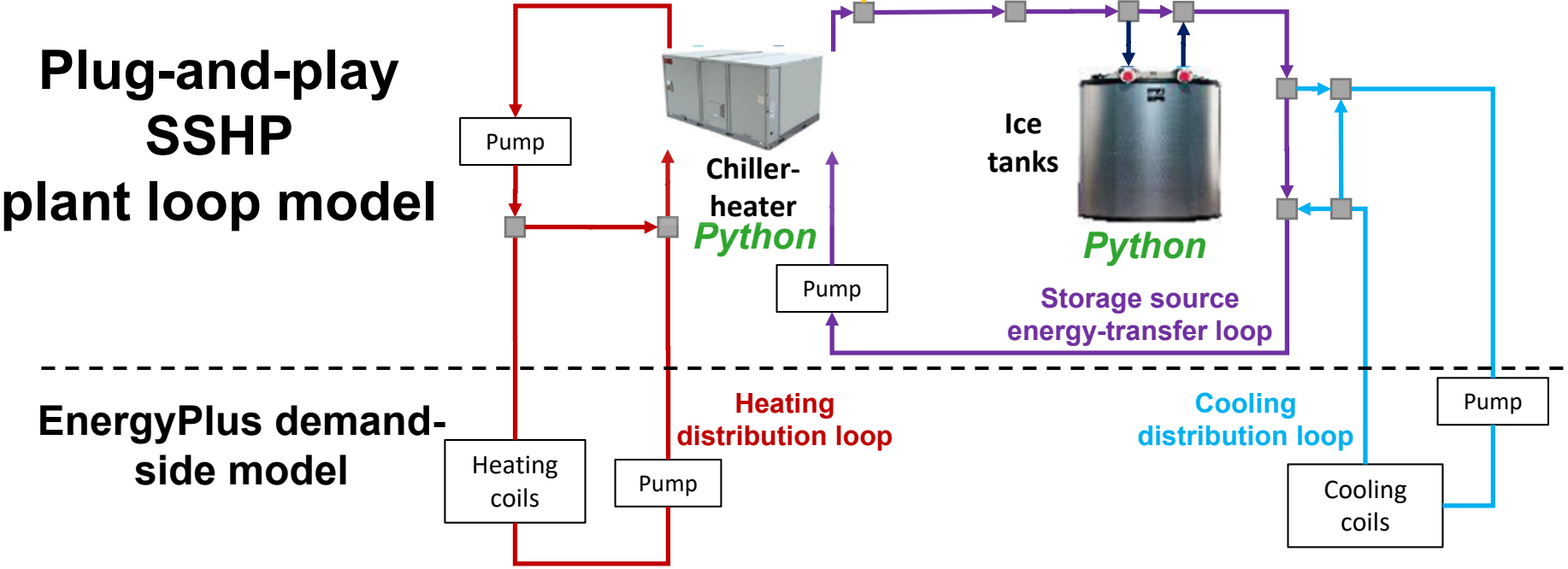
EnergyPlus Plant loop model

EnergyPlus demand-side model



This custom plant loop can easily be connected to different building models that use hydronic loops

