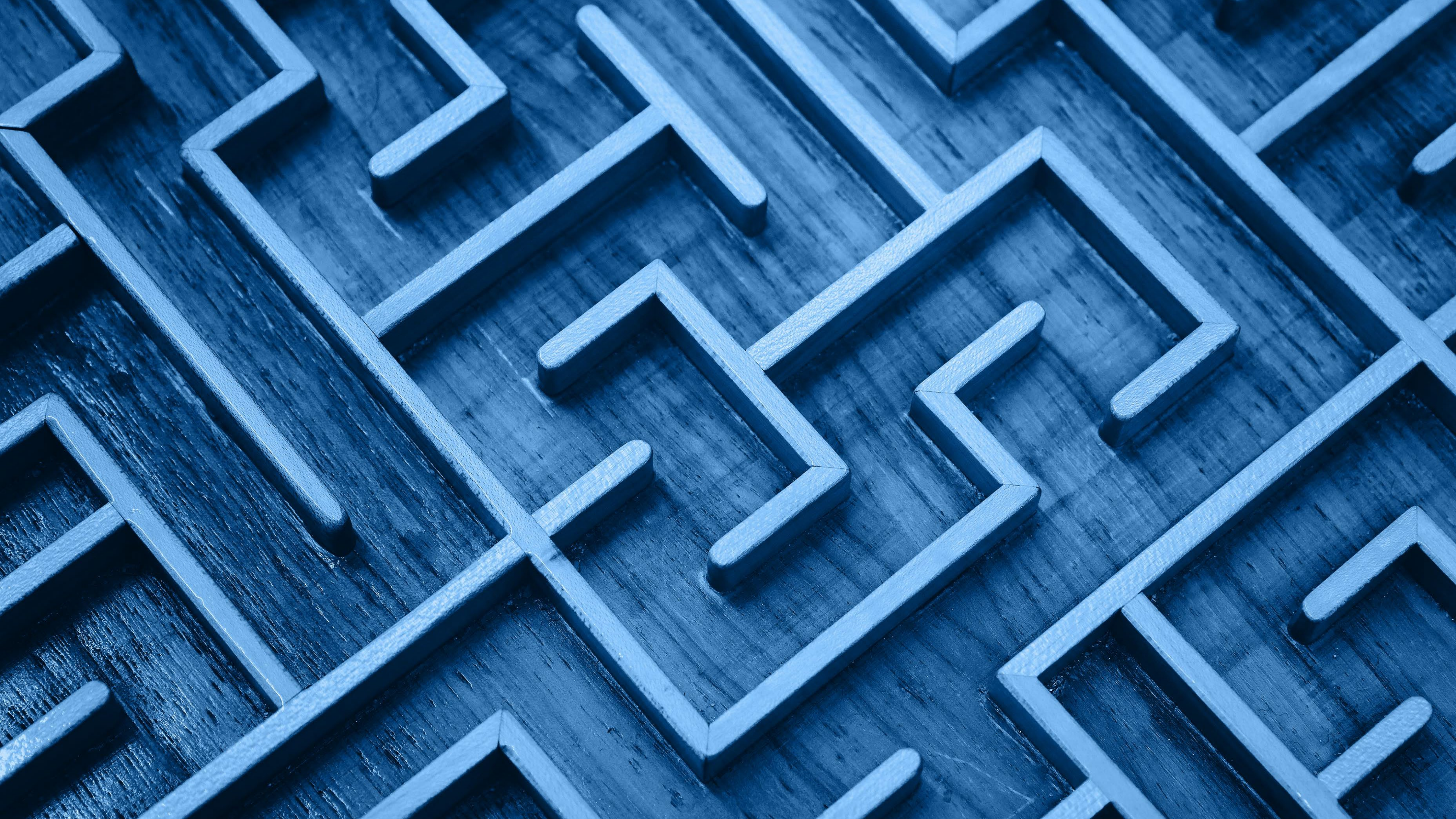


June 20th, 2023

DISPLACING CAC WITH ASHPS

Dual-Fuel Energy and Cost Savings

Ranal Tudawe

Research Analyst – Center for Energy and Environment

Center for Energy and Environment

Agenda

What is a dual-fuel system?
Background on energy models
Results and key takeaways

Big Picture

- Space heating is the biggest end use in NEEA region homes
  - Single-family homes in NEEA's footprint can attribute nearly half their annual energy usage to space heating
  - Decarbonization of space heating via electrification on a clean grid is among the best climate mitigation opportunities for buildings
  - On top of that, they are an incredible energy efficiency technology, up to 600% better than standard gas furnaces
  - But all-electric ASHP systems can be expensive to buy and also to operate compared to natural gas furnaces

- Let's start small?
  - ASHPs also cool better than code minimum central air conditioners (CACs)
  - Can we advance the ASHP market by installing ASHP as cooling measures?

