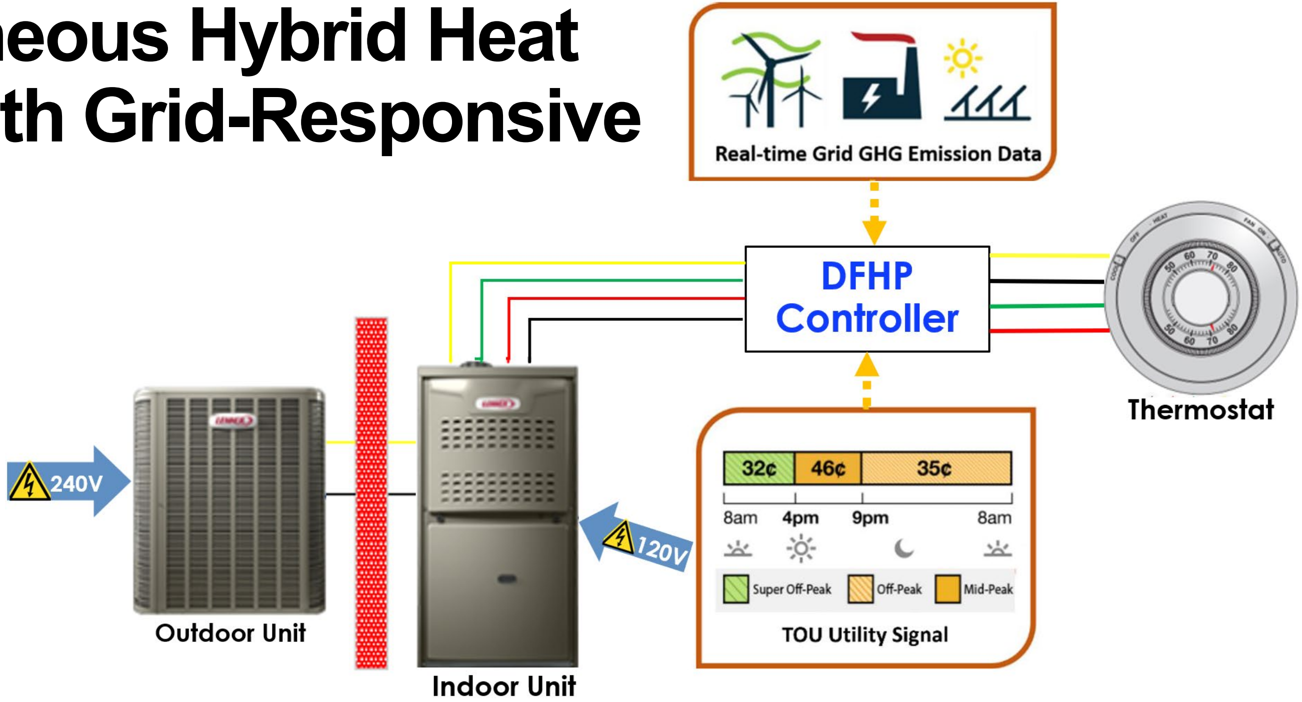
2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

Simultaneous Hybrid Heat Pump with Grid-Responsive Controls

Simultaneous Hybrid Heat Pump with Grid-Responsive Controls

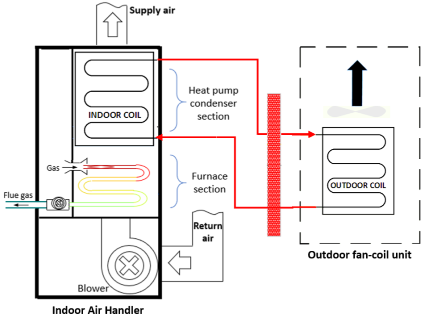


Performing Organization(s): Oak Ridge National Laboratory
PI Name and Title: Kyle Gluesenkamp, Distinguished R&D Staff
Presenter Name and Title: Steve Kowalski, Senior R&D Staff
PI Email: gluesenkampk@ornl.gov
WBS # 3.2.2.39

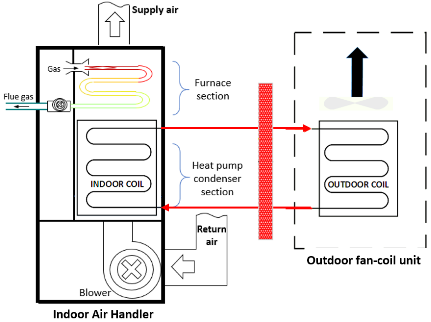
Project Summary

OBJECTIVE, OUTCOME, AND IMPACT

- Introduce transitional heat pump product to a market dominated by natural gas
- Develop a novel Seamlessly Fuel-Flexible Heat Pump (SFFHP), in which the electric heat pump can operate simultaneously with a gas furnace for maximum flexibility
- Develop a controller that minimizes emissions and cost based on real-time utility and grid data
- Accelerate decarbonization by reducing storage needs and increasing grid resilience and consumer affordability of electrification
- Enable incentive development for hybrid heat pumps by utility programs, affordable housing, and codes



Conventional Dual Fuel System Configuration (Independent Operation of HP and Furnace)



Seamlessly Fuel Flexible Heat Pump Configuration (Concurrent Operation of HP and Furnace)

TEAM AND PARTNERS

ORNL team: Kyle Gluesenkamp, Steve Kowalski, Bo Shen, Navin Kumar, Zhenning Li

Partner: Copeland

COPELAND

STATS

Performance Period: 10/2023 to 09/2025

DOE budget: $200K in FY 2024; $300K in FY 2025

Milestone 1: National impact analysis to evaluate the benefit of replacing a furnace/AC combo with a hybrid heat pump with smart controls

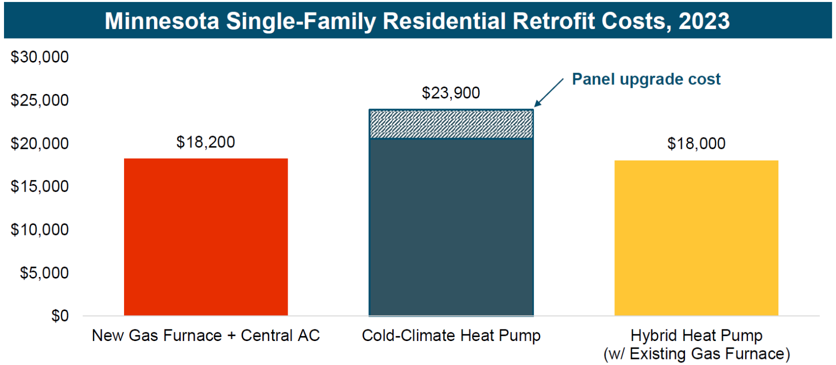
Milestone 2: Develop smart controls with dynamic utility pricing and grid emissions