Plug-and-play SSHP plant loop model



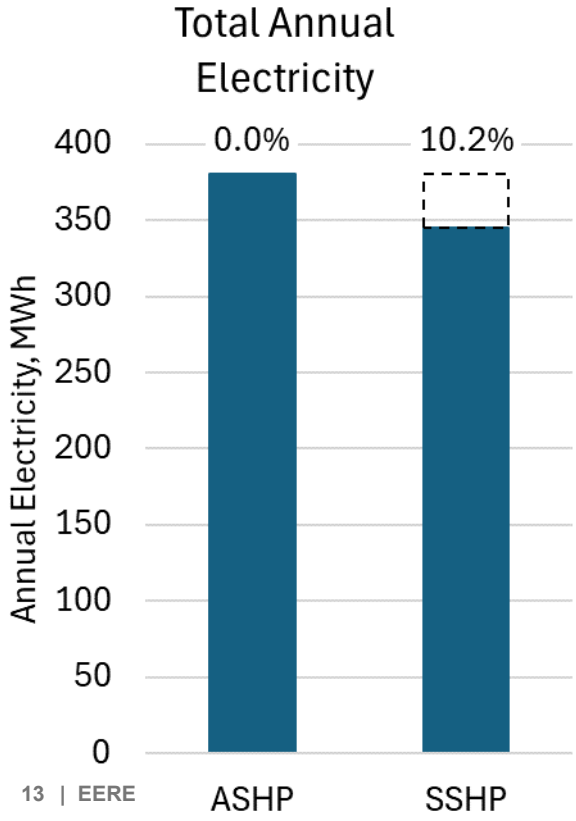
EnergyPlus demand-side model

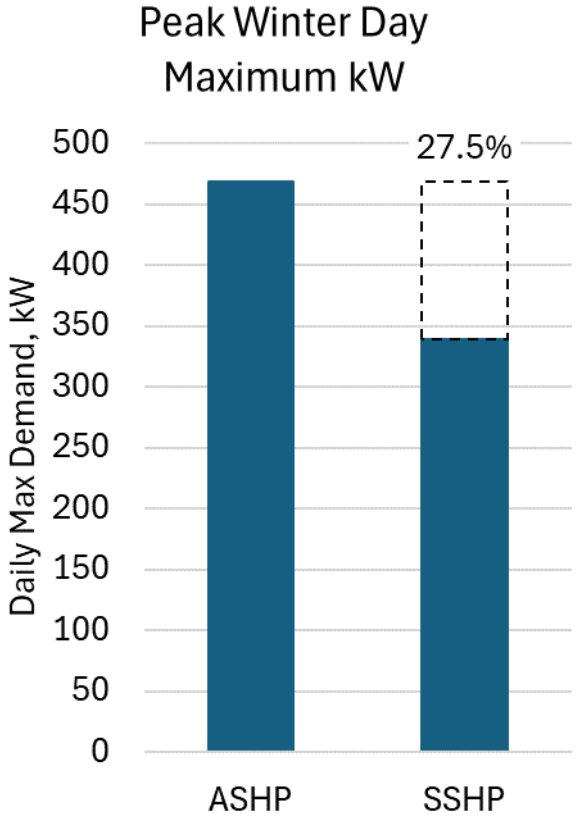
System modeling: SSHP compared to two baselines

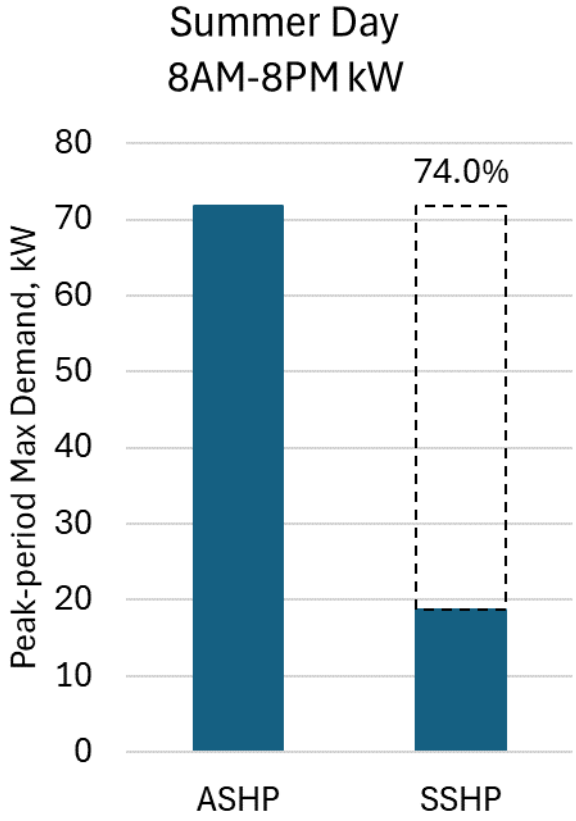
- Scenario
  - Secondary school of 210,000 ft^2 in Denver, CO
- Business as usual
  - Hydronic system with natural gas boiler (heating) and air-cooled chiller (cooling)
- All-electric options
  - Hydronic system with air-source heat pump (heating) and air-cooled chiller (cooling)
  - Hydronic system with a storage-source heat pump (SSHP) for both heating and cooling