Market Characteristics – RECS 2020 Microdata

Existing HVAC	ASHP Options	Market Size
AC replacement – with ductwork	Ducted ASHP	~2,000,000 homes
Big Opportunity – 2,000,000 homes		
Electric baseboard	Cold-climate ducted HP	~300,000 homes
Electric furnace	Ducted ccASHP	~280,000 homes
Propane furnace	Ducted dual fuel ccASHP	~82,000 homes

cee
Center for Energy and Environment

Overview of a Dual-Fuel System

FURNACE

- Furnace is typically natural gas fueled, but can use a delivered fuel
- Operates during colder heating season temperatures;
- Furnace capacity is selected for the entire heating load of the home.

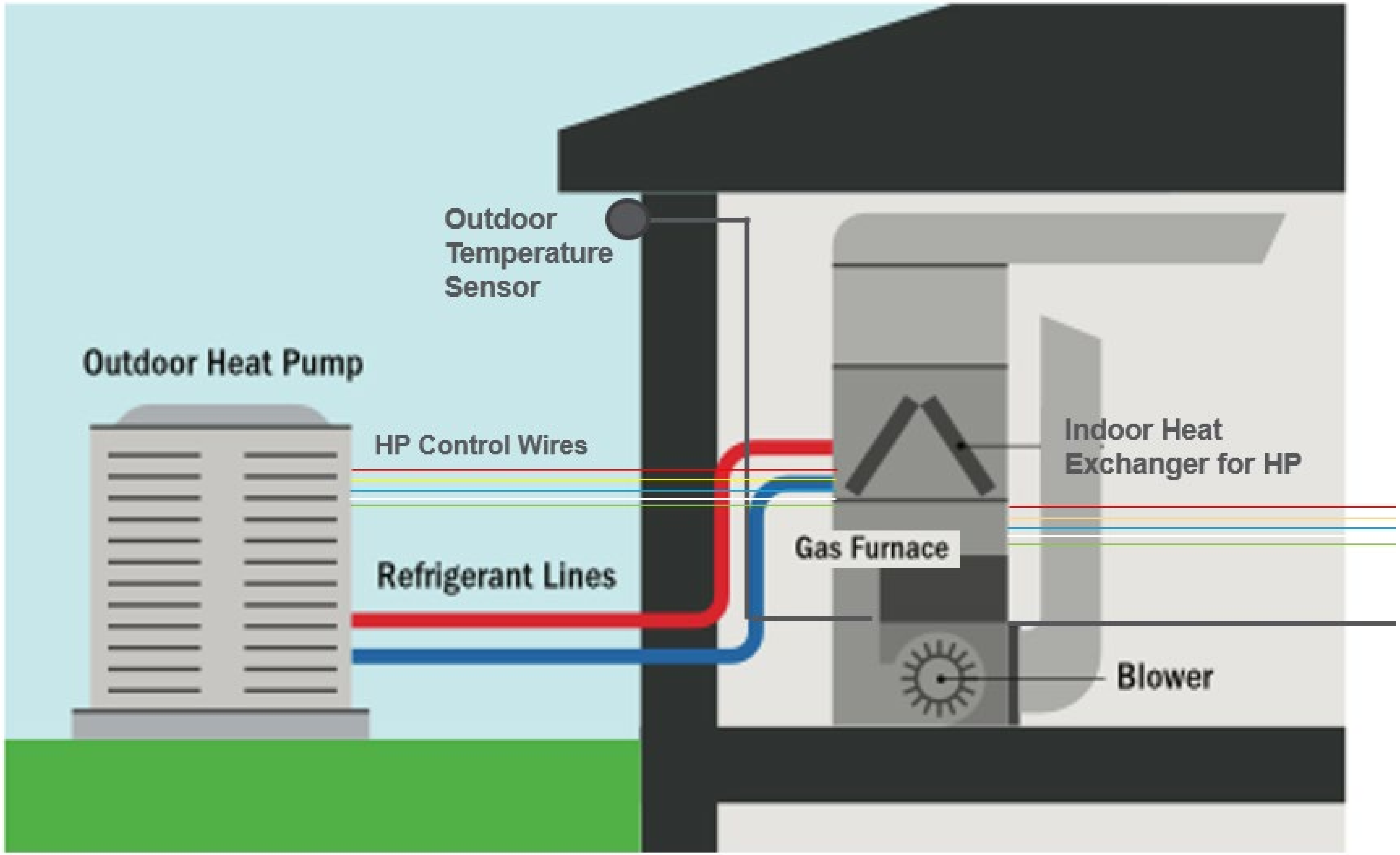
HEAT PUMP

- Heat pump uses electricity for operations
- Operates during warmer heating season temperatures
- HP capacity is selected for the AC cooling load – key design element

CONTROLLER

- Controller selects furnace or HP as heating source
- It is wired to the furnace, the HP, and an outdoor temperature sensor

Dual Fuel Configuration



The controller is located conveniently in the home

- The outdoor temperature sensor reading drives fuel source decision.
- The controller is programmed by installer for an outdoor temperature "switchover"
- The controller opens and closes 24 volt circuits (analog) to achieve control.
- There are TWO essential installation elements here:
    1. Correct wiring
    2. Proper programming

Two Switchover Temperature Types

1. Thermal Balance Point
   - An analysis of the heating load calculation and the heating capacity “curve” of the heat pump
   - Installer selects the outdoor temperature ”point” at which the HP can no longer satisfy the heating load of the home.
   - Easier of the two balance points to calculate; doesn’t tend to change over time.
2. Economic Balance Point
