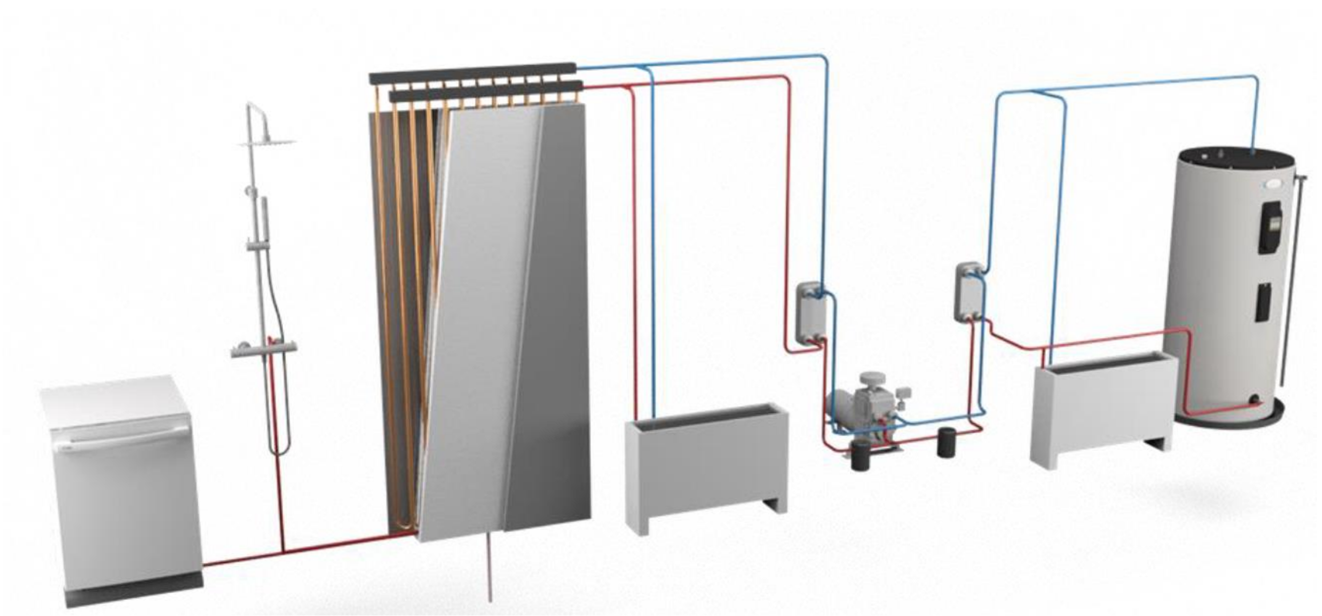
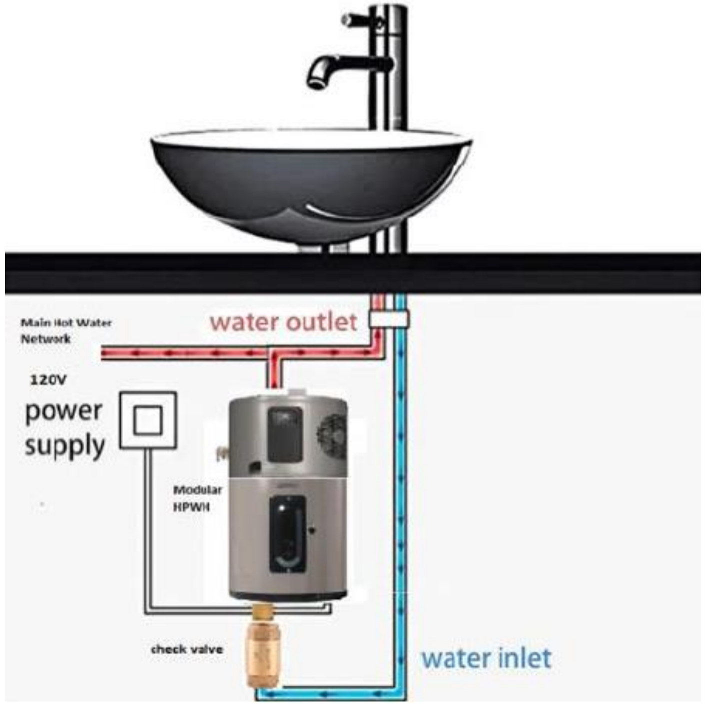
GEB by ME: Grid-interactive Efficient Buildings by Modular Design of Plug-and-play Equipment





Oak Ridge National Laboratory
Kyle Gluesenkamp, Senior R&D Scientist
gluesenkampk@ornl.gov
BTO WBS 03.02.02.54