Preliminary results

Year 1 savings Goal:
Reduce electricity use by 10% and demand by 25%

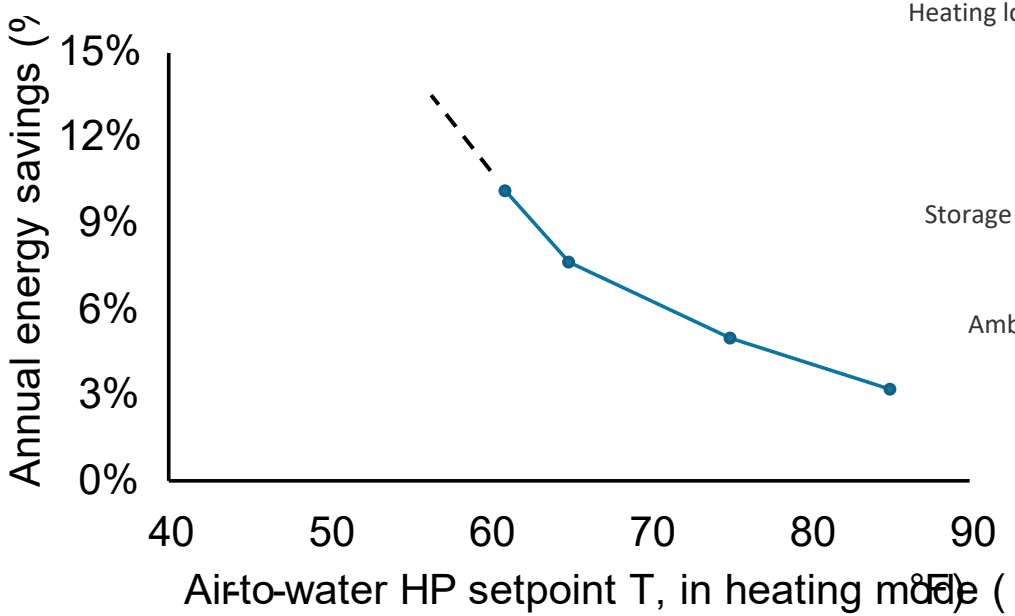


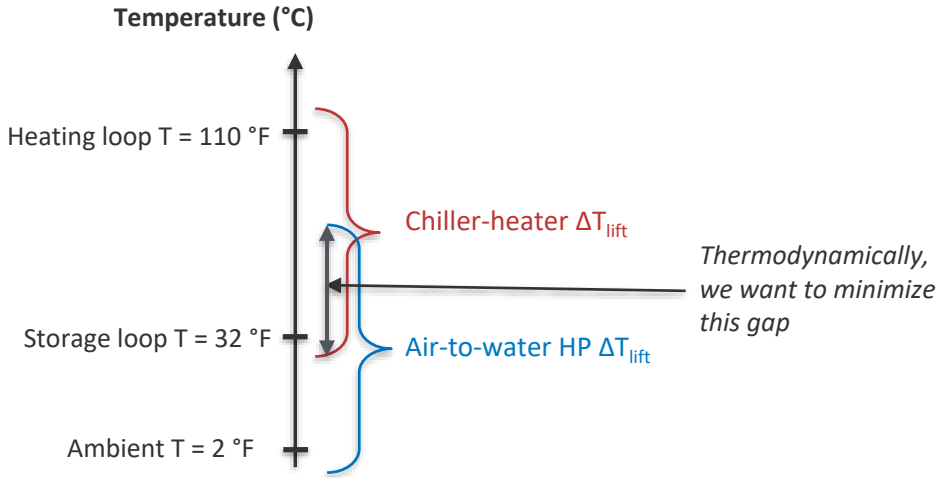




Lowering air-to-water HP setpoint temperature