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solutions that transform

Hybrid (Dual-Fuel) Systems Control Optimization for Annual Operating Cost and Emission

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Systems: Gas, Dual, and Hybrid Heat Pumps

Navin Kumar, PhD
Principal Engineer.

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Outline

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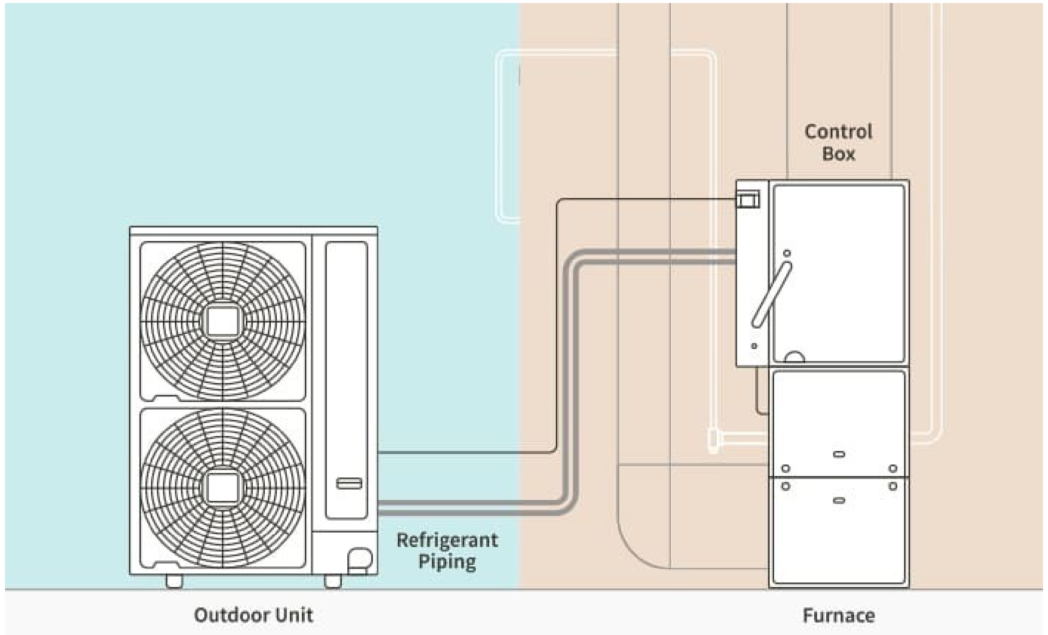
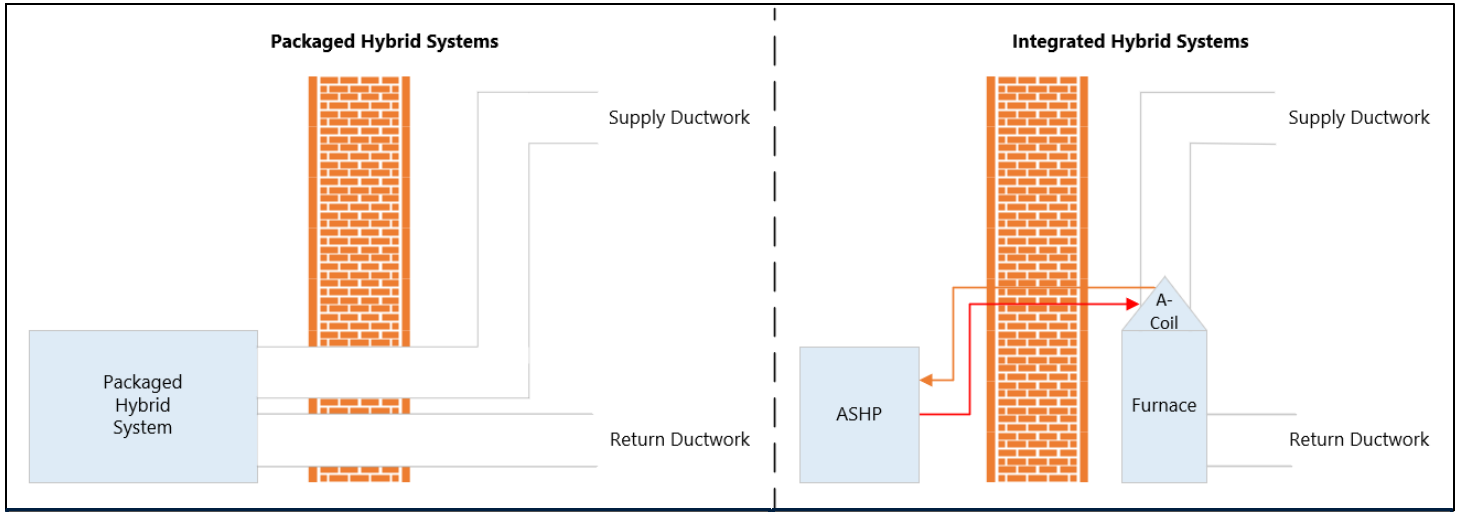
- **Introduction to Hybrid (Dual-Fuel) System**
  - Types of Hybrid (Dual-Fuel) System
  - Hybrid Control Strategies
  - Current Challenges with Hybrid (Dual-Fuel) System
- **What is the proposed Modeling of Hybrid?**
  - Motivation
  - Modeling Method
- **Outcome of Modeling?**
  - Preliminary modeling result
  - Conclusion
  - Future work



Source: https://www.hitachiaircon.com/us/products/ac-for-multiple-rooms/air365-hybrid-dual-fuel-system

What are Hybrid (Dual-fuel) System?



- ✓ Single manufacturers only
- ✓ 81% AFUE, 8 HSPF, ~16 SEER
- ✓ Weatherized furnace
- ✓ NO_x > 14 ng/J

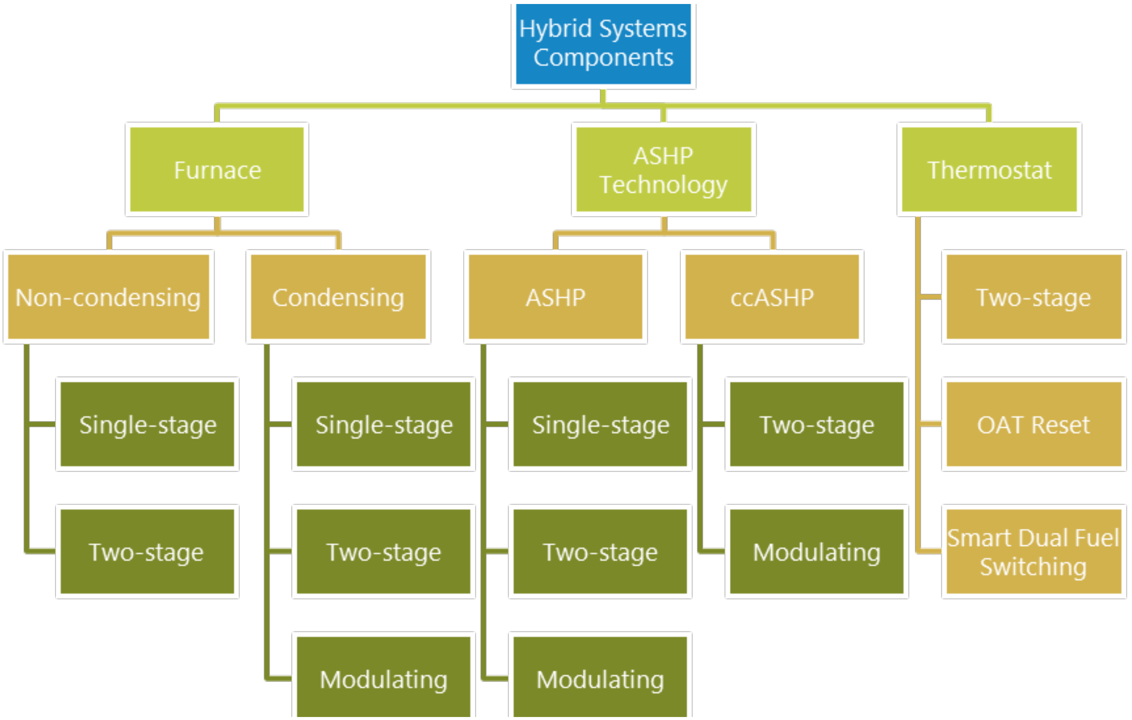
- ✓ Multiple manufacturers integrated furnace and outdoor heat pump unit
- ✓ Furnace: 80% - 95% AFUE
- ✓ SEER: 16 - 22
- ✓ HSPF: 8 - 13
- ✓ All major and white-label brands

Source: https://www.trane.com/residential/en/products/packaged-systems
Source: https://www.budgetheating.com

What are Hybrid (Dual-fuel) System?