Milestone 3: Work with CRADA partner to fabricate a system prototype

Milestone 4: Perform field testing

Problem (Key Barriers for Heat Pump Adoption)

- **Affordability for LMI households**
  - **First cost**: The upfront cost of heat pumps, even with rebates, remains a challenge for LMI households
  - **Utility costs**: Concerns over potential increases in electricity bills, particularly in cold regions
- **Cold climate heat pump adoption**
  - **Capacity limitation in cold regions**: a larger HP is required to meet the building load in cold climates
  - **Perception**: Homeowners are skeptical about the performance of heat pumps in colder climates
- **Lack of market availability of effective controls**
  - **Demand response limitations**: Insufficient integration of smart thermostats and other controls to optimize energy use to balance comfort and efficiency
  - Interoperability Issues: Current hybrid HPs lack the ability to integrate with other home automation systems



Thermostat with smart hybrid HP control

Problem – Market Landscape

- Available thermostat

Brand	Model Number	HP Heating Limiatation	Outdoor Sensor Existance	Switching Stagergy	GRID Enabled Capabilities
BKR	PCT513	Two Stages	Cloud Based	Smart Switching	GRID Cost and GHG hourly forecast (Watttime) - API
iFlow	Smart Hybrid Heating Controller	Two Stages	Physical Sensor	Smart Switching (Cost and Efficiency only)	GRID Cost
Carrier	Hybrid heat Thermostat	Modulating System (Comtabile only with Carrier System)	Phyiscal Sensor	Smart Switching (Cost and Efficiency only)	GRID Cost (Input phyiscally or through API)
Amazon	Ecobee Premium Smart Thermostat	Two Stages	Cloud Based	Switch-over temperature and Capacity (Two-stage heating)	Has demand-side management capability (TOU)
Google	Nest Learning Thermostat	Two Stages	Cloud Based	Switch-over temperature and Capacity (Two-stage heating)	No
Honeywell	Vision Pro 8000	Two Stages	Physical Sensor	Switch-over temperature and Capacity (Two-stage heating)	No
Lennox	Comfort Sense 7500	Modulating System (Comtabile only with Lennox System)	Phyiscal Sensor	Switch-over temperature and Capacity (Two-stage heating)	No
Copeland	Sensi Touch 2 smar thermostat	Two Stages	Cloud Based, No outdoor sensor	Switch-over temperature (Two-stage heating)	No

Available DFHP

Brand	Model	Heat Pump Type	Air-Handler	Building Type	Heat Pump HSPF	Control Type
Mitsubishi	Intelli-Heat	Air-to-Air HP	Centralized and Multi-Split	Resdiential	11	Switchover Temp
Daikin	VRV IV X	Air-to-Air HP	Multi-Split	Mutli-family or Commercial		Switchover Temp
Daikin	Rebel	RTU (ASHP)	Centralized	Commercial (Centralized)		Switchover Temp (With Daikin Controller) but Smart Switching with BKR)
US Boiler	AMBIENT	Air-to-Water	Mutli-Split	Single Family		Switchover Temperature
Carrier	Infinty	Air-to-Air HP	Centralized	Single Family	9 (HSPF 2)	Switcover temperature and cost
Daikin	Altherma	Air-to-Water HP	Mutli-Split	Single Family		Switchover Temp and Cost

Alignment and Impact

Alignment with National Buildings Blueprint

- **Efficiency and cost:** Improves building energy efficiency and cuts costs, aligning with DOE’s decarbonization goals
- **Emissions:** Reduces on-site emissions, aids power system decarbonization
- **Equity:** Lowers costs, aligning with energy justice goals and benefiting low-income communities

Impact

Greenhouse gas emissions reductions

Energy justice

- **Emissions reduction:** Reduces CO_2 up to 15.7% in cold climates, contributing to DOE’s 2030 and 2050 targets
- **Cost savings:** Reduces utility cost up to 64.7%, making energy-efficient tech more accessible
- **Grid resilience:** Reduces peak demand 90%, enhancing grid stability and supporting renewable energy
- **Market impact:** Reduce utility bills with low installed cost in cold climates, accelerating adoption of heat pumps for lower income households

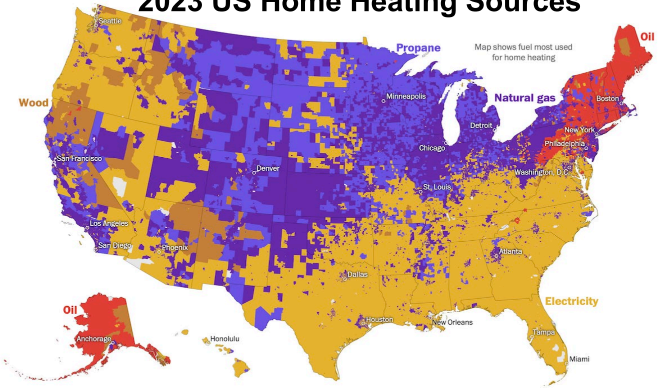
Deliverables to DOE

- A grid-responsive controller for hybrid HPs that can enable low-cost drop-in retrofits, and its cost–benefit analysis for wider adoption in underserved communities, supporting diversity, equity, and inclusion/energy justice goals