   - An analysis of the heating load of the home, and the cost per BTU of the HP and the furnace. Usually requires software to calculate
   - For manufactured supplied configurations: Installer must know the costs of both fuels (electric and gas); these costs must be fixed. Otherwise, installer brain will explode.
   - More complicated and likely to change over time.

Background on Energy Models

Background

- Centrally ducted air conditioning (CAC) systems with natural gas furnaces are the most common residential HVAC package
- Replacing CAC on failure or displacing CAC in new construction with ASHPs is a very large opportunity
- Preserving the furnace in a dual fuel (hybrid heating) configuration:
  - Eliminates difficult heat load sizing for ASHPs
  - Eliminates peak load issues
  - Enables fuel switching demand response strategies
  - Adds flexibility to ASHP system selection
  - Enables diverse, regionally appropriate decarbonization strategies

Defining the Product Segment

WHAT IT IS	WHAT IT ISNT
✓ Centrally ducted	✗ Mini-split / Multi-split / Mini-ducted
✓ Natural gas backup (dual fuel or hybrid heat)	✗ All-electric or propane backup
✓ Sized for cooling	✗ Sized for heating
✓ Single speed air source heat pump (ssASHP)	
✓ Variable speed ASHP (vsASHP)	
✓ Cold climate ASHP (ccASHP)	
✓ Interoperable or non-interoperable with existing furnace	

Objectives

- This modeling study seeks to understand ***energy and customer HVAC bill impacts*** from ASHP as CAC replacements across a variety of representative applications in the NEEA region

- ***Customer HVAC bill impacts*** depend on the relative costs of natural gas and electricity
  - Iterate through parameter space of electricity and natural gas rates to estimate bill impacts and how they are related to ASHP type and operation, namely ***switchover temperature***