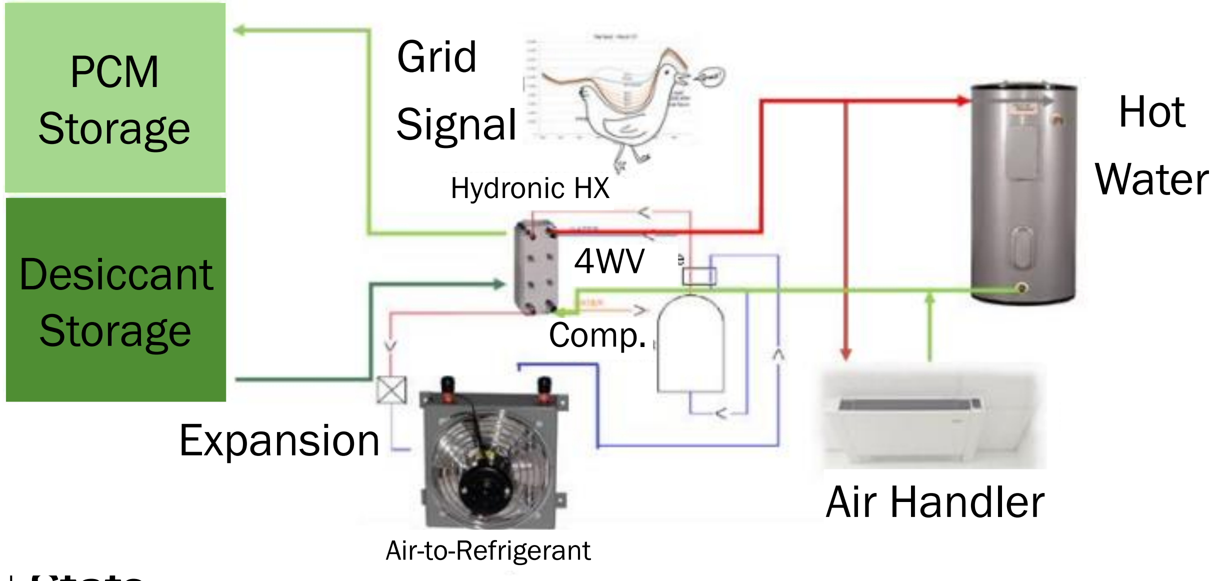
Project Summary – New Project! (Feb 2023)

Objective

- Develop and demonstrate a novel concept of modular plug-and-play equipment: a low-cost, easy-to-retrofit equipment system for the development of grid-interactive efficient buildings
- **Inform early-stage R&D** on designing next-generation equipment.

Outcome

- Catalyze the market introduction of a low-cost, easy-to-retrofit, easy-to-upgrade **ecosystem of modular equipment** for buildings
- Project deliverables: preliminary hardware prototypes and simulation results for plug-and-play equipment with grid integration
- 50% reduction in CO_2 emissions and 60% reduction in peak demand through an integrated system approach.



Team and Partners

- ORNL
- PNNL
- University of Maryland
- Melink ZERO
- NexTEMP Solutions (formerly GeoAire)

Stats

Performance Period: FY23–FY25

DOE budget: $2,250k Cost Share: $397k (15%TPC)

Milestone 1: Market and technology assessment (FY23)

Milestone 2: Modular modeling platform development (FY24)

Milestone 3: Modular heat pump water heater development, prototyping, laboratory verification (FY24)

Milestone 4: Modular, reversible hydronic heat pump development (FY25)

Milestone 5: Energy storage, water heating and waste heat recovery network demonstration (FY25)

Problem – Expensive and Siloed Equipment

- *Upgrading equipment HVAC and WH equipment is a major expense ($3.2k – 12.5k[1])*
- *Incremental upgrades are not possible*
- *Electrifying may require an electrical panel upgrade (often up to $3k[2])*

- *Split incentives: Renters are not incentivized to invest in HVAC improvements because the systems are integrated into the walls, floor, and attic, and can't be taken to their next home*

- *Current HVAC and WH systems do not communicate with each other or the grid*
- *Penetration of intermittent grid generation is difficult*

[1] American Society of Home Inspectors [2] https://www.thisoldhouse.com/electrical/reviews/cost-to-upgrade-electrical-panel

Alignment and Impact – Lower Cost & Grid Integration

The project responds to DOE BTO Emerging Technologies FY22 AOP Lab Call, topic 1C "Efficient Modular Smart Building Equipment." From the Call:

Description

- "develop an efficient **modular** smart building equipment system with grid integration capabilities"
- "inform **early-stage R&D**, accounting for energy and cost performance, and considerations across integration, use and installation."

Goal

- "provide a 50% reduction in CO2 emissions and 60% reduction in peak demand"
- "allow for easy and low-cost installation, **plug ang play**/grab and go modularity of components, easier retrofits, a **singular compressor/condenser unit**, and a low GWP refrigerant."

Explanation of Need

- "modular design enables flexibility in adding new grid-enabled equipment as it becomes available and addresses affordability through a **staged integration** approach."