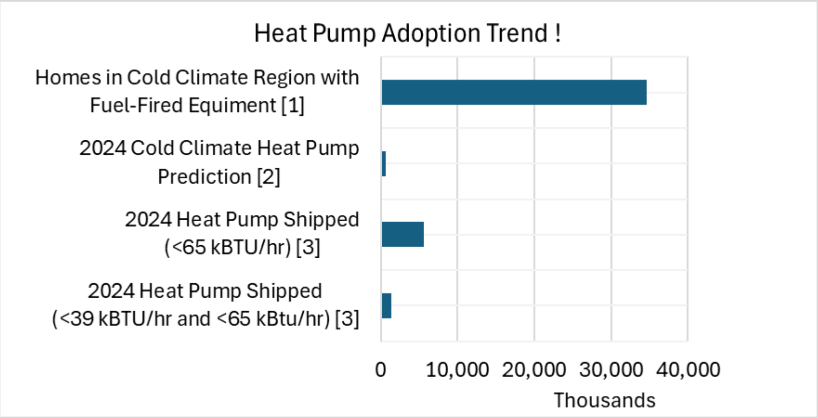
Approach – Accelerate HP Deployment

- **Lower operating costs**: Hybrid HPs reduces household heating bills in cold climates while electrifying most of the annual space heating.
- **Reduced strain on electric grid**: Eliminate electric resistance heating during the coldest winter weather, reducing the required investment in grid infrastructure.
- **Improved adoption**: Speed up nationwide heat pump adoption: for a given investment, hybrid HPs can realize more electrification than electric HPs alone.
- **Climate flexibility**: Hybrid HPs provide a critical bridge technology for cold climates, where the economics of electric heat pumps are challenging.

2023 US Home Heating Sources



https://datainnovation.org/2023/03/visualizing-home-heating-sources/

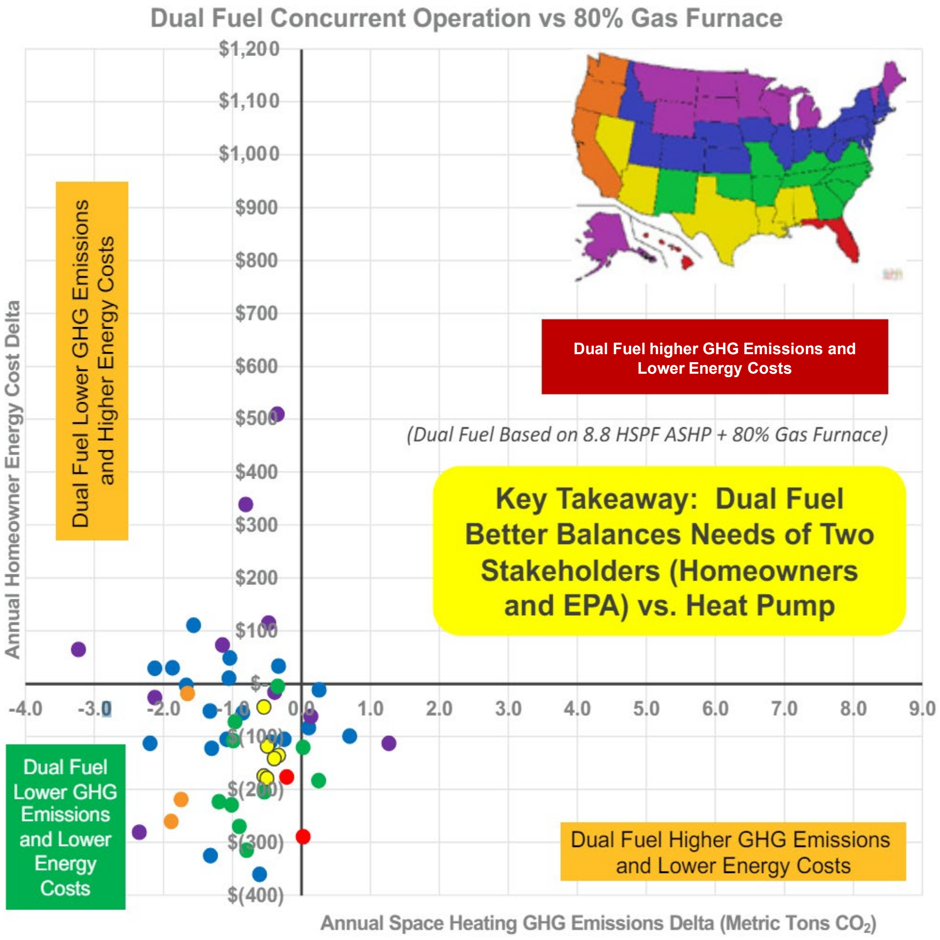


Approach – Replacing AC with HP can be the lowest-first-cost option

- Central ducted furnace/AC combos are extremely common in the US. The AC unit commonly fails before the furnace, and the owners' options include:
  - **1. install another furnace/AC combo** (default/baseline option)
  - **2. remove the furnace and install a heat pump**. Although the HP equipment is only slightly more expensive than an AC/furnace combo equipment, the installation often would involve upgrading electrical service to power the ~10 kW auxiliary backup, making this very costly.
  - **3. install a heat pump and use the existing furnace for auxiliary heat**. This would avoid or defer the electrical service upgrade and could potentially be the lowest cost option of the three, especially stacked with federal, state, and utility heat pump incentives. However, controls are not available on the market to make this option possible.
- This project aims to develop universal controller that can enable the replacement of AC units with heat pumps, using an existing furnace for backup.
- This would make electrification **the lowest first-cost option**, making it especially attractive for **LMI households to electrify**. In many locations, it would also be the lowest utility cost option.

Approach (cont'd)

- Analysis incorporating regional local grid emission rates unravels the true emission impact of HP, hybrid HP, and furnace using different realistic controls.
- This project incorporates practical, near-term market-viable control strategies to optimize emissions reductions, reflecting realistic deployment scenarios.