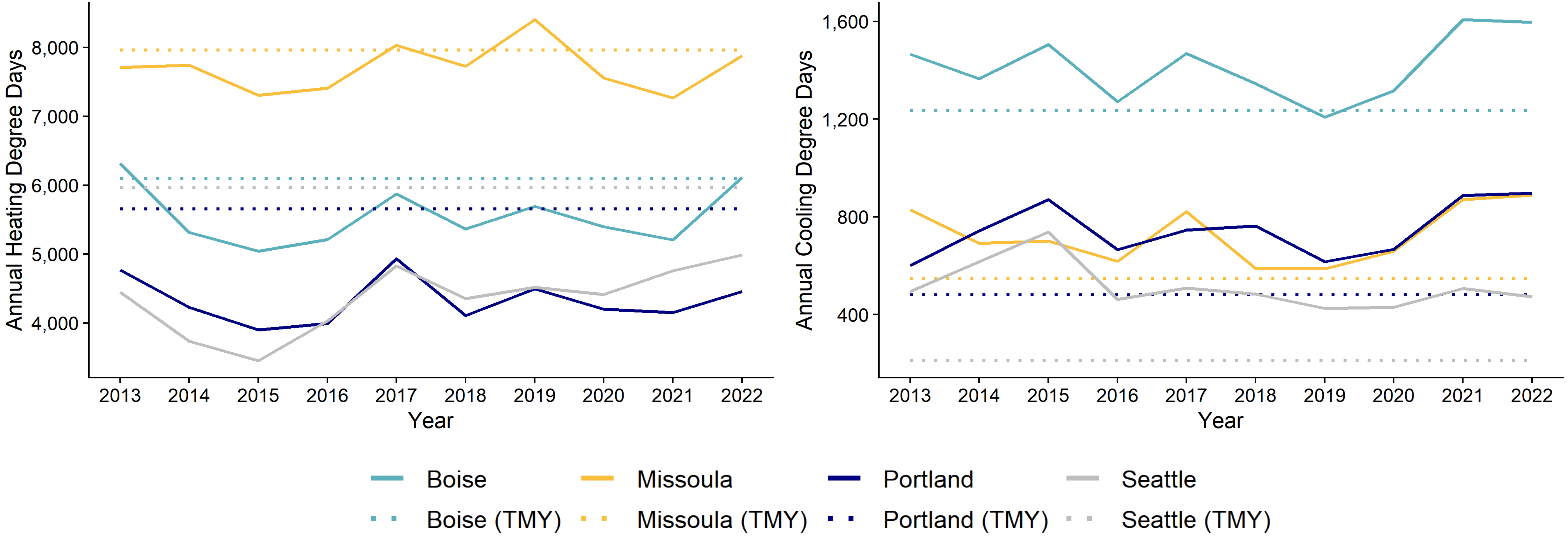
Model Considerations

- **Climate**: NEEA's footprint covers a large geography with diverse heating and cooling requirements
- **Building type**: Residential buildings vary substantially in size, age, design, and efficiency
- **ASHP type**: Products for ASHP systems as CAC replacement spans from federal minimum efficiency single speed systems to high performance cold climate variable speed systems
- **Replacement type**: ASHPs as CAC replacements can replace the CAC outdoor unit while keeping the furnace/air handler or they can replace the furnace/air handler as well, adding combustion and fan efficiency compared to the baseline
- **Switchover temperature**: Dual-fuel systems are commonly operated such that ASHP is used in mild weather and a gas furnace in cold weather; the outside temperature at which these systems 'switchover' can vary for many reasons
- **Utility rates:** Electric and natural gas costs vary by location and time. Given the sensitivity of ASHP economics to energy costs; this study reflects a wide parameter space to see how ASHP bill impacts vary in response to electric and gas rate combinations
- **Baseline HVAC:** While cooling efficiency is fixed, baselines furnace AFUEs vary regionally