Alignment and Impact – Lower Cost & Grid Integration

Accelerate Electrification

- Accelerates electrification of US residential sector by creating affordable solutions and offering more consumer choice through smaller equipment with low (or no) installation cost

Transform Building Equipment Options and Decarbonize the Grid

- Domestic water heating and space conditioning is responsible for 56.3% (US EIA 2022) of residential building energy usage
- Communicating residential water heating and HVAC energy use to the grid (GEB) makes renewable penetration easier

Diversity, Equity, and Inclusion

- Avoiding panel upgrades and lower first-cost equipment offers access to state-of-the art technology to a lower income households
- HVAC equipment that is DIY and modular incentivizes renters and multi-family residents to invest in better living quality technology

Approach – Novel Modular HVAC Ecosystem

New Modular *Product Ecosystem*

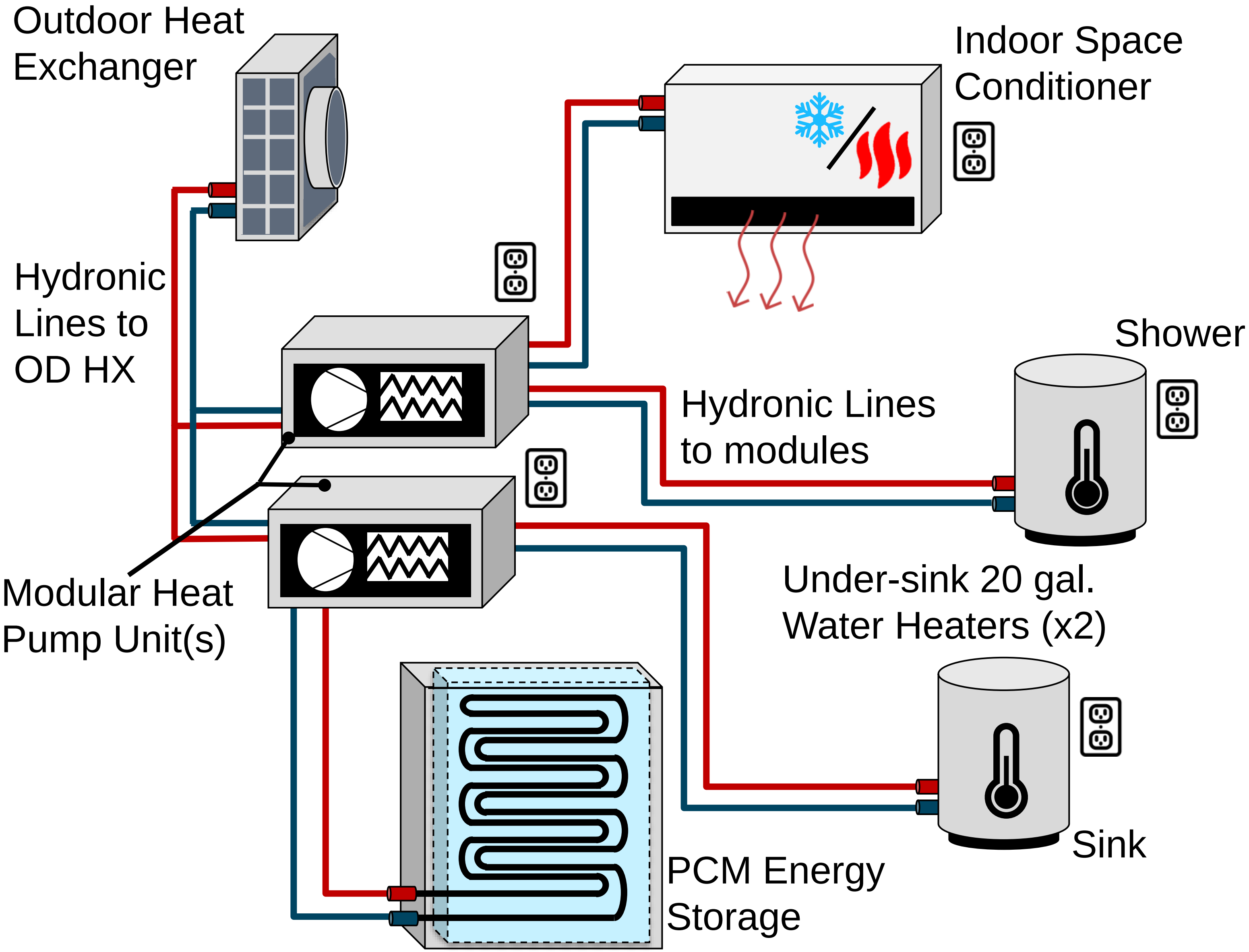
- Modular heat pump units create thermal energy interconnection
- Consumers can upgrade their HVAC system selectively without professional installation

Minimum Viable Ecosystem

- 1x Modular Heat Pump Unit
- 1x Outdoor Heat Exchanger
- 1x Indoor Unit (water heater or space conditioner)