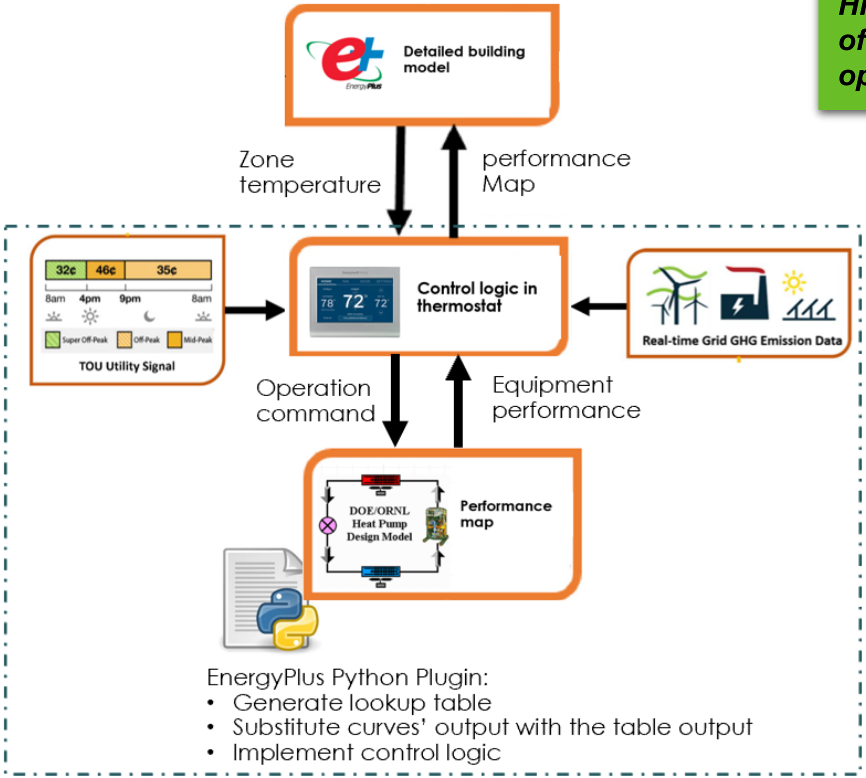


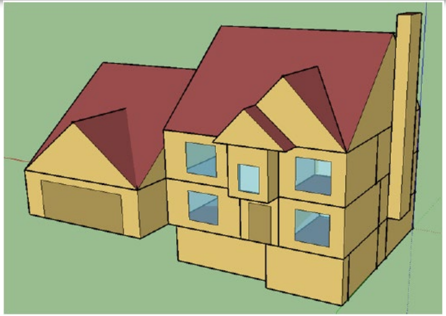
[1] Brian Butler et al. Dual-fuel Technology Balances the Residential Electric HVAC Equation, Copeland White Paper, July 2023

Approach Heat Pump Design Model - E+ Co-simulation Framework

HPDM[1] based Co-simulation platform of building and equipment models to optimize controls for hybrid HPs

- Use DOE/ORNL Heat Pump Design Model for hybrid HP performance modeling
- Use EnergyPlus to simulate a IECC 2014 residential building
- Use EnergyPlus Python plug-in to bridge HPDM and E+ and implement control algorithms

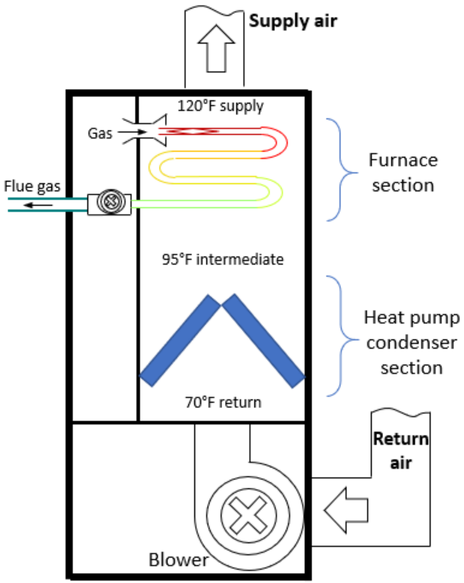




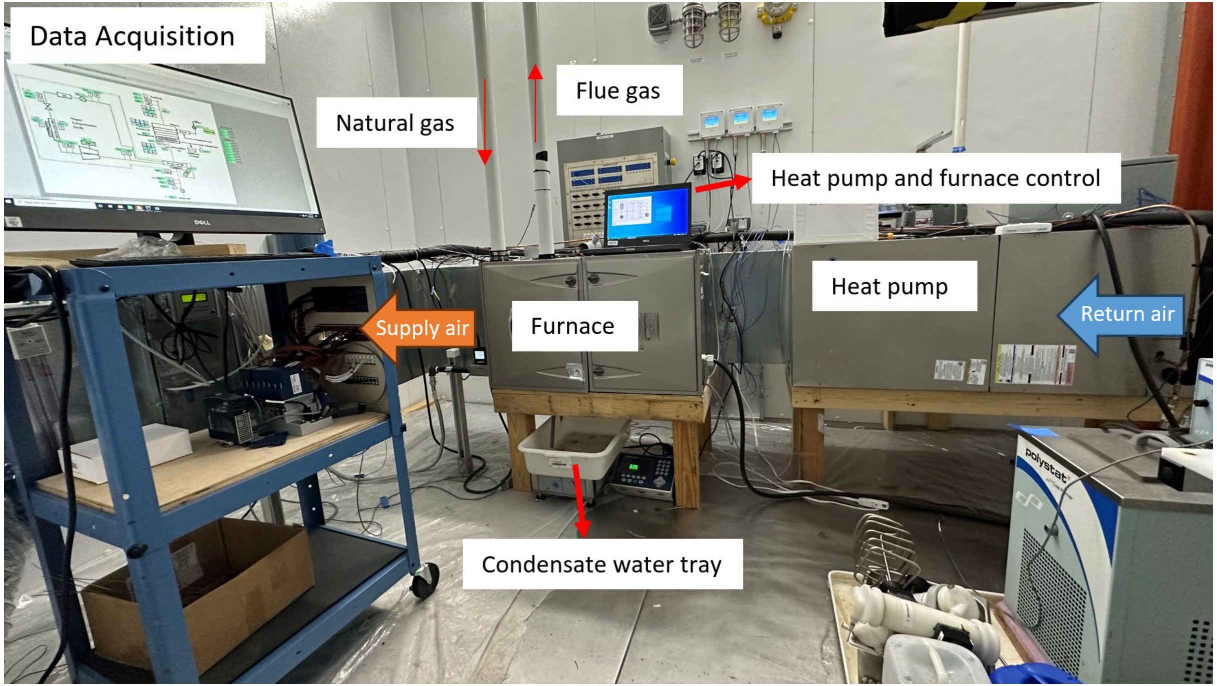
Variables		Input value
U-value (W/m²·K)	Exterior wall	0.42
	Roof	0.392
	Window	0.46
Infiltration (ACH)		0.205
People (#)		4
Lighting (W/m²)		2.1*
Electric equipment (W)		124
Heating setpoint (°C)		20 (4 a.m. to 10 p.m.)
Heating setback setpoint (°C)		17.2 (10 p.m. to 4 a.m.)
Hot water setpoint (°C)		51.6
Capacity of gas furnace (kW)		24.9
Efficiency of the boiler (%)		80