Integrated Hybrid System

- ❑Multiple possible solutions and configurations in A la Carte and single-manufacturer hybrid system
  - ❖***A la carte Hybrid*** system approach offers homeowners the freedom to select from different manufacturers’ products. Limited to non-communicating systems
    - ✓Can be integrated with homeowners' current equipment choice
    - ✓Upgrade to a higher efficiency component
    - ✓Requires low-capital investment
    - ✓Increase market adaption
  - ❖***Single Manufacturer Hybrid*** combination of a single manufacturer’s furnaces, ASHPs, and thermostats can be both non-modulating and modulating systems.
    - ✓Premium pricing (depending)
    - ✓High-efficiency system
    - ✓Advance control capability



Hybrid (Dual-fuel) Control Strategies and Thermostats:

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Hybrid Heating Strategies

✓Two-stage Heating

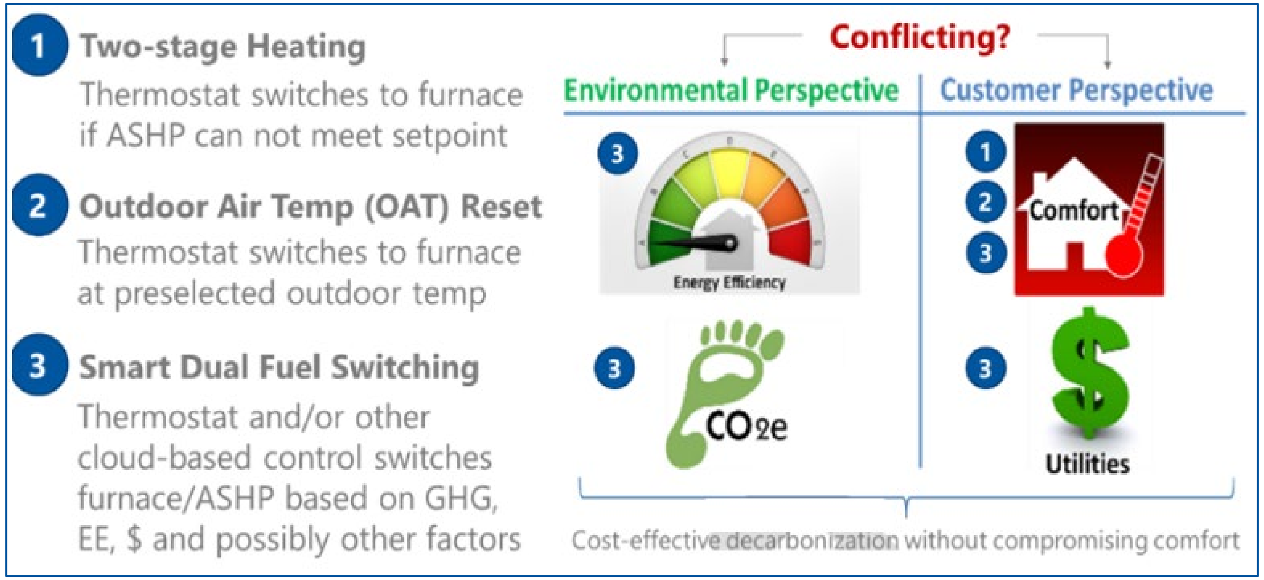
✓OAT Reset

✓Smart Dual-Fuel Switching (SDFS)

Smart Thermostats

✓Majority of smart thermostats in the market can operate with both two-stage and OAT reset strategies

✓Some thermostats in the market have the capability to support smart dual-fuel switching.



Source: https://www.ecobee.com/en-us/
Source: https://bkrenergy.ca/our_products/
Source: https://www.carrier.com/residential/en/us/products/thermostats/smart-thermostats/

Current Challenges !

Hybrid Systems Method of Testing (MOT) Development

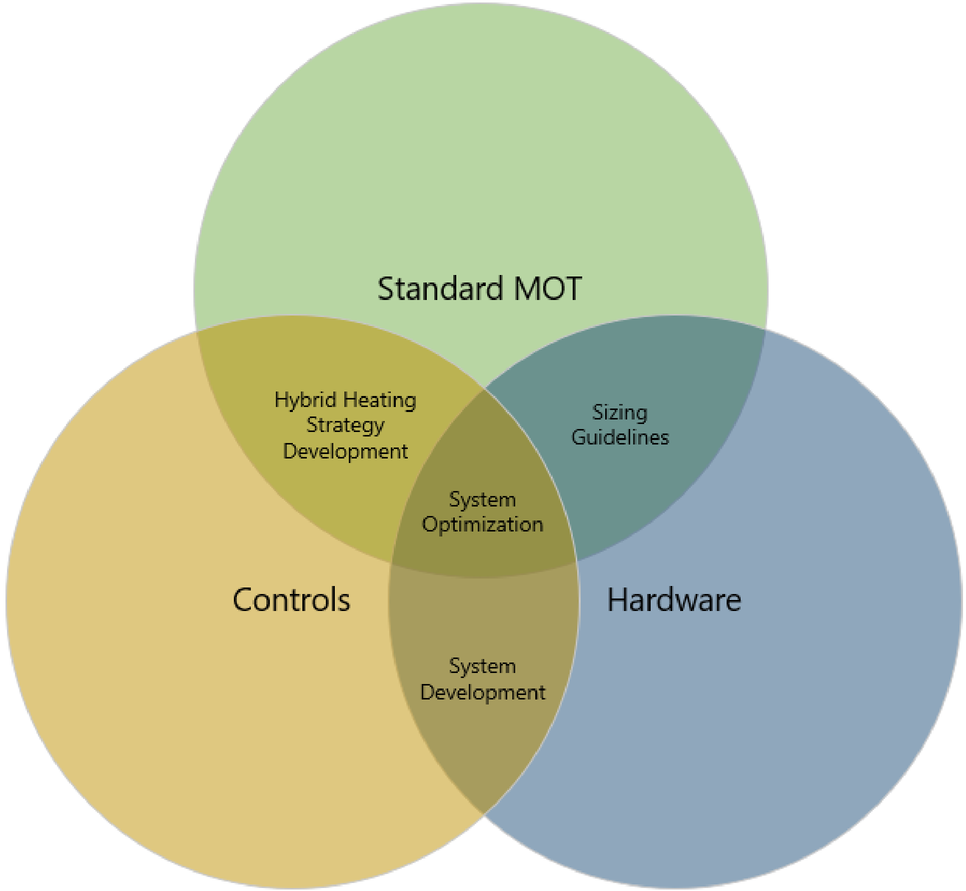
- Developing a standard MOT for hybrid systems could be a monumental task, considering the large variety of options in the market and the impact of different climates and grid regions.
- But without a common MOT and rating standards, it's a challenge to evaluate the potential benefit of hybrid systems

Advance Controls

- The majority of thermostats in the market don't have advanced controls to optimize the hybrid system for minimizing operating cost and GHG emissions while maintaining comfort – especially for communicating systems (i.e., cold-climate heat pumps)
- Advance controls are influenced by equipment selection, sizing, and control strategy

Sizing

- There are no sizing tools to accurately size the heat pump
  - Do we size the heat pump for cooling or heating?