Plug-and-play & Grab-and-go

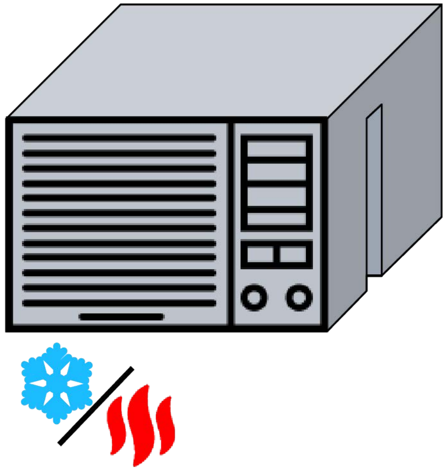
- 120 V power source like other consumer products
- Hydronic connections between units allow for DIY assembly/disassembly



Approach – All-encompassing HVAC technology

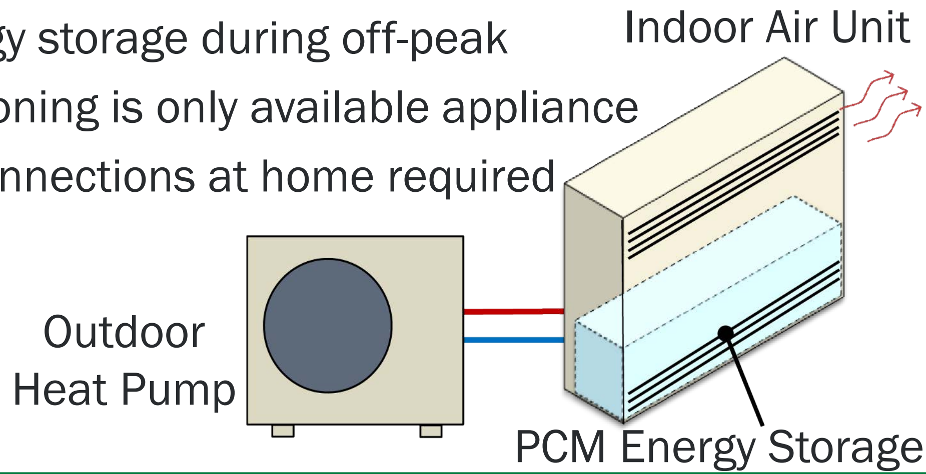
Packaged Window Heat Pump

- Cooling and heating window unit
- Space conditioning only
- No storage or GEB capability



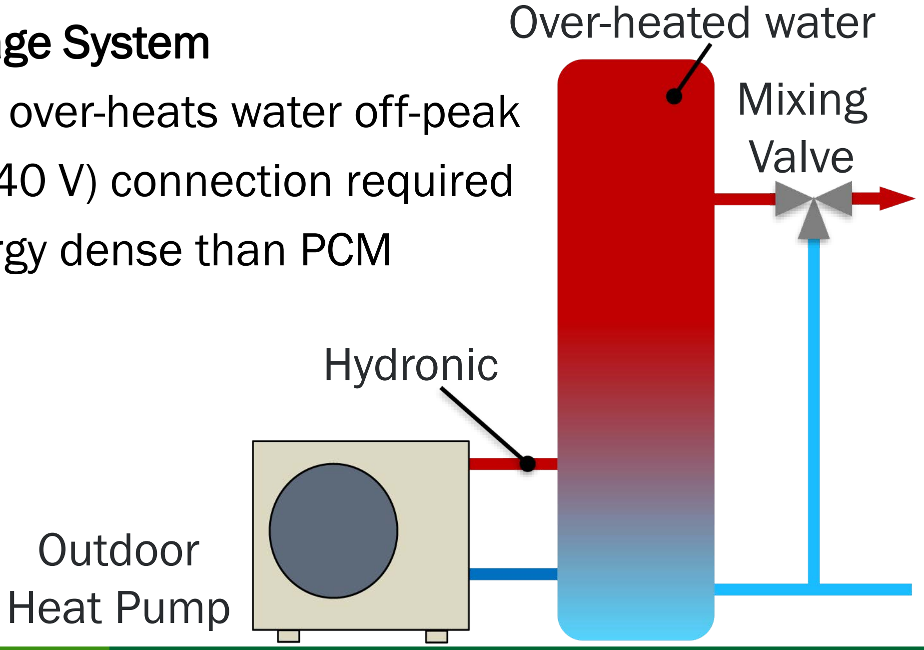
Thermal Storage Mini-Split Heat Pump

- Thermal energy storage during off-peak
- Space conditioning is only available appliance
- Refrigerant connections at home required



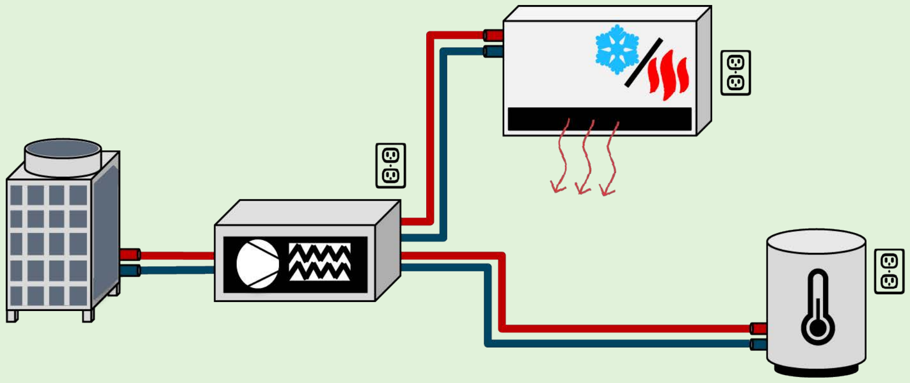
Water Heater Storage System

- CO_2 heat pump over-heats water off-peak
- High-voltage (240 V) connection required
- Water less energy dense than PCM