[1] https://hpdmflex.ornl.gov

Progress Seamlessly Fuel-Flexible Heat Pump



Additional details in ORNL Invention Disclosure 81921483



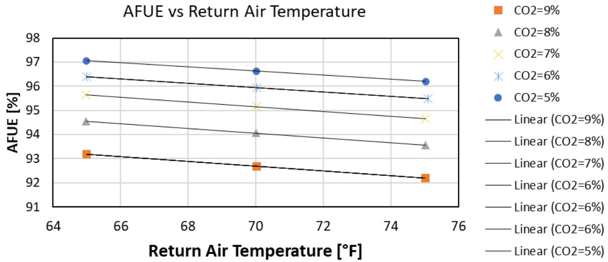
SFFHP Prototype

Laboratory evaluation of SFFHP: COP > 3.0 and AFUE > 95% @ 17°F

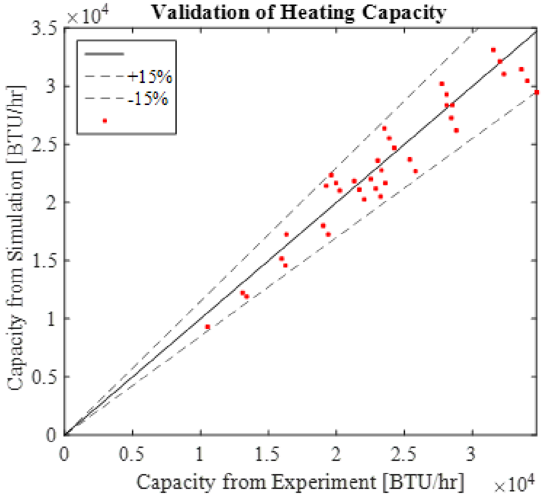
Progress Prototype Testing of SFFHP

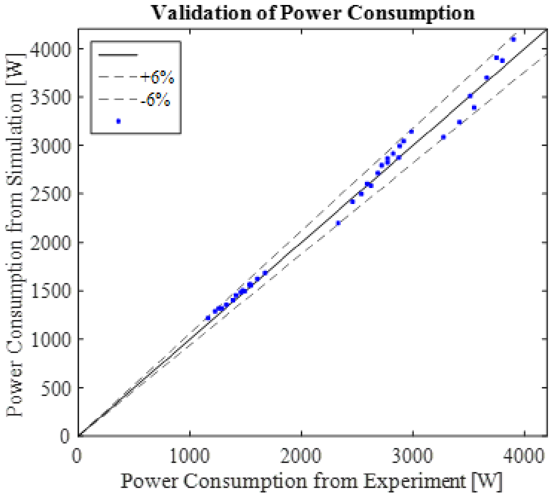
Heat Pump Test Data Range

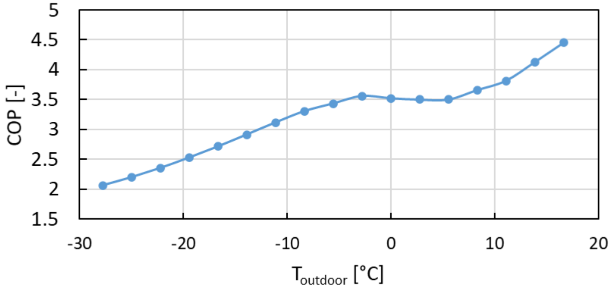
Operation Mode	Outdoor Temperature (°F)	Indoor Return Air Temperature (°F)	Air Flow Rate of Indoor Blower (ft^3/min)	Air Flow Rate of Outdoor fan (ft^3/min)
Heating	−3 to 67	65 to 75	650–1,500	4,100



Performance curve of furnace

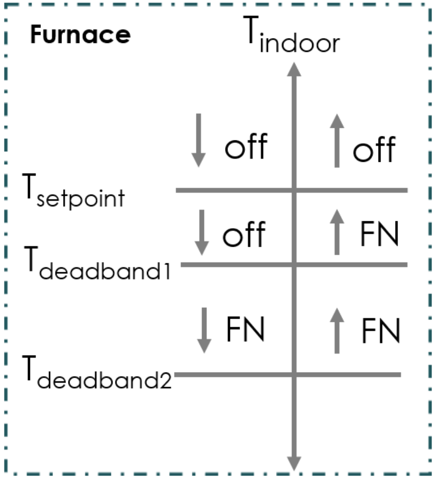


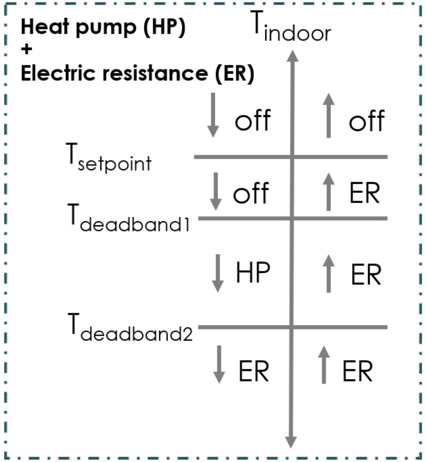




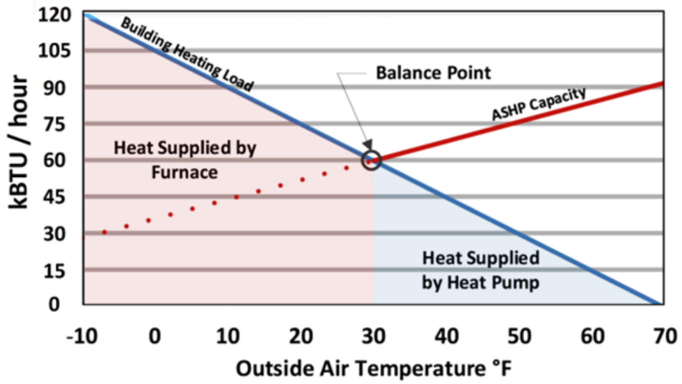
Performance curve of the heat pump

Progress Equipment Control Logic Used in the Simulation





Conventional DFHP Control



Model-based optimal control of smart DFHP and SFFHP

Problem Formulation:

$Objective\text{-}1: Minimize(Utility\ Cost)$

$Objective\text{-}2: Minimize(CO2Emission)$

Design Variable: $Ratio_{HPtoTotal}$ for every hour

Objectives Normalization:

$$Objective-1: Utility\ Cost^{norm} = \frac{Utility\ Cost(Ratio_{HPtoTotal}) - Utility\ Cost_{min}}{Utility\ Cost_{max} - Utility\ Cost_{min}}$$

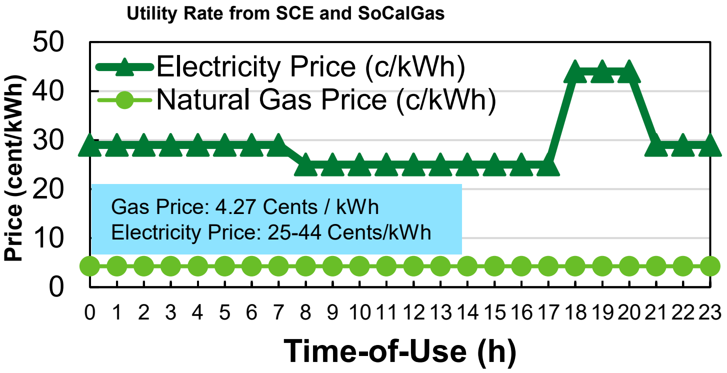
$$Objective-2: CO2Emission^{norm} = \frac{CO2Emission(Ratio_{HPtoTotal}) - CO2Emission_{min}}{CO2Emission_{max} - CO2Emission_{min}}$$

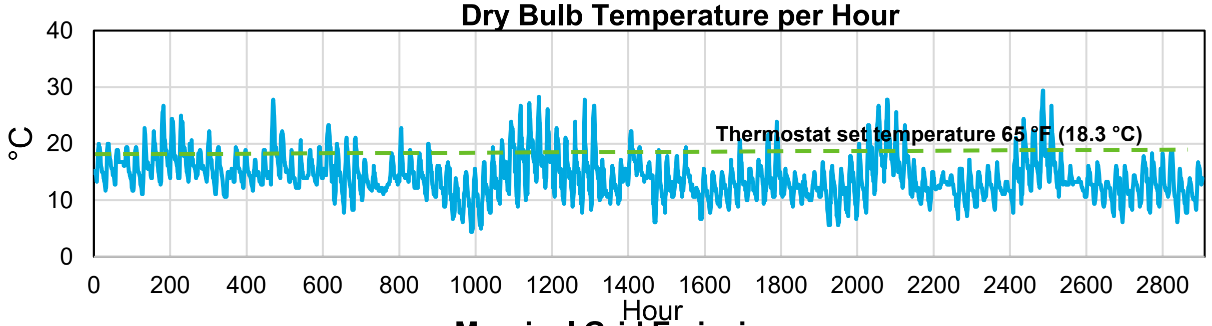
$$fitness = w_1 \times Utility\ Cost^{norm} + w_2 \times CO2Emission^{norm}$$

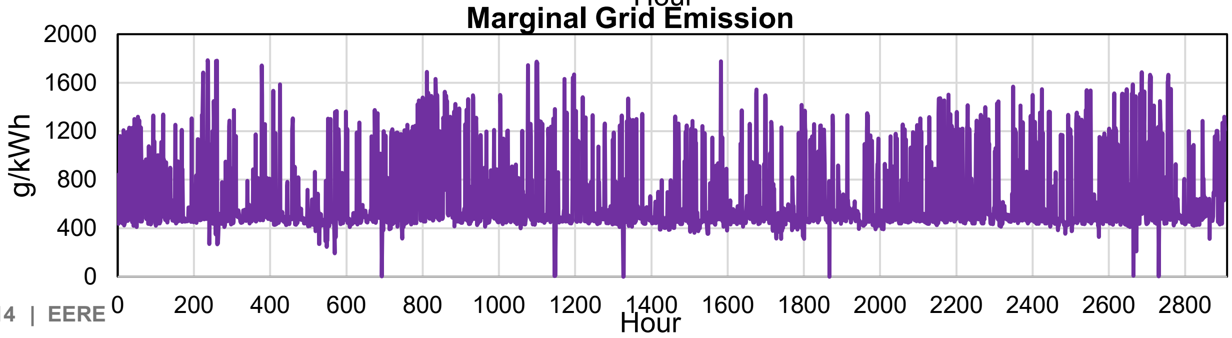
$$where\ w_1 + w_2 = 1$$

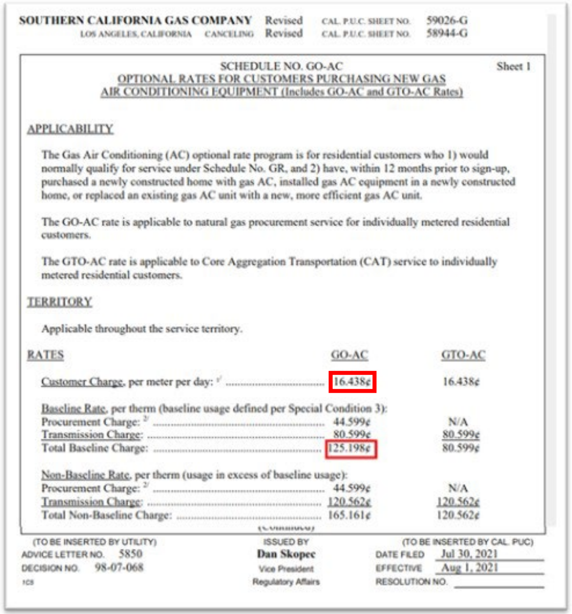
Progress Case Study in Los Angeles

1. Used Los Angeles weather data
2. 65°F as heating set point temperature
3. Time-of-use utility rate from Southern California Edison (SCE)
4. Gas price from SoCalGas, including the daily meter charge
5. Marginal grid emission data from WattTime









SOUTHERN CALIFORNIA GAS COMPANY Revised CAL. P.U.C. SHEET NO. 59026-G
LOS ANGELES, CALIFORNIA CANCELING Revised CAL. P.U.C. SHEET NO. 58944-G

SCHEDULE NO. GO-AC
OPTIONAL RATES FOR CUSTOMERS PURCHASING NEW GAS
AIR CONDITIONING EQUIPMENT (Includes GO-AC and GTO-AC Rates)

Sheet 1

APPLICABILITY

The Gas Air Conditioning (AC) optional rate program is for residential customers who 1) would normally qualify for service under Schedule No. GR, and 2) have, within 12 months prior to sign-up, purchased a newly constructed home with gas AC, installed gas AC equipment in a newly constructed home, or replaced an existing gas AC unit with a new, more efficient gas AC unit.