Motivation of Hybrid (Dual-Fuel) Modeling

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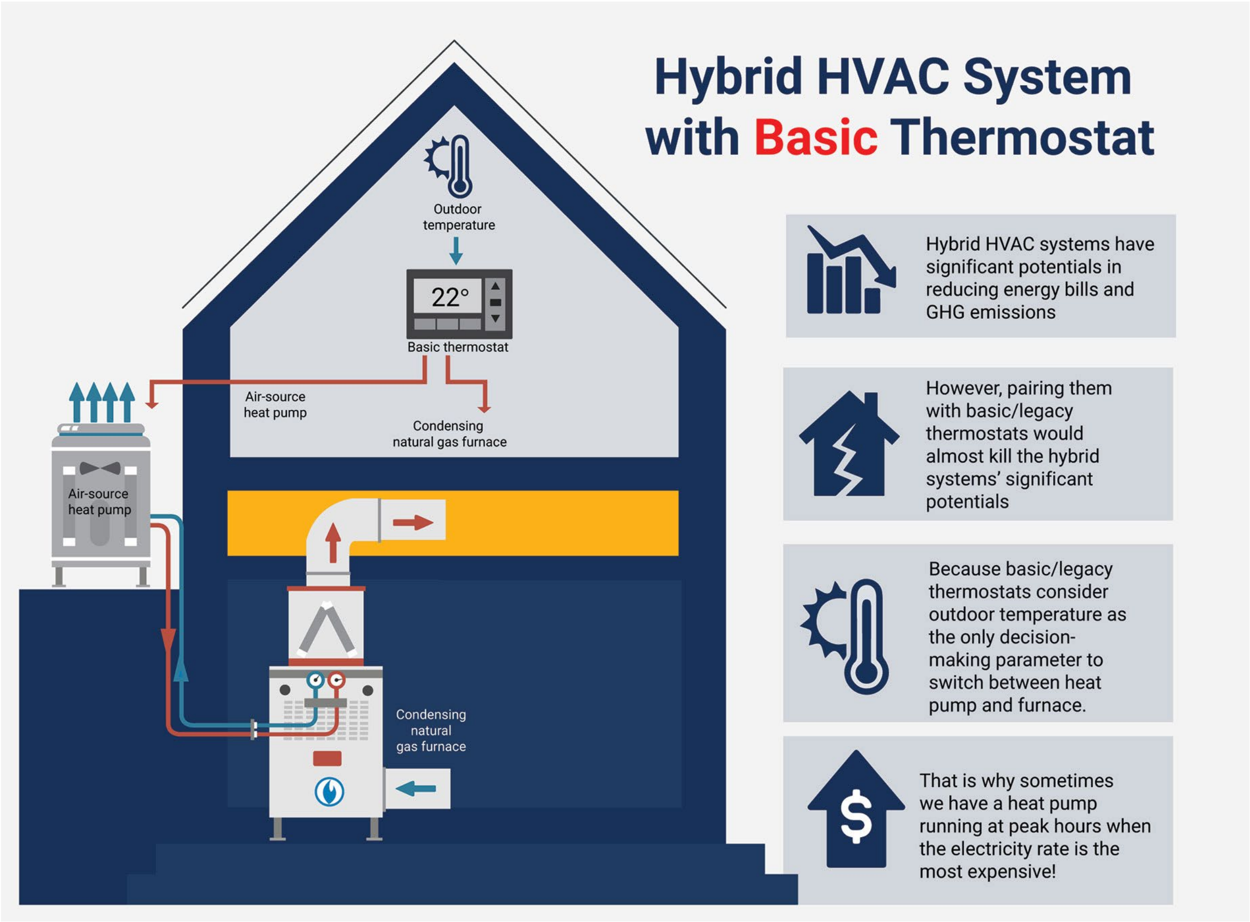
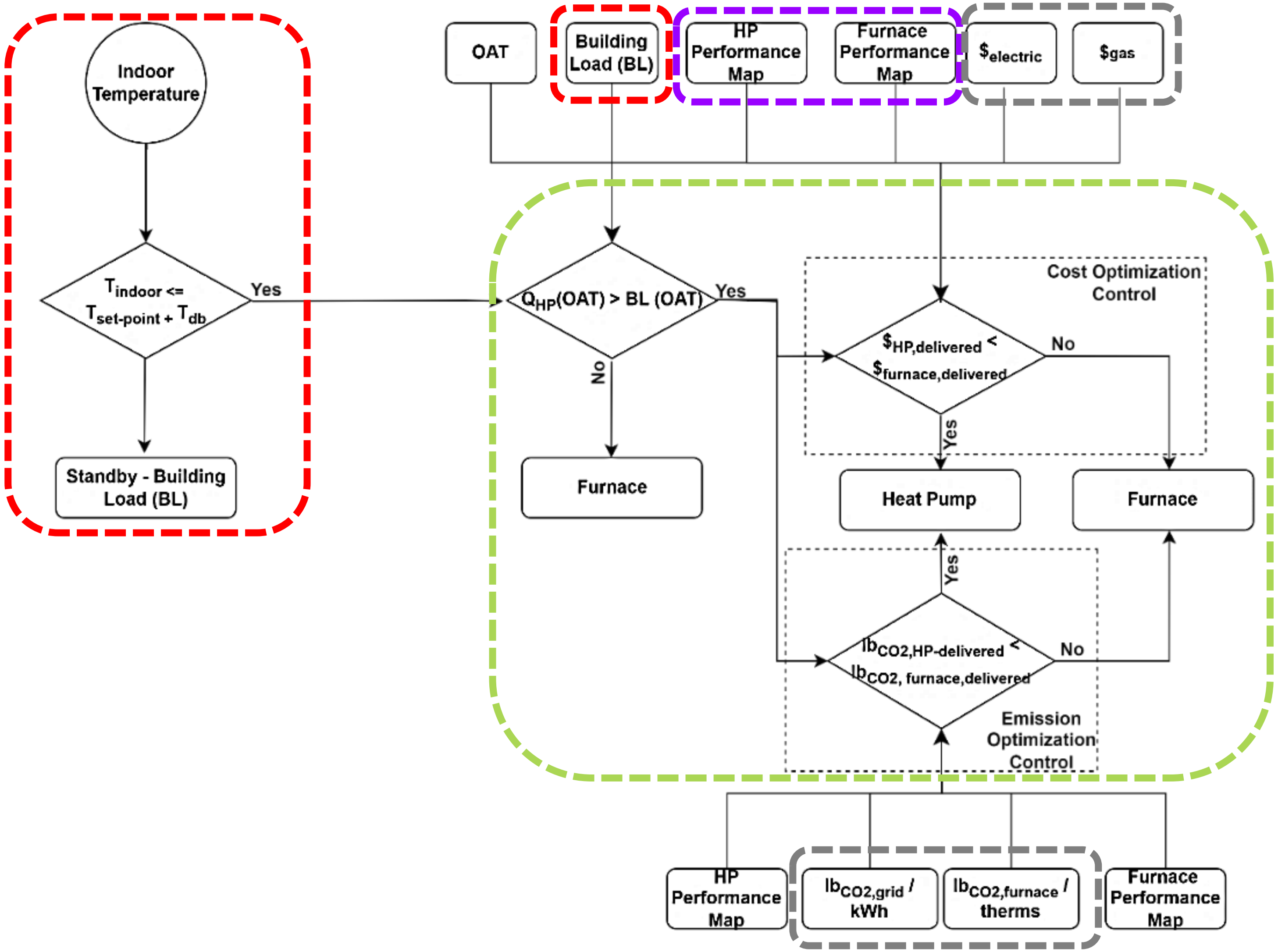
- **What is the benefit of a Hybrid System?**
  - ❑Operating Cost?
  - ❑Emission Reduction?
  - ❑Payback?
- **How to size the heat pump for the Hybrid System?**
  - ❑Size for Summer Load (ASHP)?
  - ❑Size for Winter Load (ccASHP)?
- **Control Strategy?**
  - ❑Smart Control vs. Switchover Control



Source: https://www.bkrenergy.ca/

Modeling Method



Hybrid (Dual-Fuel) Model

- The model is made up of four sub-core programs:
  - ✓ *Building and Thermostat*
  - ✓ *Appliances Performance*
  - ✓ *Utility Rates and Emission Data*
    - *Natural Gas: Gas utility*
    - *Electric Rates: OpenEI.org*
    - *Emission: WattTime*
  - ✓ *Core Decision Logic*

Modeling Method – Building Thermostat Model

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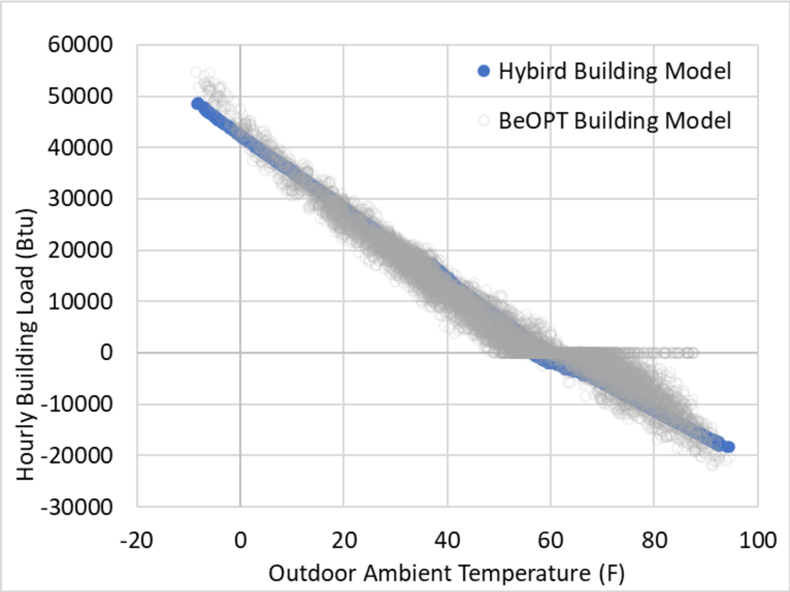
- The building model is a semi-empirical linear lumped capacitance model based on balance point temperature, peak heating load, and temperature, outdoor ambient temperature, and building capacitance.
- The model only considers sensible load – No latent load is included in the model
- This hybrid building model is evaluated and compared with DOE BeOPT data.