can increase electricity savings

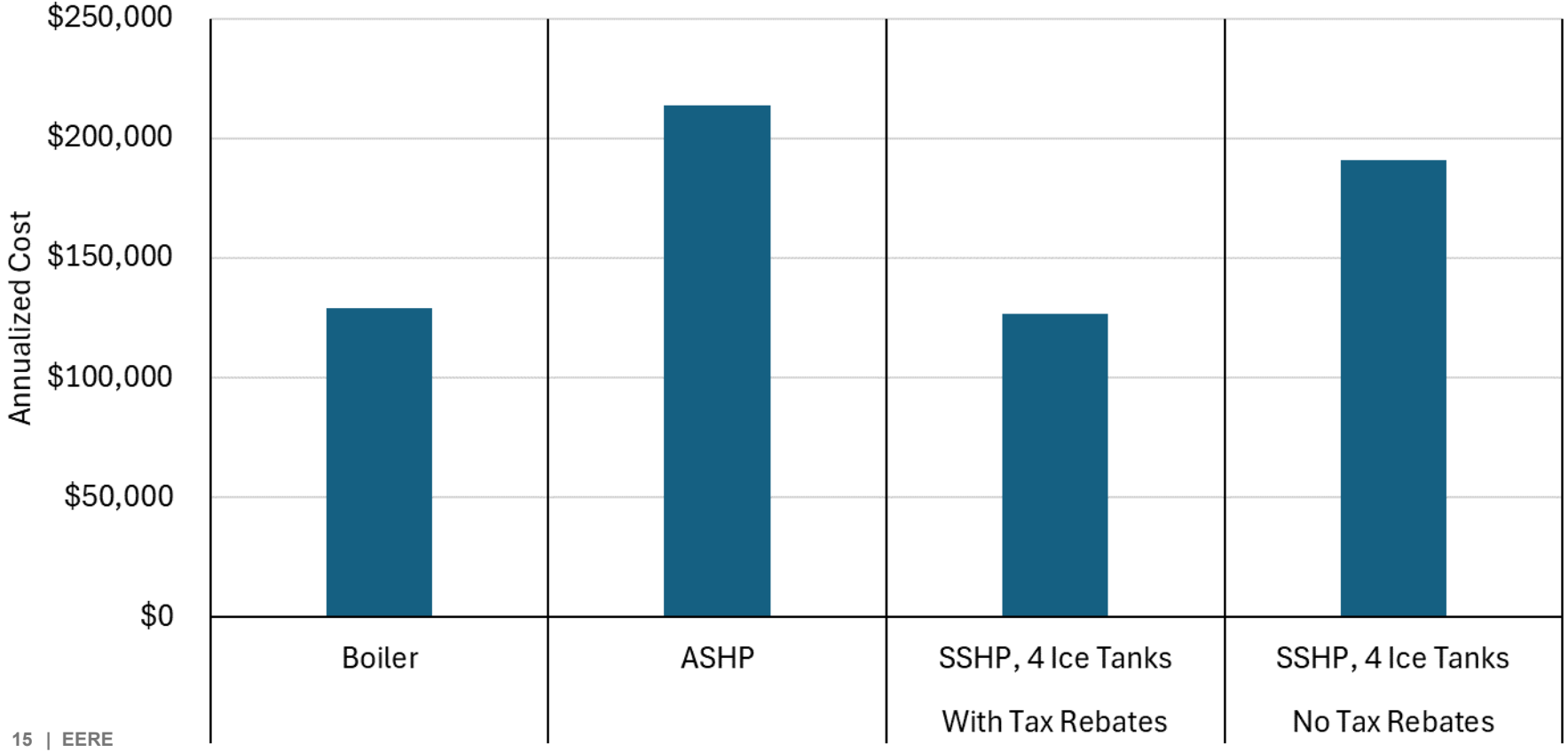
Existing Trane air-to-water HPs are not designed to operate below 60 F supply T. Adjustments to this equipment will increase savings.