Scenarios of Interest

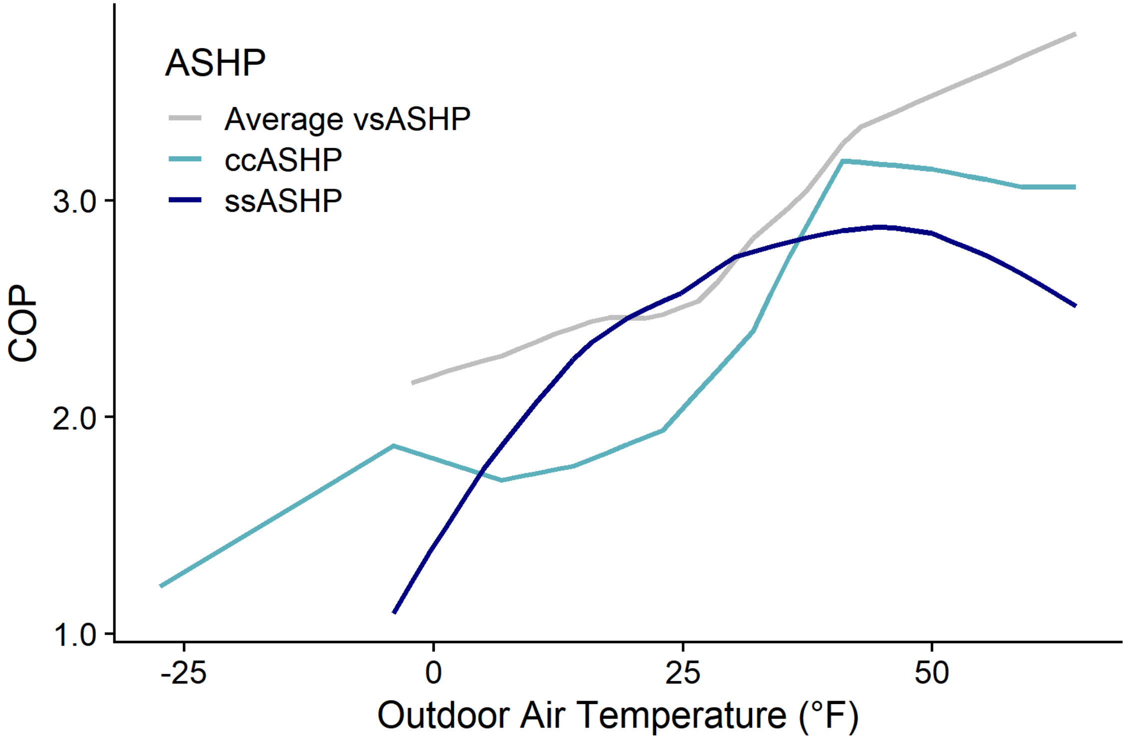
Variable	Details
Climate	• TMY2020 weather for Seattle, WA; Portland, OR; Boise, ID; Missoula, MT
Building type	• SF_SEEM1 1344sf (slab on grade) UA 263 • SF_SEEM2 2200sf (crawl) UA 474 • SF_SEEM3 2688sf (basement) UA 610
ASHP type	• Single speed ASHP (ssASHP) • Variable speed ASHP (vsASHP) • Cold climate variable speed ASHP (ccASHP)
Replacement type	• CAC only (keep furnace) • CAC + Furnace (full replacement)
Switchover temperature	• Temperature at which ASHP switches to backup furnace • Between 0°F and 65°F (regionally appropriate values)
Utility rates	• Electric rates varied from 0.08 to 0.12 $/kWh • Natural gas rates varied from 0.70 to 1.50 $/therm
Baseline HVAC	• Furnace AFUE 90% - 96% (regionally appropriate value) • SEER1 14.2 CAC