Equations	Variables	User Input
$BL\ (T_o, T_i) = \dot{Q}_c(peak) \times \left[\frac{T_{bal} - T_o}{T_{bal,d} - T_{des}}\right]$	$\dot{Q}_c(peak)$ - Heating Design Load T_{des} - Heating Design Temperature $T_{bal,d}$ - Design Balance Point Temp T_o - Outdoor Ambient Temperature $BL\ (T_o, T_i)$ – Building Load	$\dot{Q}_c(peak)$ T_{des} $T_{bal,d}$ T_{t-stat} ΔT_{db}
$T_{bal} = T_{bal,d} + T_i(t) - T_{t-stat}$	$T_i(t)$ – Indoor Temperature T_{t-stat} - Indoor Set-point	
$C = \frac{\dot{Q}_c(peak)}{8 \times N_{cycle,max} \times \Delta T_{db}}$ Capacitance is based on Henderson & Rengarajan correlation)	$N_{cycle,max}$ - Number of cycles ΔT_{db} - Deadband C - Capacitance	
$T_i(t + \Delta t) = T_i(t) + \frac{\Delta t\ [BL - \dot{Q}_s]}{C}$	$T_i(t + \Delta t)$ – Change in indoor temperature	

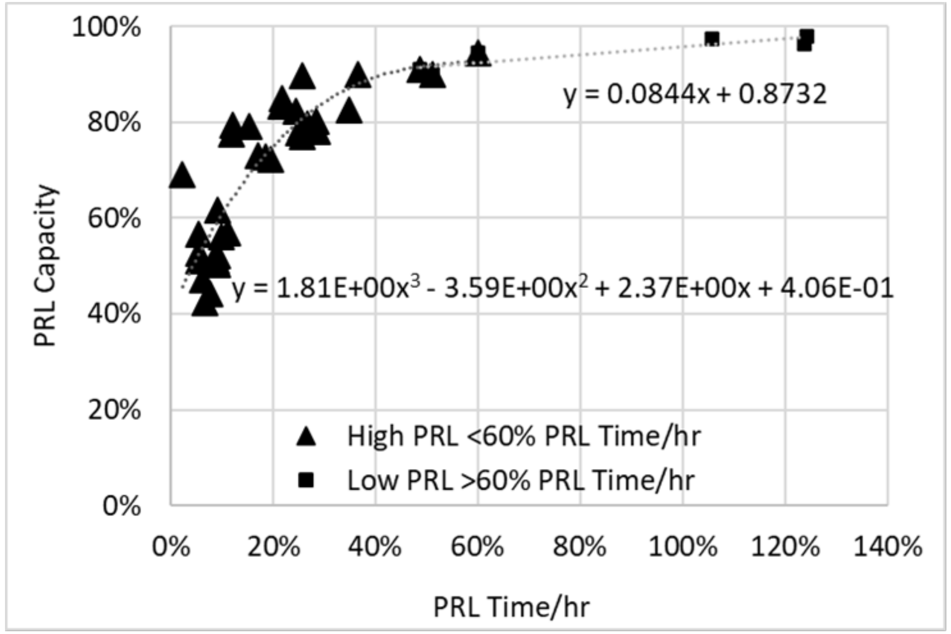


Modeling Method – Building Sizing

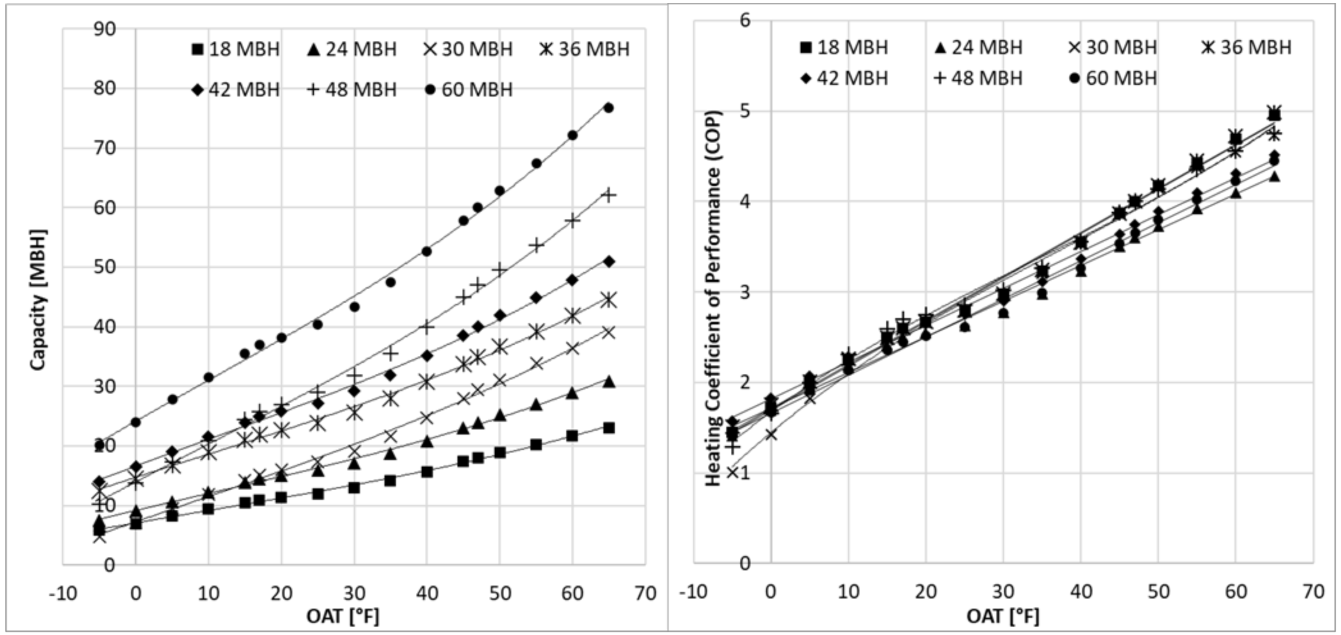
Location (IECC Climate)	Home Properties	Utility Rates	Peak Heating Load (MBH)	Peak Cooling Load (MBH)	Balance Point Temp (°F)	Equipment Sizing (MBH)		
						Furnace Capacity	ASHP[1] Capacity @47°F	ccASHP[2] Capacity @5°F
Pocatello, ID (Climate 6B)	Conditioned – 2270 sq.ft IECC 2018	Natural Gas - $1.16/therms Electricity - $0.138/kWh	52 @ -10.8°F	20 @ 96.8°F	60	60	36	60
Raleigh, NC (Climate 4B)		Natural Gas - $1.13/therms Electricity - $0.123/kWh	32 @ 10.5°F	25 @ 98.1°F	60	45	36	36

1. ASHP is sized for cooling season – 9 HSPF Heat Pump
2. ccASHP is sized for heating season – 10.5 HSPF Heat Pump

Modeling Method – Heat Pump Model



Experimental Part-Load Data (Laboratory)