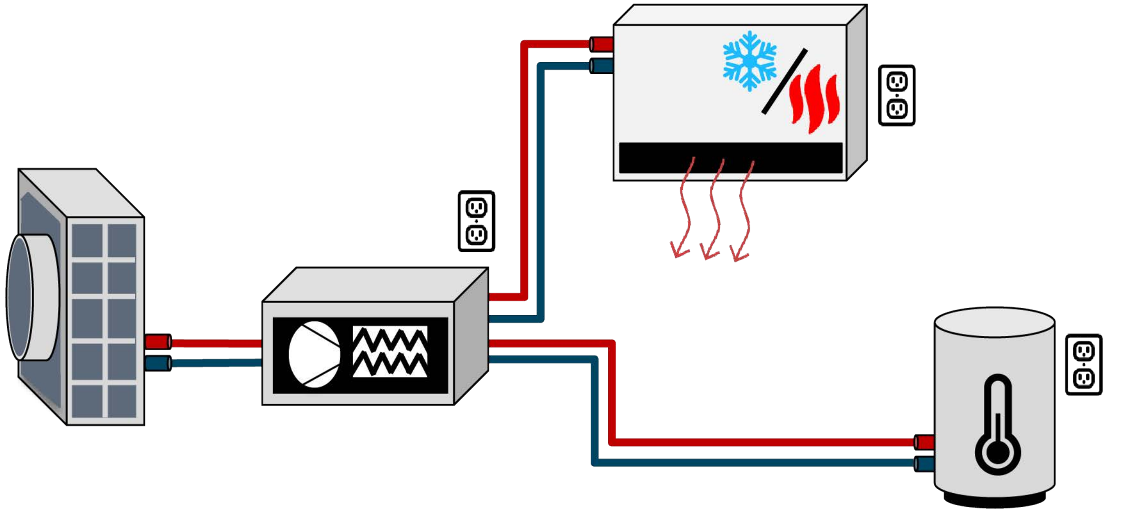


GEB by ME Ecosystem

- Multiple appliances
- Easy DIY 120 V and hydronic quick-connects
- Energy storage and grid-connected load shifting



Approach – Novel Cost Solution & Equipment Development



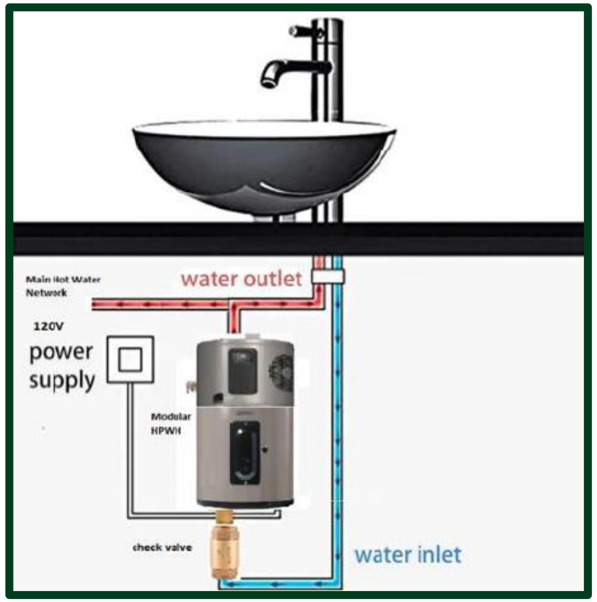
Lower Cost through Simple Installation

- DIY installation through quick-connect hydronics, plug and play/grab and go device ecosystem
- 120 V plug-in power for each module

Device Ecosystem

- Modular HVAC components communicate and work together
- Reversible heat pump integration with thermal energy appliances facilitates response to different appliance demands and grid signals

Modular 20-gal Heat Pump Water Heater



- Compact, modular 20-gal HPWH to provide instant hot water at use location, connected to main hot water network
- Focus on FHR (smaller tank) and low cost (market competitive)

Approach – Project Delivery

Water Heater Development

- Development and assembly of new modular 20-gal HPWH
- HPWH will be new technology; performance validation needed as Go/No-go milestone

Build Minimum Ecosystem

- Development and assembly of modular reversible heat pump and PCM storage
- Reversible heat pump is centerpiece of ecosystem, PCM storage is main load shifter
- Confirm sustained HPWH performance with heat pump and storage ecosystem