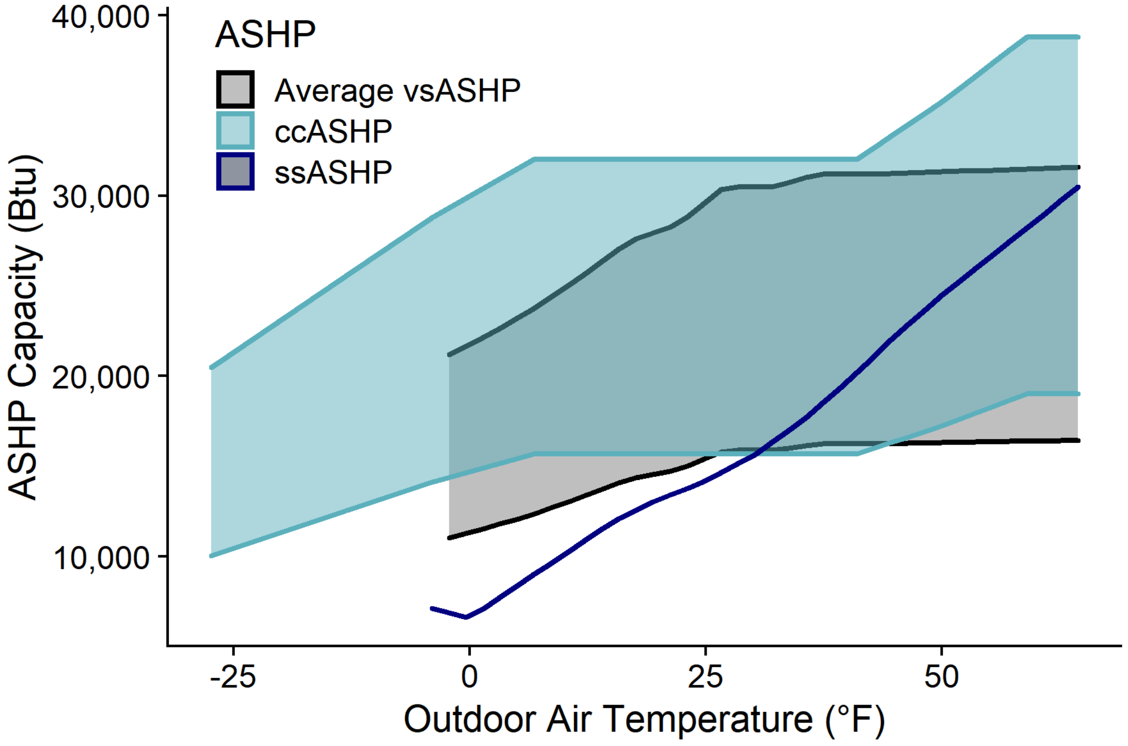
TMY2020 vs Historic Weather



ASHP Archetypes

ASHP Archetype	SEER1	HSPF1
Single speed ASHP (ssASHP)	15	9
Variable speed ASHP (vsASHP)	20	10.5
Cold climate variable speed ASHP(ccASHP)	18	10