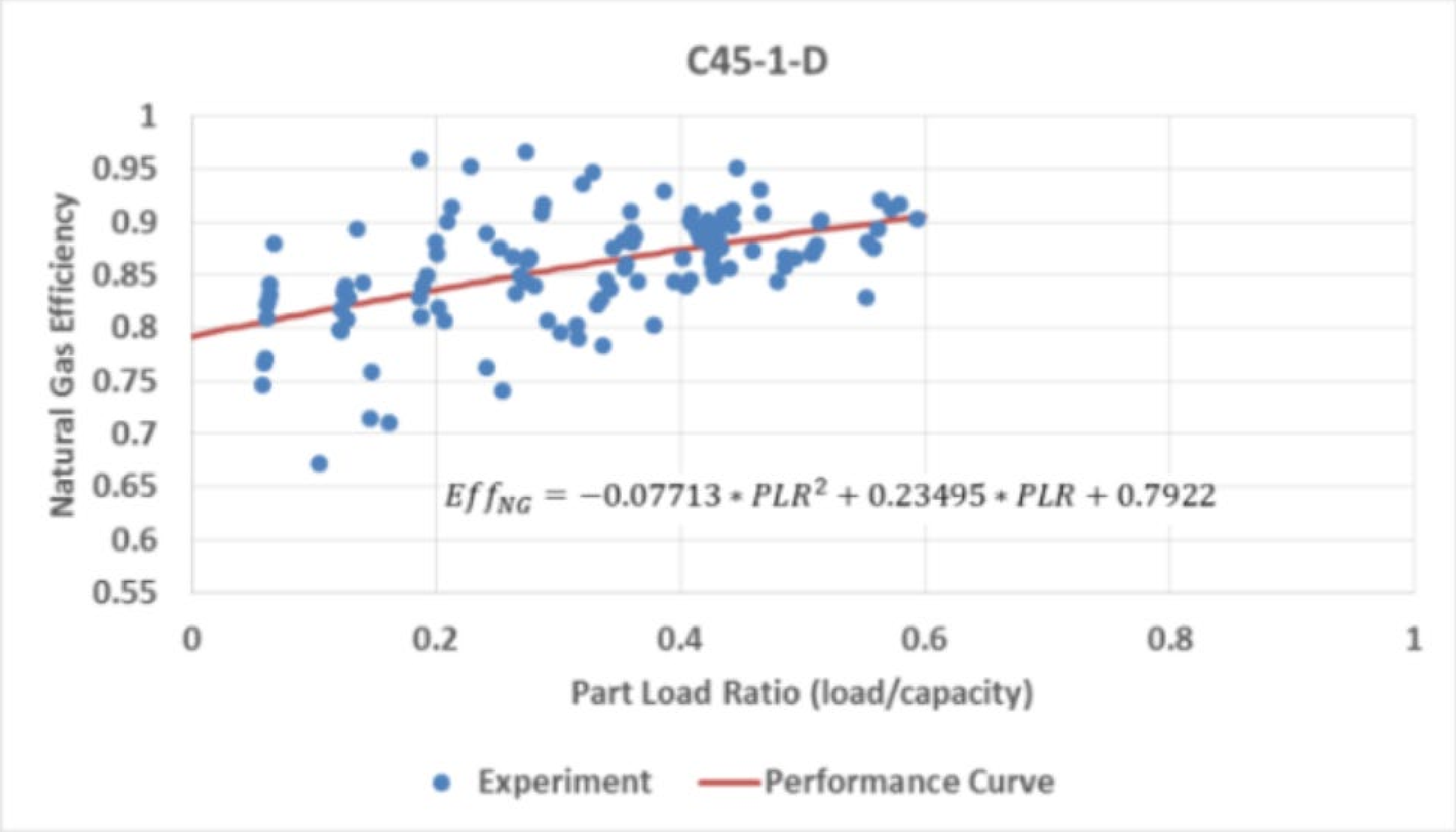


Manufacturer Steady-State Data

Modeling Method – Furnace Model

- Laboratory data was utilized and corrected for different AFUE equipment

- The laboratory data was based on a 95 AFUE furnace.

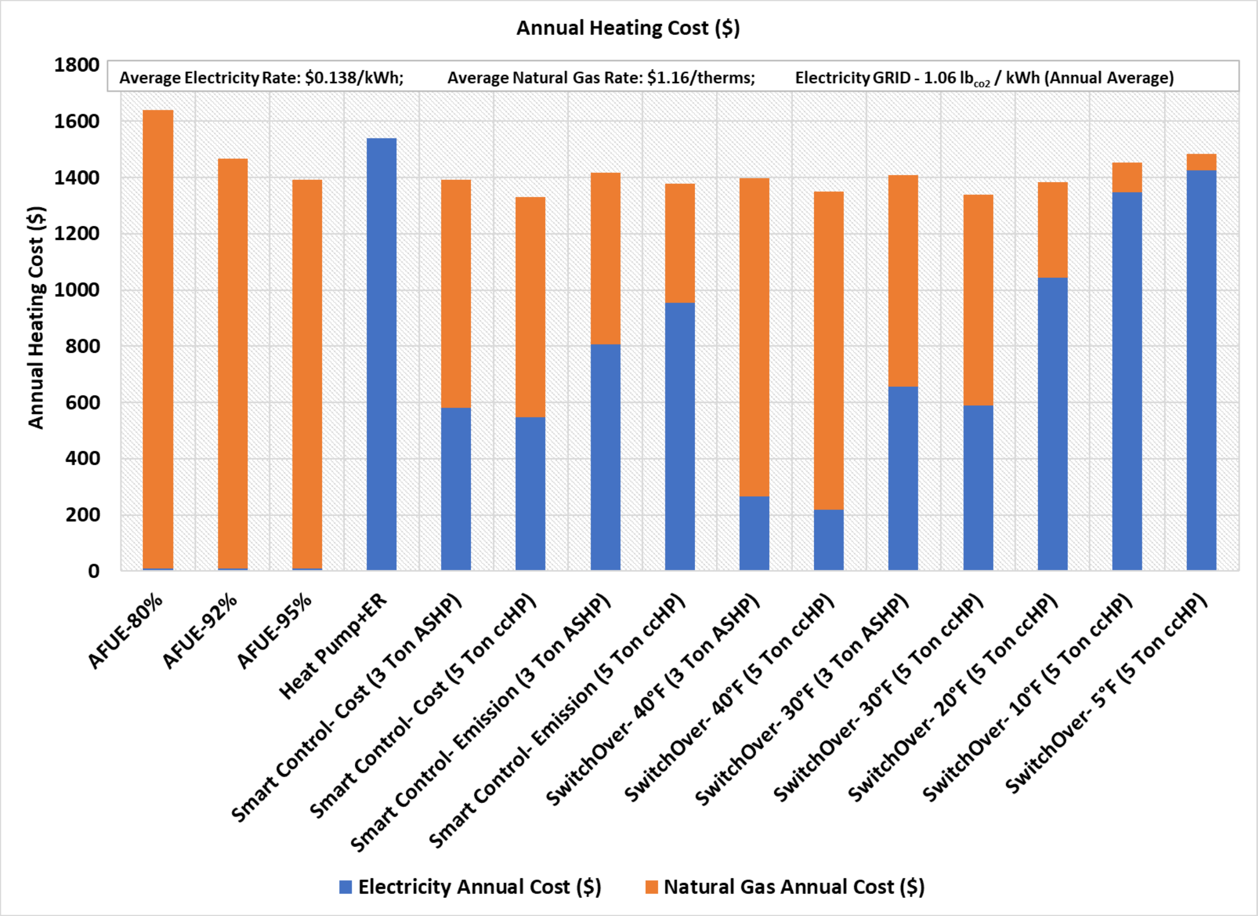


$$\eta = \left(-0.07713 \times \left(\frac{Load_{delivered}}{Q_{max}}\right)^2 + 0.23495 \times \left(\frac{Load_{delivered}}{Q_{max}}\right) + 0.7922\right) * \frac{Furance\ AFUE}{95}$$

Outcome – Pocatello, ID (Climate 6B)

Furnace versus ASHP versus ccASHP

- A hybrid (dual-fuel) system with a 3-ton ASHP has a similar magnitude of operating cost as a 95 AFUE furnace.
- A hybrid (dual-fuel) system with a 5-ton ccASHP reduces the operating cost by:
  - ✓ 19% compared to 80% AFUE furnace
  - ✓ 4% compared to 95% AFUE furnace
- Complete electrification with 5-ton ccASHP and electric resistance increased the operating cost by:
  - ✓ 6.5% compared to 95% AFUE furnace
- For both hybrid (dual-fuel) systems, a switchover temperature of 30˚F representative of the smart controller with cost optimization mode.
  - ✓ ccASHP could operate down 5˚F, with increased in operating cost



Outcome – Pocatello, ID (Climate 6B)