The GO-AC rate is applicable to natural gas procurement service for individually metered residential customers.

The GTO-AC rate is applicable to Core Aggregation Transportation (CAT) service to individually metered residential customers.

TERRITORY

Applicable throughout the service territory.

RATES	GO-AC	GTO-AC
Customer Charge, per meter per day: [1/]	16.438¢	16.438¢
Baseline Rate, per therm (baseline usage defined per Special Condition 3):		
Procurement Charge: [2/]	44.599¢	N/A
Transmission Charge:	80.599¢	80.599¢
Total Baseline Charge:	125.198¢	80.599¢
Non-Baseline Rate, per therm (usage in excess of baseline usage):		
Procurement Charge: [2/]	44.599¢	N/A
Transmission Charge:	120.562¢	120.562¢
Total Non-Baseline Charge:	165.161¢	120.562¢

(Continued)

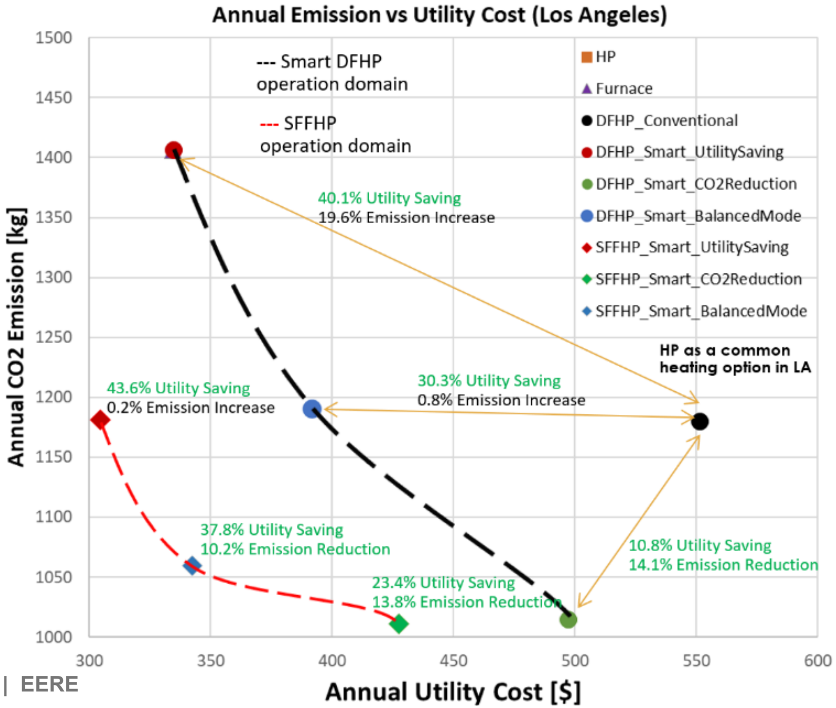
(TO BE INSERTED BY UTILITY)
ADVICE LETTER NO. 5850
DECISION NO. 98-07-068
1C8

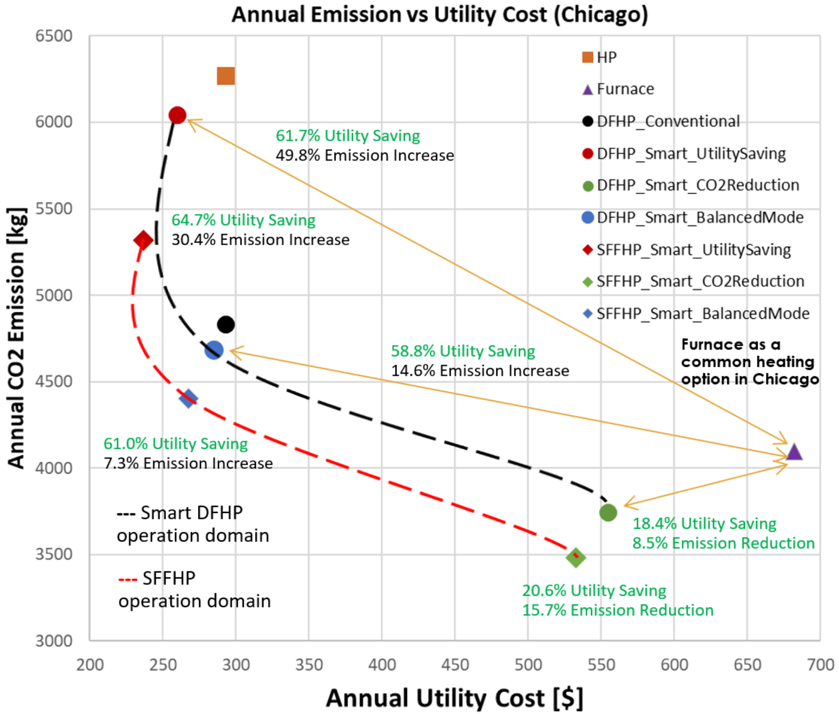
ISSUED BY
Dan Skopec
Vice President
Regulatory Affairs

(TO BE INSERTED BY CAL. PUC)
DATE FILED Jul 30, 2021
EFFECTIVE Aug 1, 2021
RESOLUTION NO.