In-House Performance Testing

- Field demonstration of individual components in ORNL test home
- Field demonstration of final modular ecosystem in ORNL test home
- Development and validation of grid-responsive controls with ecosystem

Approach – Barriers, Challenges, & Mitigation

120V Compressor Availability

- Challenge: Compressor availability at selected size powered by 120 V may not be available on market
- Mitigation: Use a 240 V compressor for laboratory evaluation of HPWH and work with a compressor supplier and OEM in parallel to create new 120 V market

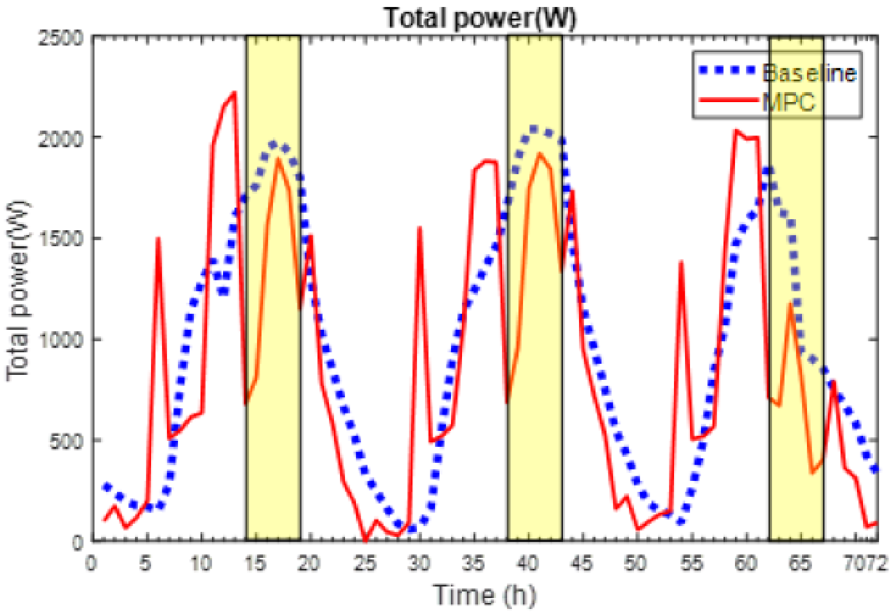
Water Heater Performance and Cost

- Challenge: FHR of 67 gallons for current NG storage water heaters difficult for HPWH to achieve; will need two 20-gal HPWH to meet
- Mitigation: Early Go/No-go evaluation stage to confirm feasibility

Approach – Demonstrating Benefit through End Use

ORNL Test Home

- Expected benefit will be demonstrated via simulation, with experimental validation in the laboratory evaluations and evaluation in ORNL test home
- Expected outcome is 50% reduction in CO2 emissions and 60% reduction in peak demand through an grid-efficient ecosystem approach
- Reduction in electricity bill similar to EnergyPlus Atlanta Model-Predictive Control (MPC) of a heat pump system with storage capabilities (23% reduction)



- **Three-day electricity cost:**
  - MPC control:
    Electricity bill = \$6.1406 (23.01% cost savings)
  - Baseline control:
    Electricity bill = \$7.9763

Approach – Market Engagement and Stakeholders

Market Impact

- Allow for low-cost installation and easy retrofit with plug-and-play modularity of components
- Result in a payback period shorter than 5 years due to the higher whole-house energy efficiency and easier installation

Market Engagement

- Will seek multiple stakeholder viewpoints on stakeholder needs and preferences, cost targets and affordability
  - ✓ *E.g., building owners/occupants, supply chain, retrofit workforce network, utilities, low-income programs and organizations*
- Will publish a market assessment of the modular equipment system