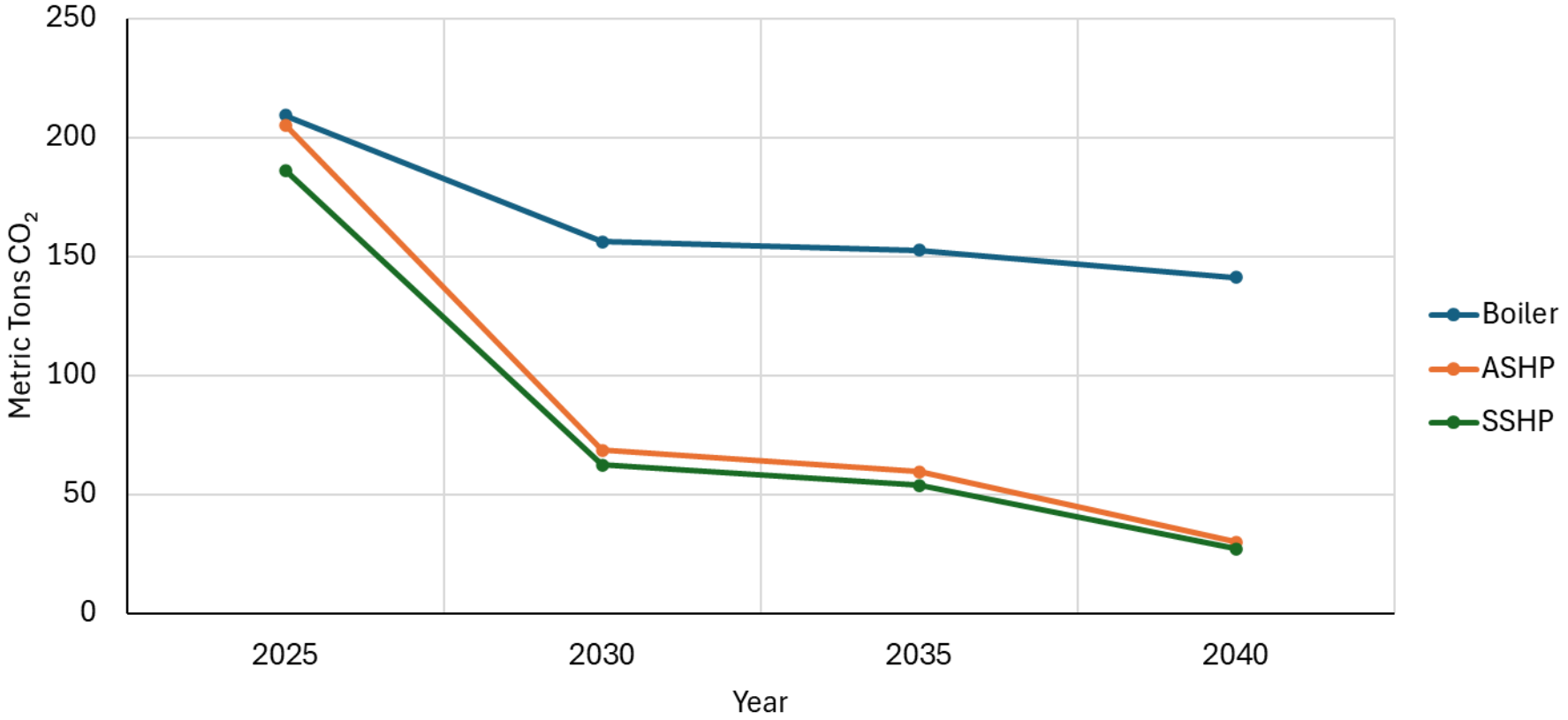
Preliminary results

Cost Comparisons

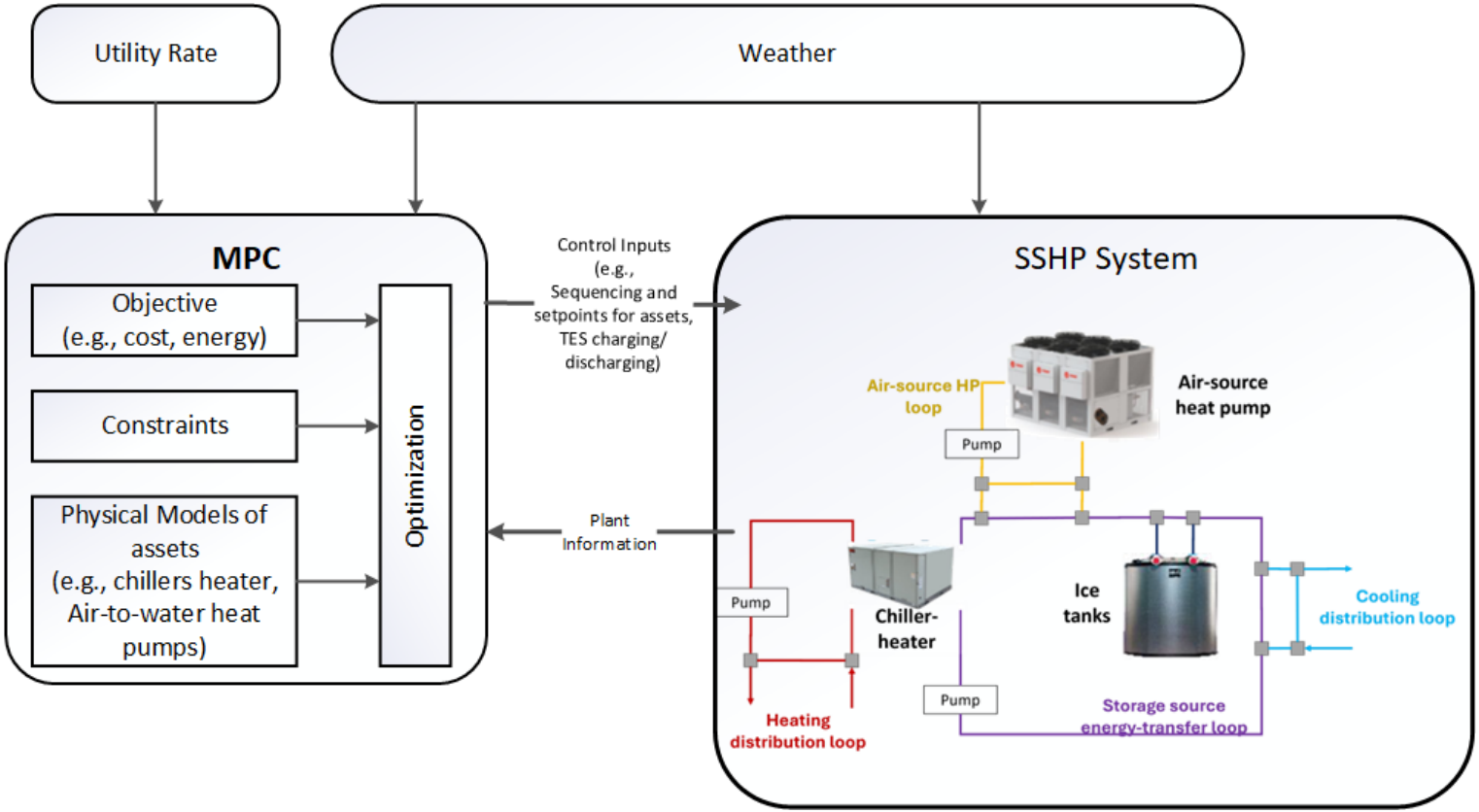


Preliminary results

CO_2 Emissions



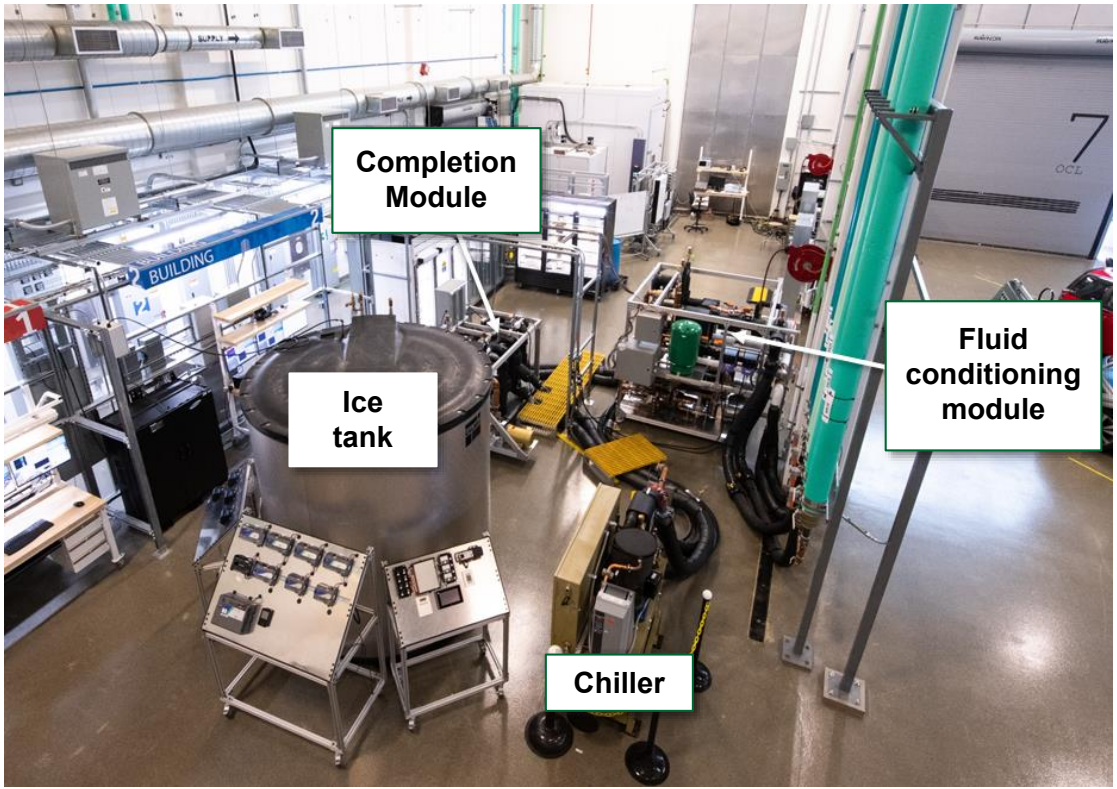
Future work: Model predictive control



Future work: hardware-in-the-loop experiments

- Existing equipment at NREL laboratory is designed for cooling operation

- We will update this to enable heating operation
  - This also provides insight on the steps required for converting a central chiller plant to a central heating + cooling plant