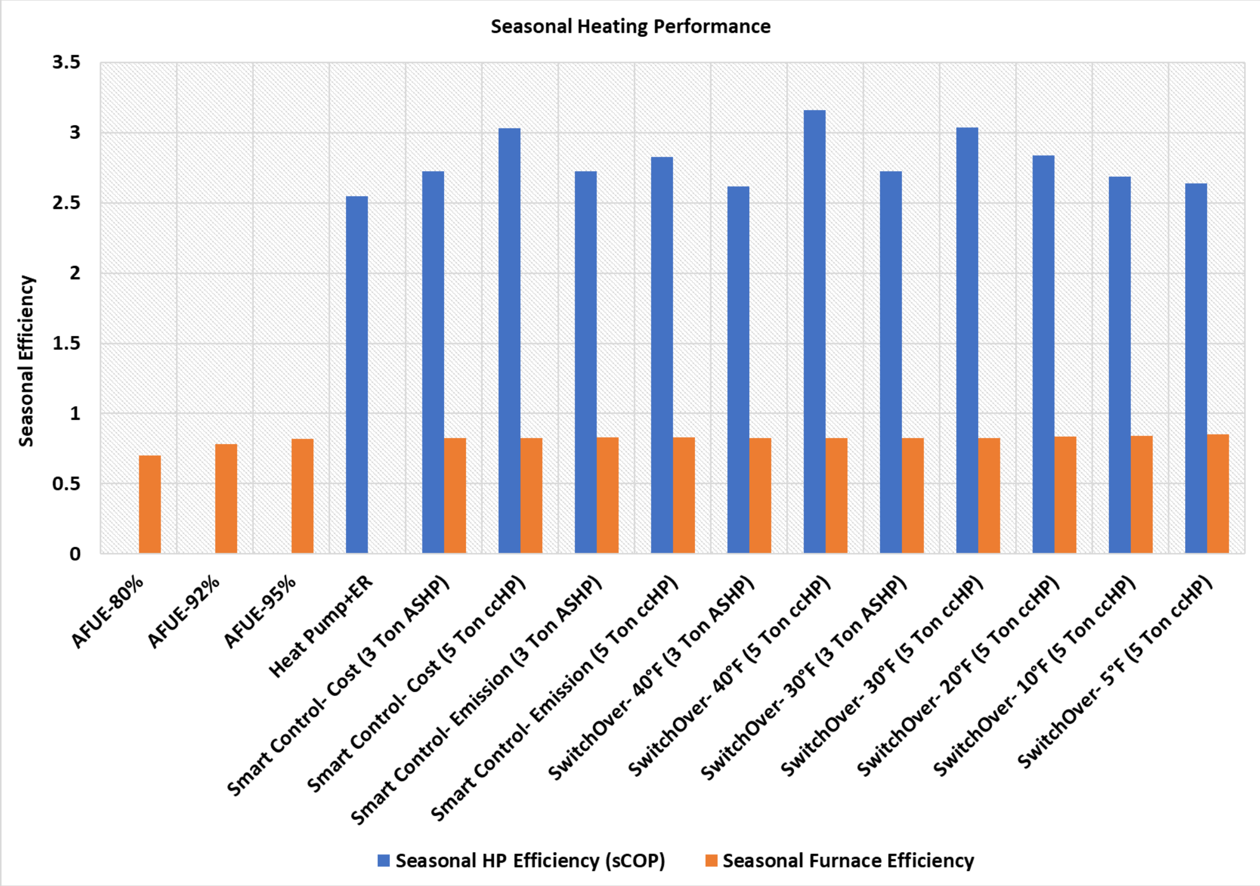
ASHP versus ccASHP

– Seasonal Heating Efficiency:

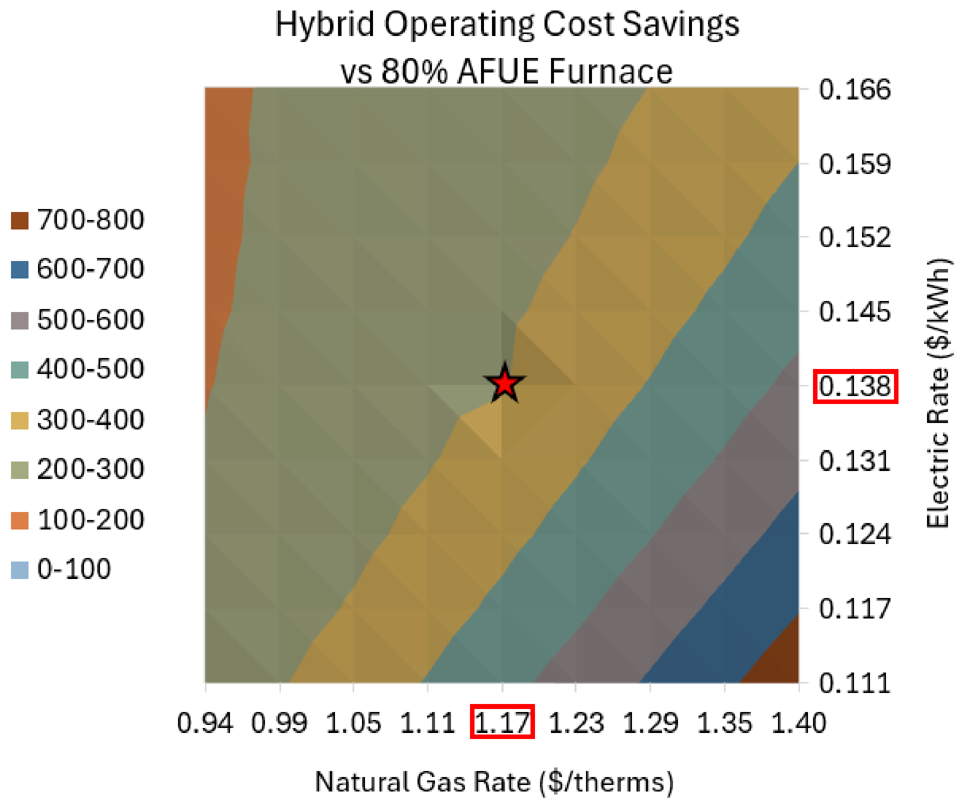
✓Hybrid (Dual-Fuel) with ASHP ~ sCOP 2.75 @ >30˚F

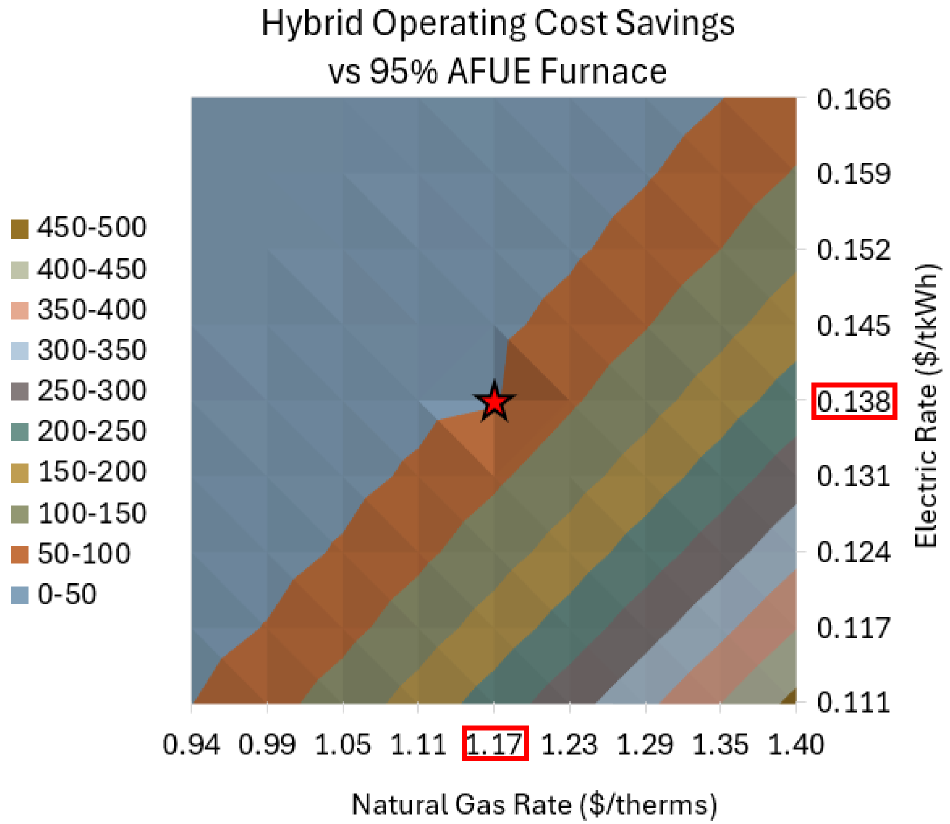
✓Hybrid (Dual-Fuel) with ccASHP ~ sCOP 2.70 @ >5˚F

✓ ccASHP + Electric Resistance ~ sCOP 2.5



Outcome – Pocatello, ID (Climate 6B)
Effect of Utility Rates on Hybrid Operating Cost