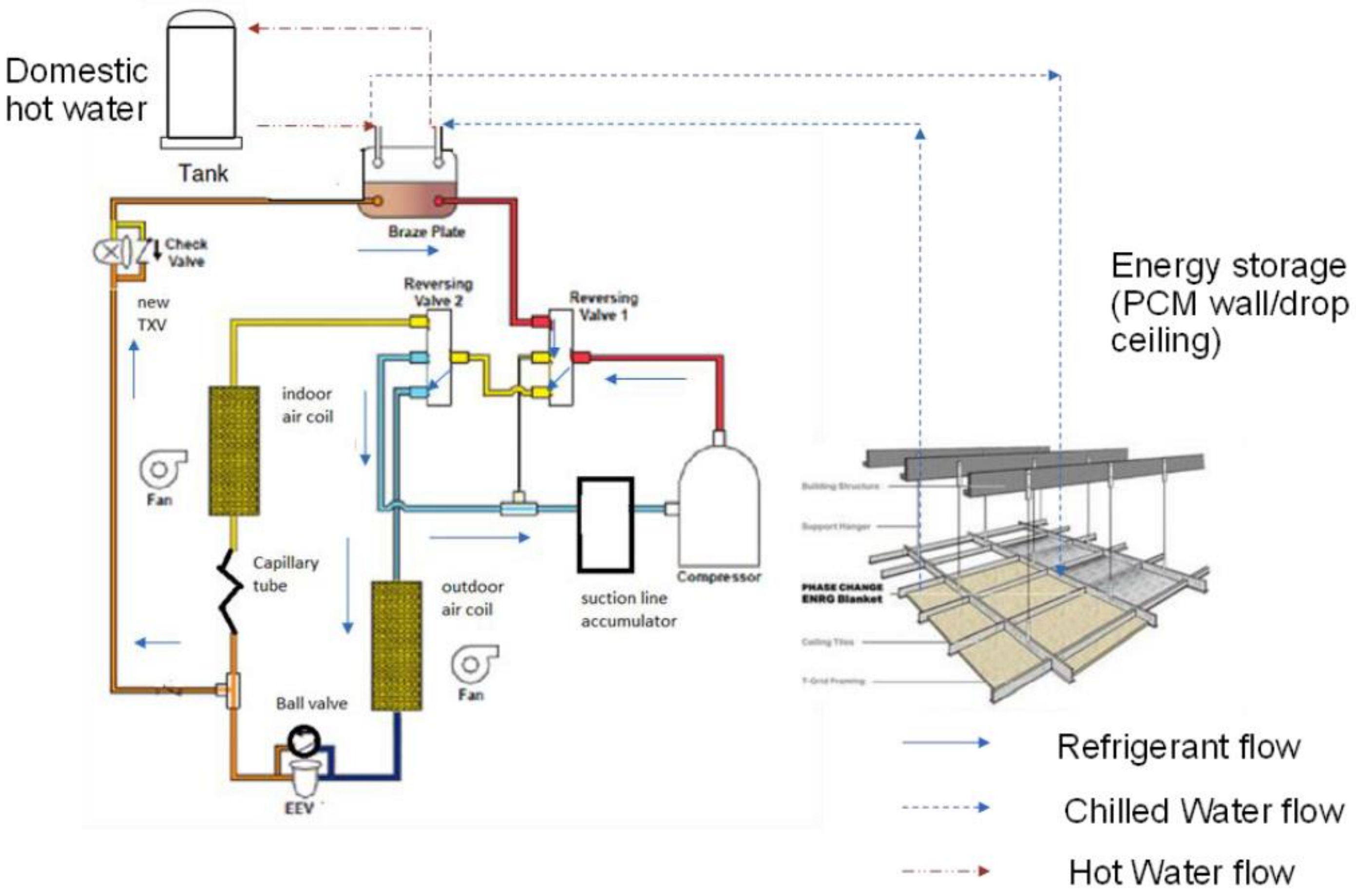
Progress & Project Beginnings – Related Previous Work

R290 Window AC

- 2017: ORNL developed window air conditioner using R290 (propane) under the maximum charge limit and with higher efficiency than existing commercially-available units

Heat Pump with Integrated PCM Storage (right)

- 2020-2022: ORNL developed multi-functional heat pump with hot water storage circuit to store energy in PCM walls/floors/drop ceilings



Future Work & End Vision

Project Tasks

1. Market and technology assessment of current technology and path forward
2. Modular modeling platform development with UMD
3. Modular heat pump water heater development, prototyping, and validation for hardware
   - Sizing and selecting compressor, heat exchangers, compressorized system components, storage tank
   - Goal of UEF > 3.3 and FHR > 30 gal per one modular 20-gal HPWH unit
4. Modular reversible hydronic heat pump development integrated with energy storage and water heater
5. Expand and evaluate reversible hydronic heat pump system with water heater, energy storage, and outdoor system addition
6. Grid-responsive supervisory agent-based modular controls development

Project to illustrate a vision for a new affordable HVAC product ecosystem

- Experimentally demonstrate proof-of-concept for novel modular plug-and-play HVAC equipment
- Develop modular controls that enable simple plug-and-play system operation
- Provide modular simulation platform for design and analysis support, and use for make performance predictions of large-scale deployment
- Publish a market assessment of the modular equipment system