Thank you

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Reference Slides

Project Execution

	FY2023				FY2024				FY2025				FY2026			
Planned budget	$300k				$470k				$230k				$400k			
Spent budget	$400k				$0k				$0k				$0k			
		Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work																
Q1: Component model implementation plan selected			◆													
Q2: Advisory group formation				◆												
Q3: System configurations determined for further analysis					◆											
Q4: System configuration in EnergyPlus complete						◆										
Q5: System model simulations and Preliminary Techno-economic Analysis complete (**Go/No-Go**)							◆									
Q6: Model predictive control algorithm established								◆								
Q7: Lab measurement and control points determined								◆								
Current/Future Work																
Q9: Optimal TES size and control results (**Go/No-Go**)								◆		◆						
Q12: Component-level control implemented in lab													◆			
Q13:MPC implemented in lab's supervisory controller													◆			
Q15: Finalize commercialization and demo plan for LMI communities															◆	
Q16: Hardware-in-the-Loop experimentation complete																◆

Team



Jason Woods

Sr. Research Engineer

PI



Eric Bonnema

Sr. Research Engineer

Building Modeling



Venkatesh Chinde

Research Engineer

Model Predictive Control



Kelsea Dombrovski

Community Energy Researcher

Stakeholder Engagement

Team and Advisory Group

Trane Technologies:

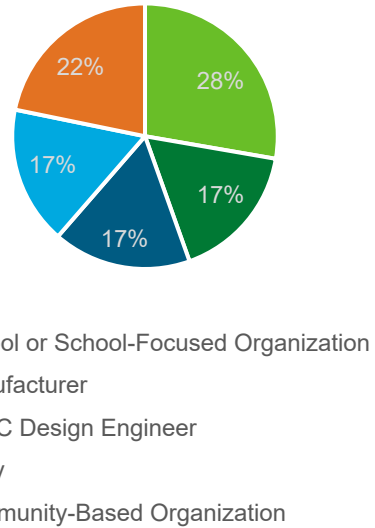
Trane is supporting this project through:

- Provided equipment datasheets for modeling
- Co-developed two of the custom python models with NREL
- Developing a commercialization and deployment plan for this technology
- Modifying NREL's existing equipment, and updating the controls software, to enable both heating and cooling operation

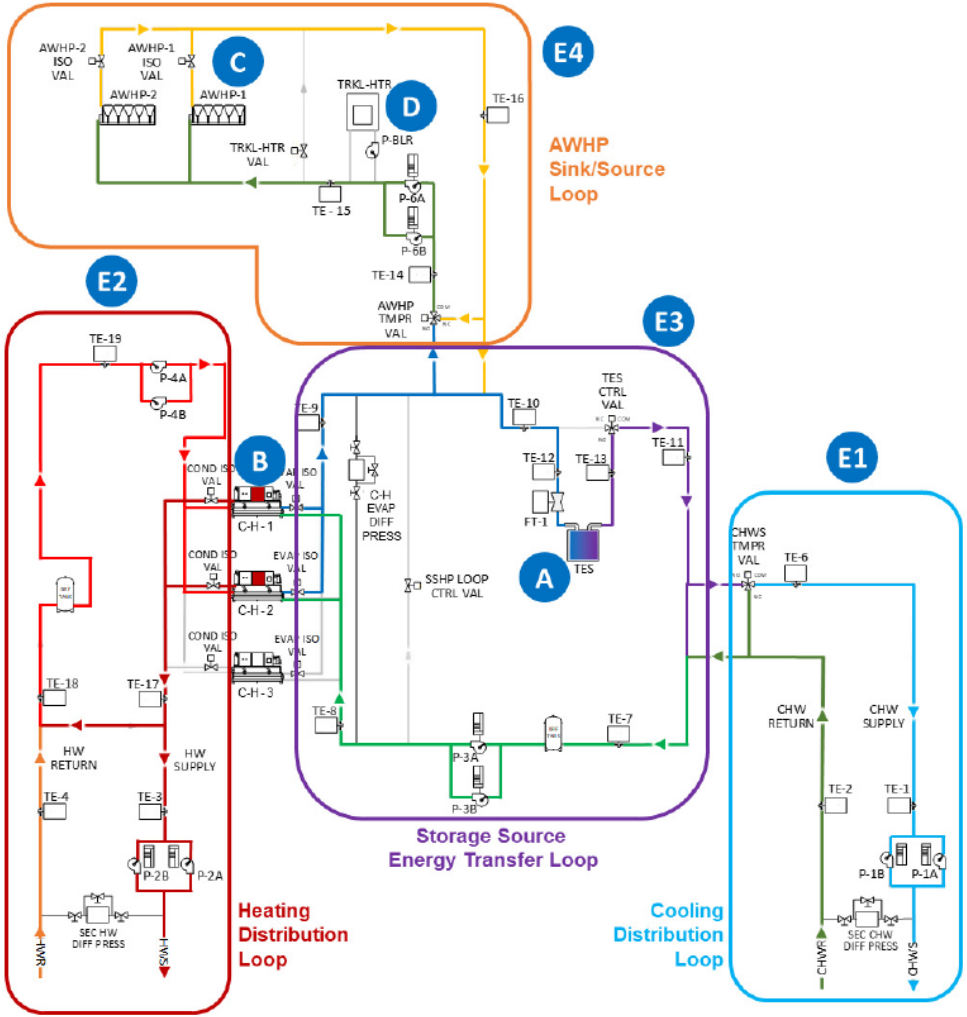
Advisory Group, 18 Members (to date):