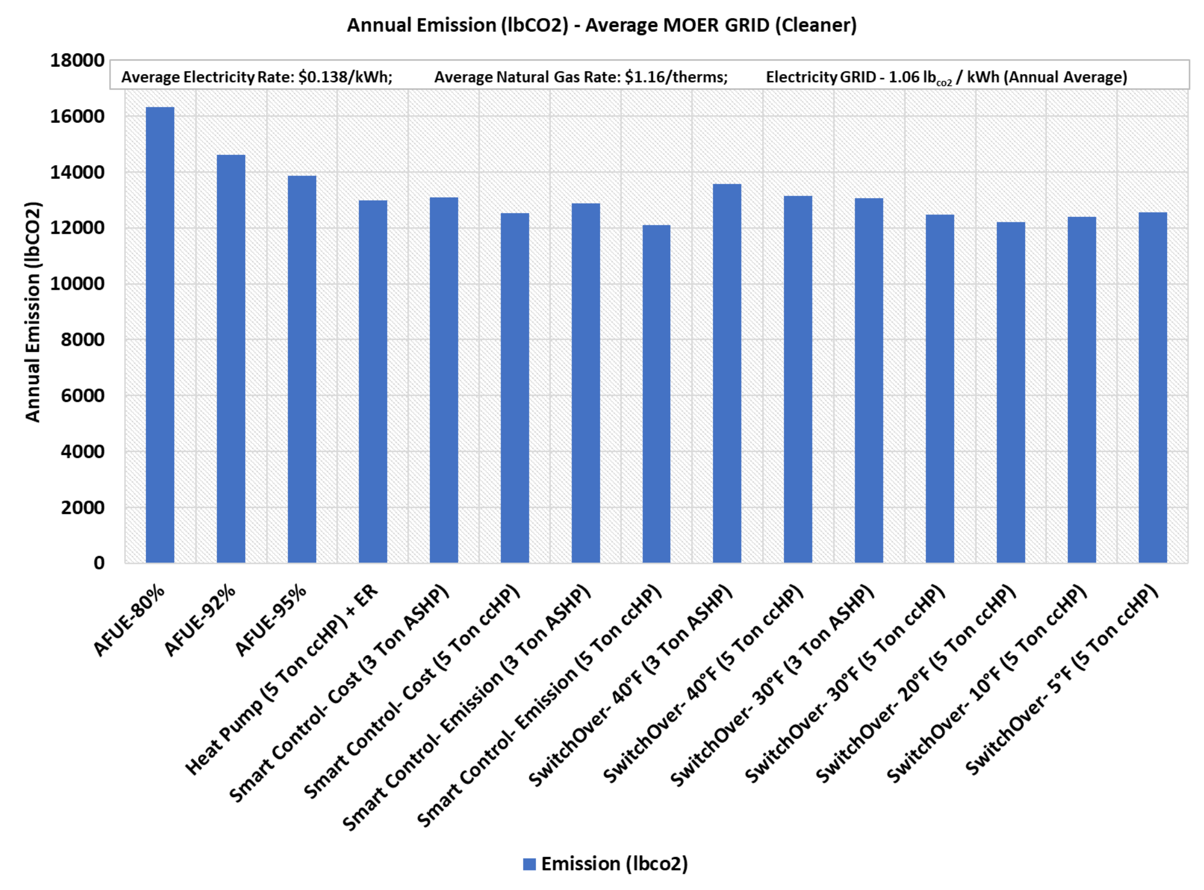


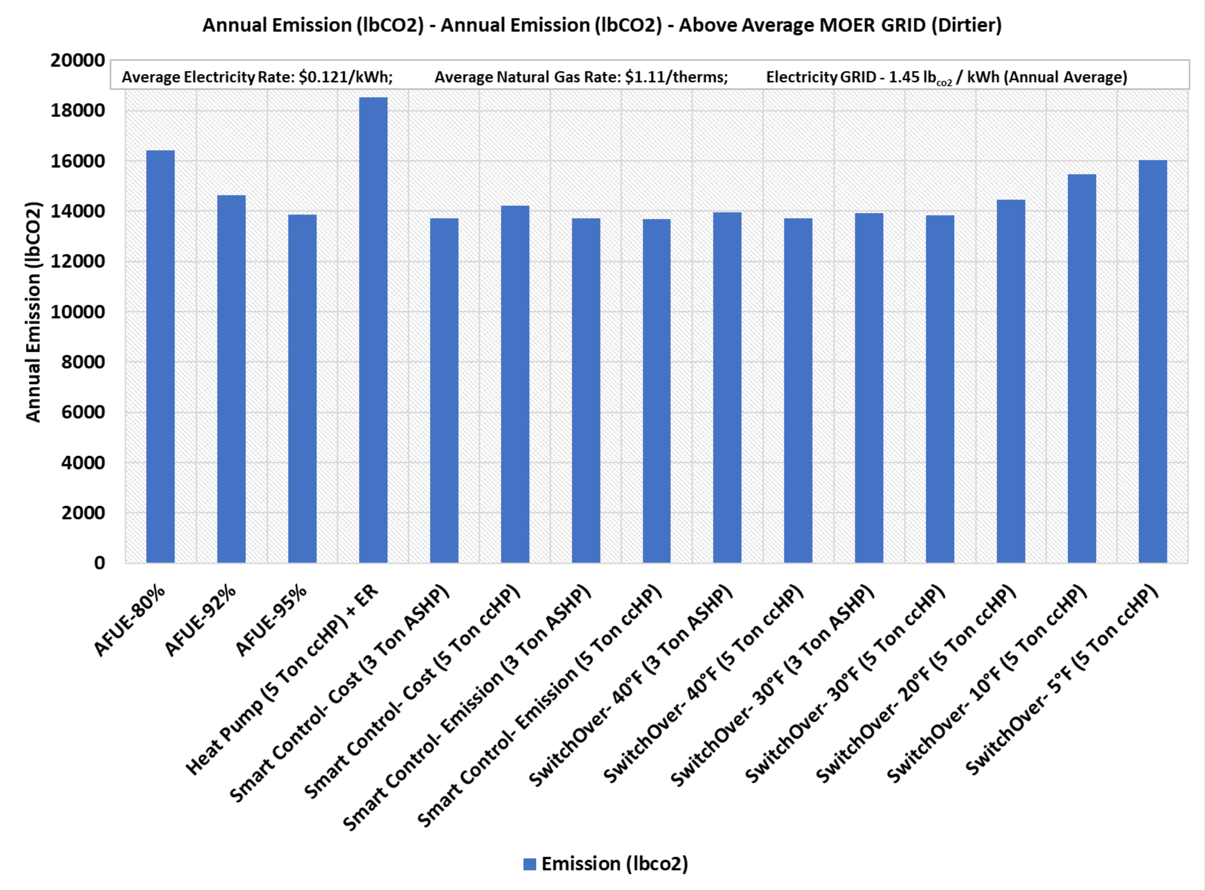


Study the effect of Natural Gas and Electricity Rates on Hybrid Systems

- ✓ Varied the rates by ±20%
- ✓ In all cases (±20% variation), the hybrid dual-fuel system provided annual cost-savings for space heating compared to an 80 AFUE Furnace
- ✓ Whereas with a 95 AFUE furnace, it was more worthwhile to utilize a furnace when the Natural Gas Rate is less than $1.17/therms and electricity rates are more than $0.138/kWh

Outcome – (Pocatello, ID)Climate 6B





Study the effect of Electric GRID (MOER) on Hybrid Emission

- ✓ A hybrid (Dual-fuel) system could potentially have enormous benefits in reducing greenhouse gas (GHG) emissions in colder regions with above-average (Dirtier) Electric GRID.

Outcome – Raleigh, NC (Climate 4B)

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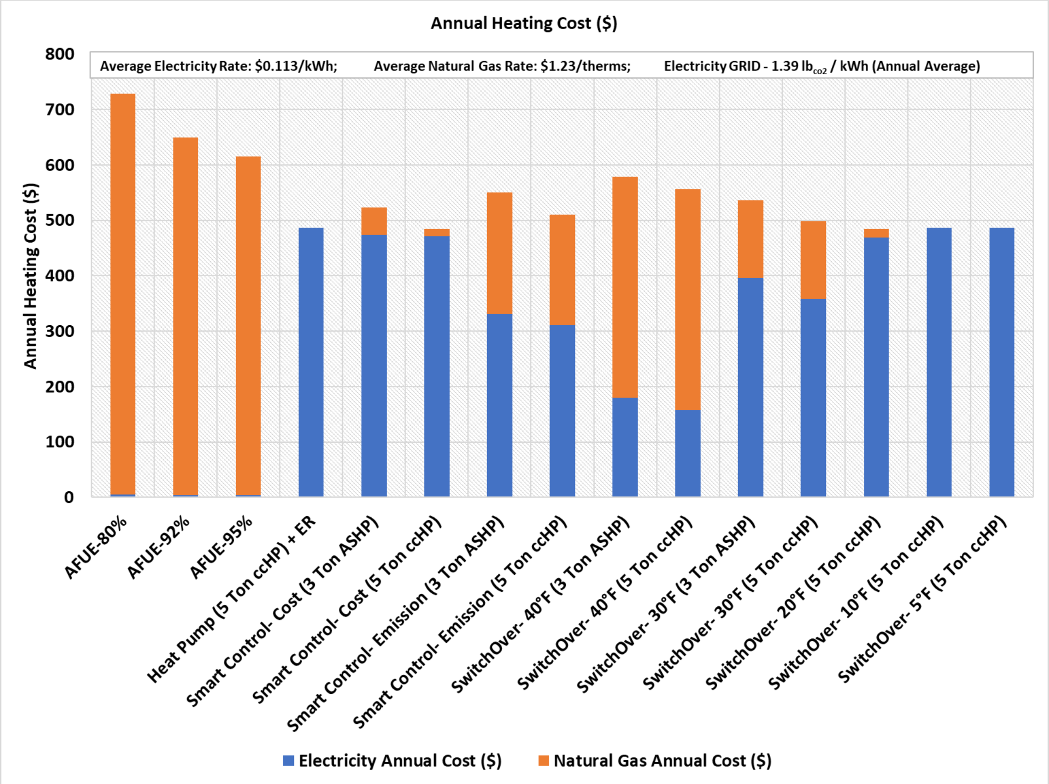
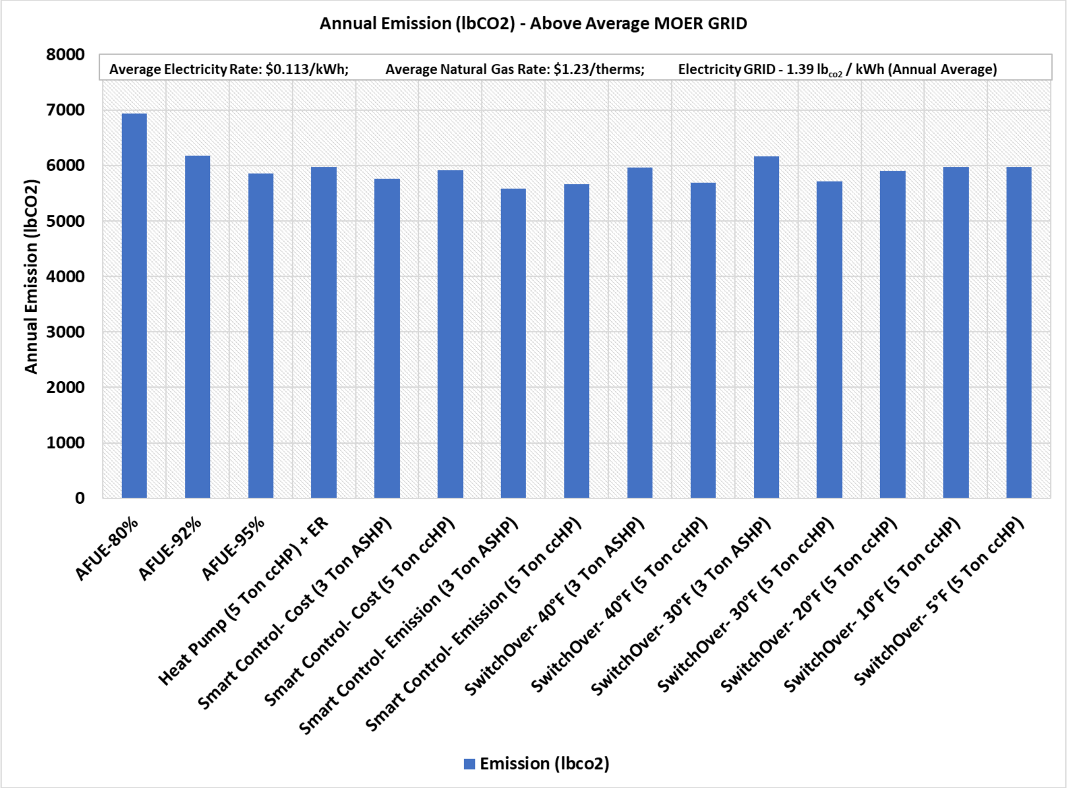