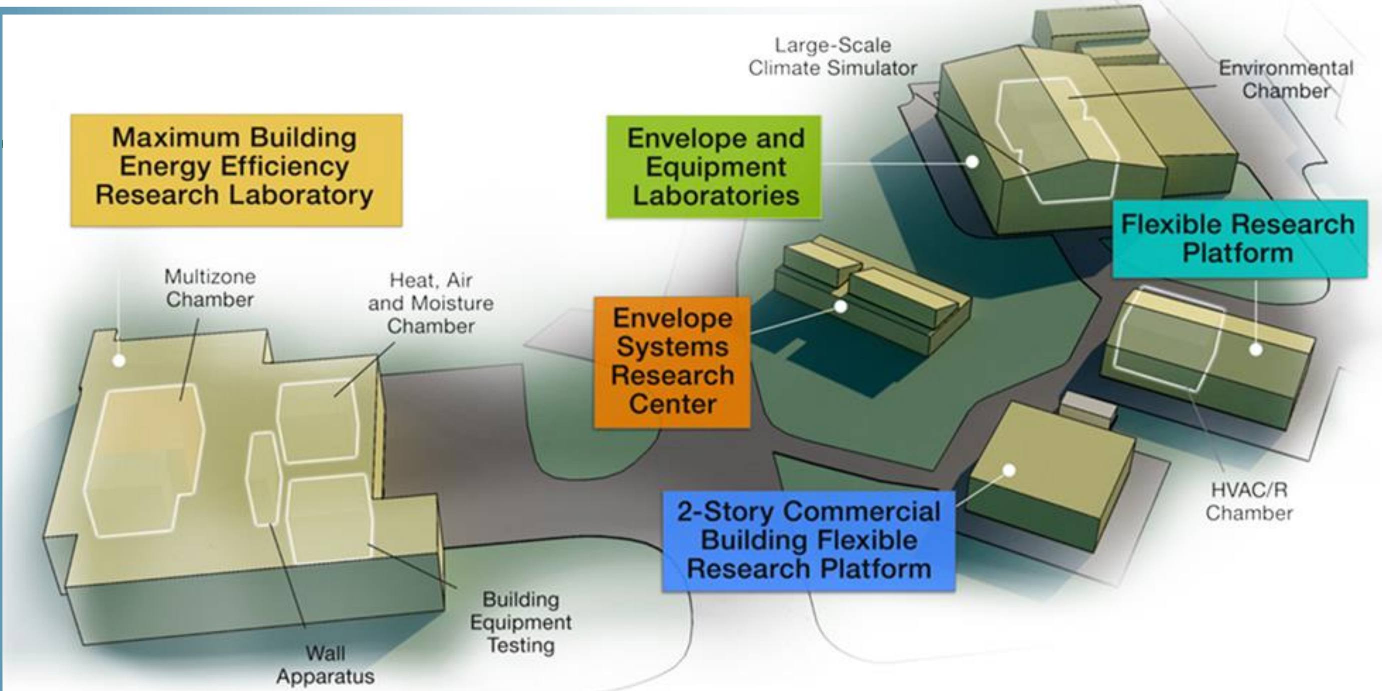
Thank you

Oak Ridge National Laboratory

Dr. Kyle Gluesenkamp,

Senior R&D Staff, Subprogram Manager for Thermal Energy Storage

(971) 221-9222 | gluesenkampk@ornl.gov



ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 60,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Execution

Project Start: February 2023

Task		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
1	Market and technology assessment												
2	Modular modeling platform development												
3	Modular heat pump water heater development, prototyping, laboratory verification.												
4	Modular, reversible hydronic heat pump development (energy storage and water heating), prototyping, laboratory verification.												
5	Expand the reversible hydronic heat pump to be an energy storage, water heating and waste heat recovery network, with an outdoor system addition.												
6	Grid-responsive, supervisory agent-based modular controls development												
7	Submission of final report												
Milestone													
1	Submit market and Technology assessment report												
2	Development of Modelica simulation platform for component level , system integration and optimization												
3	Assemble and instrument the modular HPWH prototype												
4	Laboratory performance evaluation verifies the performance goals, reaching a UEF > 3.3 and FHR > 30 gallons with running one modular HPWH					Go/No-Go							
5	Assemble and instrument the modular reversible hydronic prototype in environmental chamber and pass the shakedown test												
6	Laboratory performance evaluation verifies the performance goals, keeping the same HPWH performance metrics, storing cooling/heating energy in PCM storage tanks to sustain 60% peak hours and meet the load of a single bedroom									Go/No-Go			
7	Start field demonstration of a modular HPWH												
8	Start field demonstration of a modular hydronic heat pump												
9	Demonstrate the final modular home energy architecture in an ORNL's test home												
10	Design of local controls for both energy efficiency and grid responsiveness												
11	Design of supervisory coordination for equipment network												
12	Submit the project final report												

Team

Oak Ridge National Laboratory

Kyle Gluesenkamp (PI) – Conceptualization and Design, Project Management

Bo Shen: Hardware Design

Xiaobing Liu: Hardware Design and Industry Communication

Jamie Lian: Controls Design

Borui Cui: Controls & Storage Modeling

Zhenning Li: Model transitioning

Tugba Turnaoglu: PCM System Design

Sylas Rehbein: System Design, Experimental Design & Evaluation

Pacific Northwest National Laboratory

Michael Poplawski: Market Research

Anay Waghale: Market Research

Majid alDosari: Technology Assessment

Trisha Gupta: Technology Assessment

NexTEMP – Industry Partner

Cary Smith, Garen Ewbank, Garry Sexton, Paul Bony: control interface with BMS and equipment installation/operation

University of Maryland

Reinhard Radermacher: System Modeling

Daniel Bacellar: System Modeling

Vikrant Aute: System Modeling

Haopeng Liu: System Modeling

Melink ZERO – Industry Partner

Micah Zender, Roshan Revankar: validation of components