- Chris Colasanti, Associate Partner – Deep Carbon Reduction, JB&B
- Mary Filardo, Executive Director, 21st Century School Fund and Consortium Partner, The National Center on School Infrastructure
- Kristen Funk, Senior Director of Commercial and Industrial Energy, Minnesota Center for Energy and the Environment
- Josh Higgins, Director of Maintenance, Grounds, and Operations, Eaton School District
- Ed Jolly, Maintenance and Equipment, Adams 12 Five Star Schools
- Bruce Lindsay, Business Development Lead – Thermal Storage Systems, Trane Technologies
- Mark MacCracken, Vice President and CALMAC Portfolio Leader, Trane
- Dustin Meredith, Systems Portfolio Leader, Trane Technologies
- Shannon Oliver, Senior Project Manager, New Buildings Institute
- John Pantzke, Manager of Energy Services, Stearns Electric Association
- Andy Steiner, Senior Mechanical Engineer, KBSO Consulting
- Anura Energy (1 member, program manager)
- Energy Outreach Colorado (1 member, senior management)
- Horwitz, LLC. (1 member, mechanical engineer)
- Minnesota Center for Energy and the Environment (1 member, senior research engineer)
- National Council on School Facilities (1 member, school facilities professional)
- Xcel Energy (2 members, product developer and solutions engineer)

Advisory Group Industry Representation



Detailed SSHP configuration



Detailed SSHP configuration

Legend for prior slide:

A. Thermal Energy Storage (TES) The TES is both a heat energy source for heating and a cool energy source for cooling the building. They use the latent heat of water's change of state to store energy effectively and efficiently in a compact package.

B. Water-to-Water Chiller-Heaters (C-H) C-H's take energy recovered from the building cooling, AWHP unit(s) and/or the TES and provide elevated temperature heating supply water to meet the building heating loads.

C. Air-to-Water Heat Pumps AWHPs provide heating and cooling energy.

D. TES Trickle Charging Unit Trickle charging units are primarily electric boilers but any heating unit that can operate at extreme low OATs can be applied, such as low temp AWHP, geothermal heat pumps or fossil fueled boilers.

E. Four Key Hydronic Loops The four hydronic loops are to meet the diverse flow requirements of the various system components and enable efficient and simple system pumping energy optimization.

1. Chilled water variable flow distribution. This is a classic variable flow chilled water distribution system.
2. Heating water variable flow distribution. This is a classic variable flow heating water distribution system.
3. Storage source energy transfer loop. This loop provides flow control for the C-H units as well as the TES. It facilitates heating and cooling energy flow between the various system components. It also helps mitigate the impact of AWHP defrost cycles.
4. Air-to-water heat pump sink/source loop. This loop manages the flow and temperature to the AWHPs as well as trickle-heater boilers. It also is the external source and sink for charging and collecting energy for the TES system.