Progress Efficacy of Smart Controlled Hybrid HP

- In Los Angeles, optimal control strategies deliver up to 40% utility cost and up to 14% CO_2 reduction
- In Chicago, optimal control strategies deliver up to 62% utility cost and up to 9% CO_2 reduction





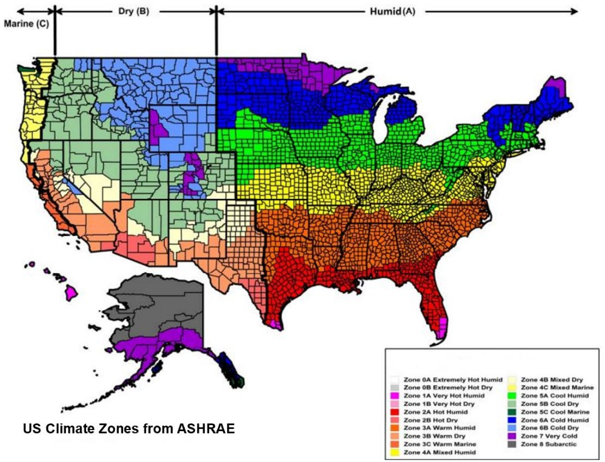
Future Work (in-progress)

Simulation plan

- Estimate national savings in CO_2 and utility costs across different heating climate zones
- Evaluate equipment performance based on current and future grid emission scenarios, i.e., use current marginal grid emissions and future grid emission scenarios for 2035 and 2050
- Simulate multiple cities to represent each heating climate zone
- Compare performance of hybrid heat pump with cold climate heat pump

Equipment Type being simulated in Progress

System type	HP type	HP sizing	Auxiliary heating	Furnace type	Controls
1. Furnace	-	-	-	Single stage	Conv.
2. HP	Single speed	Cooling load	Yes	-	Conv.
3. CCHP	Multi-stage or variable speed	Heating load	No	-	Conv.
4. Conv. DFHP	Single speed	Cooling load	No	Single stage	Conv.
5. Smart DFHP	Single speed	Cooling load	No	Single stage	Smart
6. Smart SHHP	Single speed	Cooling load	No	Multi-stage	Smart



Multiple cities being simulated in each heating climate zones

Future Work and Publications

Control Algorithm Development and Implementation

- Create and validate control algorithms that maximize emission reductions and utility cost savings
- Implement the control algorithms into hardware for testing in laboratory conditions

Control Shakedown

- Conduct initial testing of the prototype controller with heat pumps and furnaces

Laboratory Validation

- Complete lab testing of the prototype controller to ensure proper functionality and integration

Field Validation

- Field-test the prototype controller to assess its commercialization readiness

Publications

[1] Li, Z., Gluesenkamp, K. R., Kowalski, S. and Shen, B. "Benefits of Dual Fuel Heat Pump Grid-Responsive Control: A Model-Based Control Optimization Approach Using Building and Equipment Co-Simulation." 2024. Energy & Buildings. 131: 230-243.

[2] Li, Z., Gluesenkamp, K., Kowalski, S. and Shen, B., 2024. An Affordable, Minimum-carbon Hybrid Heat Pump with a Grid-Responsive Retrofittable Controller. 2024 ACEEE Summer Study, Pacific Grove, CA

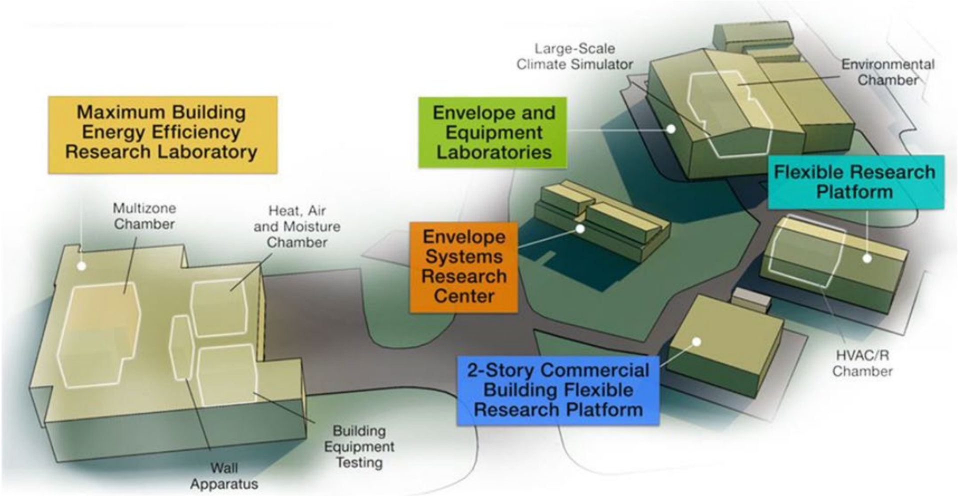
[3] Li, Z., Gluesenkamp, K., Shen, B., Munk, J., Zandi, H., Cheekatamarla, P. and Kowalski, S., 2022. Seamlessly Fuel Flexible Heat Pump with Optimal Model-based Control Strategies to Reduce Peak Demand, Utility Cost and CO2 Emission. 2022 ACEEE Summer Study, Pacific Cove, CA

Thank you

Oak Ridge National Laboratory

Steve Kowalski , Senior R&D Staff
(865) 574-4458 / kowalskisp@ornl.gov

WBS # 3.2.2.39



The **Building Technologies Research and Integration Center** (**BTRIC**) at ORNL has supported DOE BTO since 1993. BTRIC is composed of more than 60,000 ft^2 of lab facilities conducting R&D and development to develop affordable, efficient, and resilient buildings and reduce their greenhouse gas emissions 65% by 2035 and 90% by 2050.

Scientific and Economic Results

139 publications in FY 2024
140+ industry partners
60+ university partners
16 R&D 100 Awards
64 active Cooperative Research and Development Agreements

BTRIC is a DOE-Designated National User Facility

Reference Slides

Project Execution

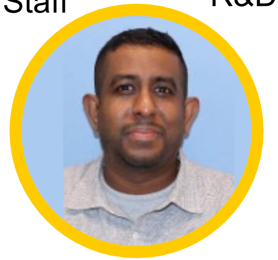
	FY2024				FY2025				FY2026		
Planned budget	$200k				$300k				$200k		
Spent budget	0				0				0		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Past Work											
FY24 Q1 Milestone: Co-simulation framework											
FY24 Q2 Milestone: EnergyPlus Simulation											
FY24 Q3 Milestone: DFHP Perfromance Summary Journal											
Current/Future Work											
FY25 Q1 Milestone: National Impact Analysis											
FY25 Q2 Milestone: Control algorithm development											
FY25 Q3 Milestone: Control logic implementation											
FY25 Q4 Milestone: Control shakedown											
FY26 Q1 Milestone: Laboratory validation of controller											
FY26 Q3 Milestone: Field validation of controller											
FY25 Q4 Milestone: Final reporting											

Team

Kyle Gluesenkamp
Distinguished R&D Staff

Steve Kowalski
Senior R&D Staff

Bo Shen
Senior R&D Staff



Navin Kumar
Technical Staff

Zhenning Li
R&D Staff

Tom Buescher
Platform leader

Brian Butler
R&D Staff