- ❑ The benefit of the Hybrid (Dual-fuel) system is limited in Raleigh, NC, to emission reduction.
  - ✓ Hybrid heating operating cost is higher than just operating a high-efficiency heat pump
  - ✓ Has the potential to reduce the emission by 4% compared to a 95 AFUE furnace
    - Whereas complete electrification increases the emission by 2% compared to a 95 AFUE furnace.

Summary

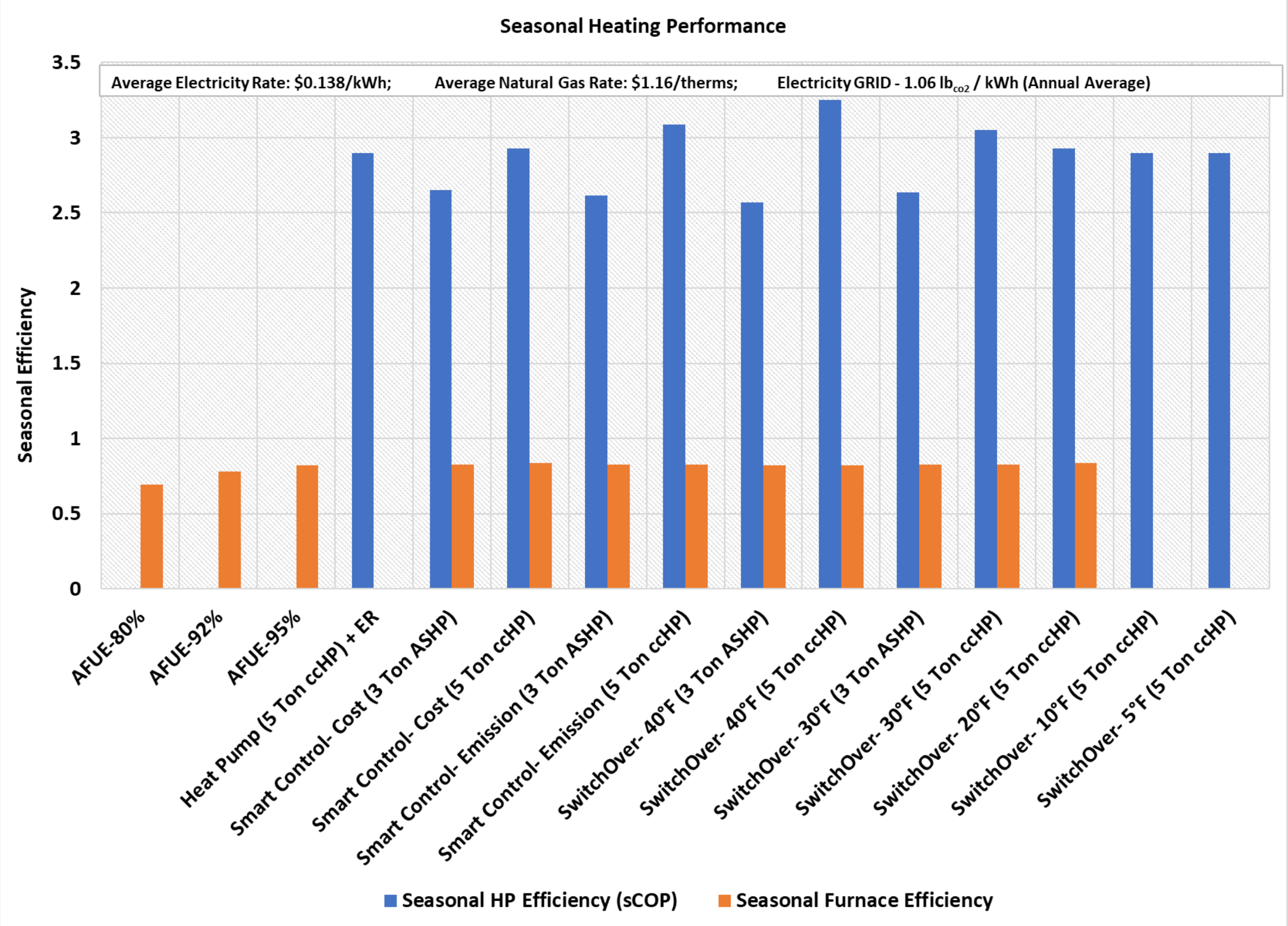
Climate Region	Heating Cost Savings ($) [1]				Emission Reduction (lbs_{co2}) [1]				Equipment Payback (Years)				Sizing of Heat Pump
	95 AFUE Furnace	Hybrid 1	Hybrid 2	ccASHP	95 AFUE Furnace	Hybrid 1	Hybrid 2	ccASHP	95 AFUE Furnace	Hybrid 1	Hybrid 2	ccASHP	
Pocatello, ID (Climate 6B)	248	249	309	100	2469	3464	4239	3361	4	8	27	40	Hybrid - 1
Raleigh, NC (Climate 4B)	112	205	243	242	1071	1353	1272	960	8.5	22	28	16	ccASHP

- In this study, we have highlighted the benefit of a hybrid heating system through modeling compared to conventional furnaces and cold-climate heat pump-only operation.
- The model accounts for the balance between operating costs/CO2 emissions with comfort.
- The model demonstrated that a hybrid heating system can potentially reduce heating operating cost by 18% (Climate 6B) and 33% (Climate 4B) and up to 25% reduction in emission compared to an 80% AFUE furnace
- In mild climate regions (Climate 4B), the cold-climate heat pumps were able to achieve similar outcomes as an hybrid system with reduced payback period.
- With the hybrid (dual-fuel) system, user comfort will be maintained, as the furnace could kick on and provide the required heating at low ambient temperatures. Therefore, the hybrid heating system is an attractive option for energy-efficiency and emission-reduction programs.

[1]Compared to an 80% AFUE Furnace Hybrid
1 : 95% Furnace + HSPF 9 HP (ASHP) ; Hybrid 2 : 95% Furnace + HSPF 10.5 (ccASHP); ccASHP : HSPF 10.5


Thank You!

Support Slide - Outcome – Climate 4B



Support Slide Outcome – Effect of Utility Rate on Hybrid