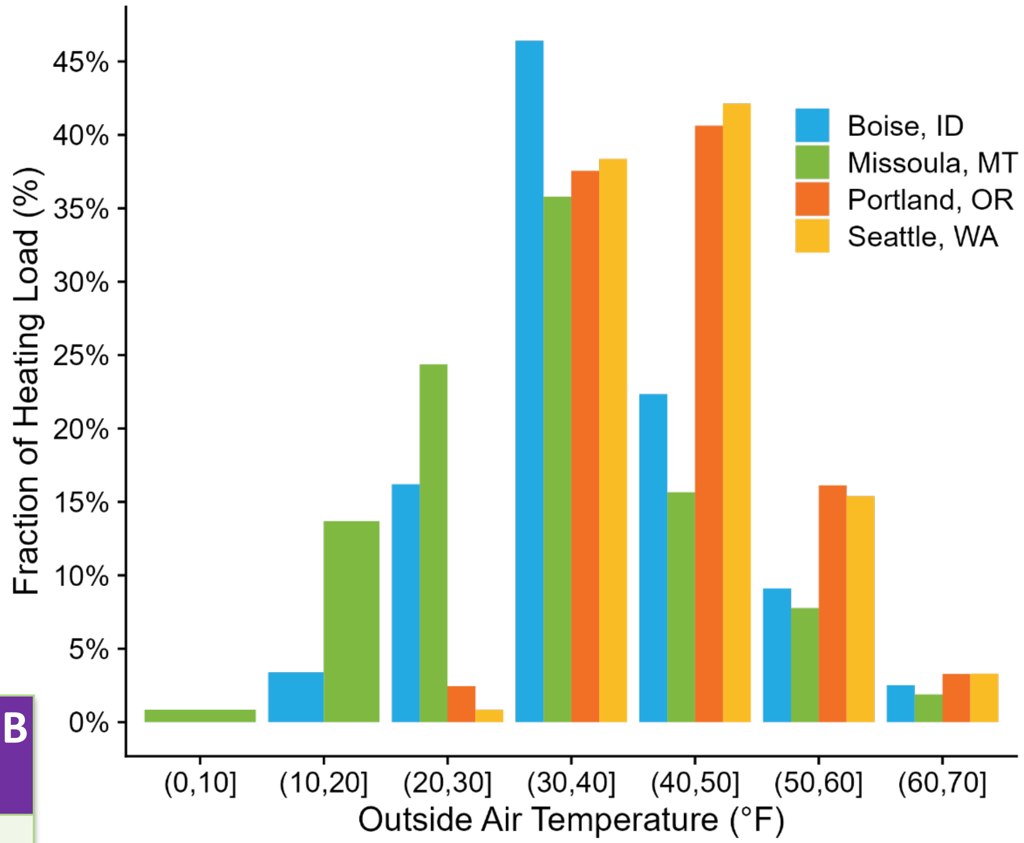




Model Results - Energy

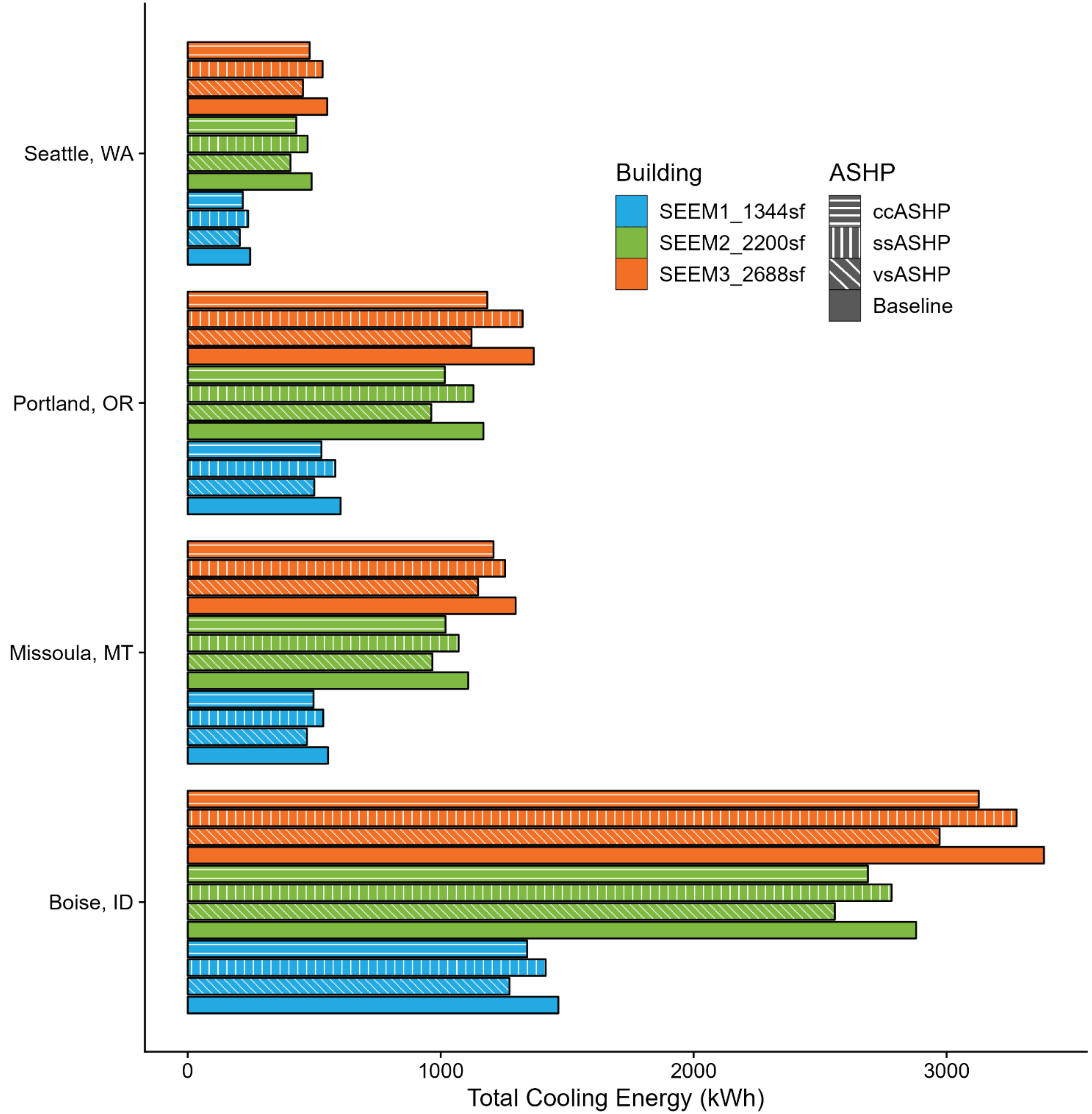
Large Regional Differences in Heating Load

- Portland and Seattle have negligible heating load below 30 °F
- Boise has 20% of the heating load below 30 °F, but mostly above 20 °F
- Missoula has 39% of the heating load below 30 °F, but mostly above 10 °F

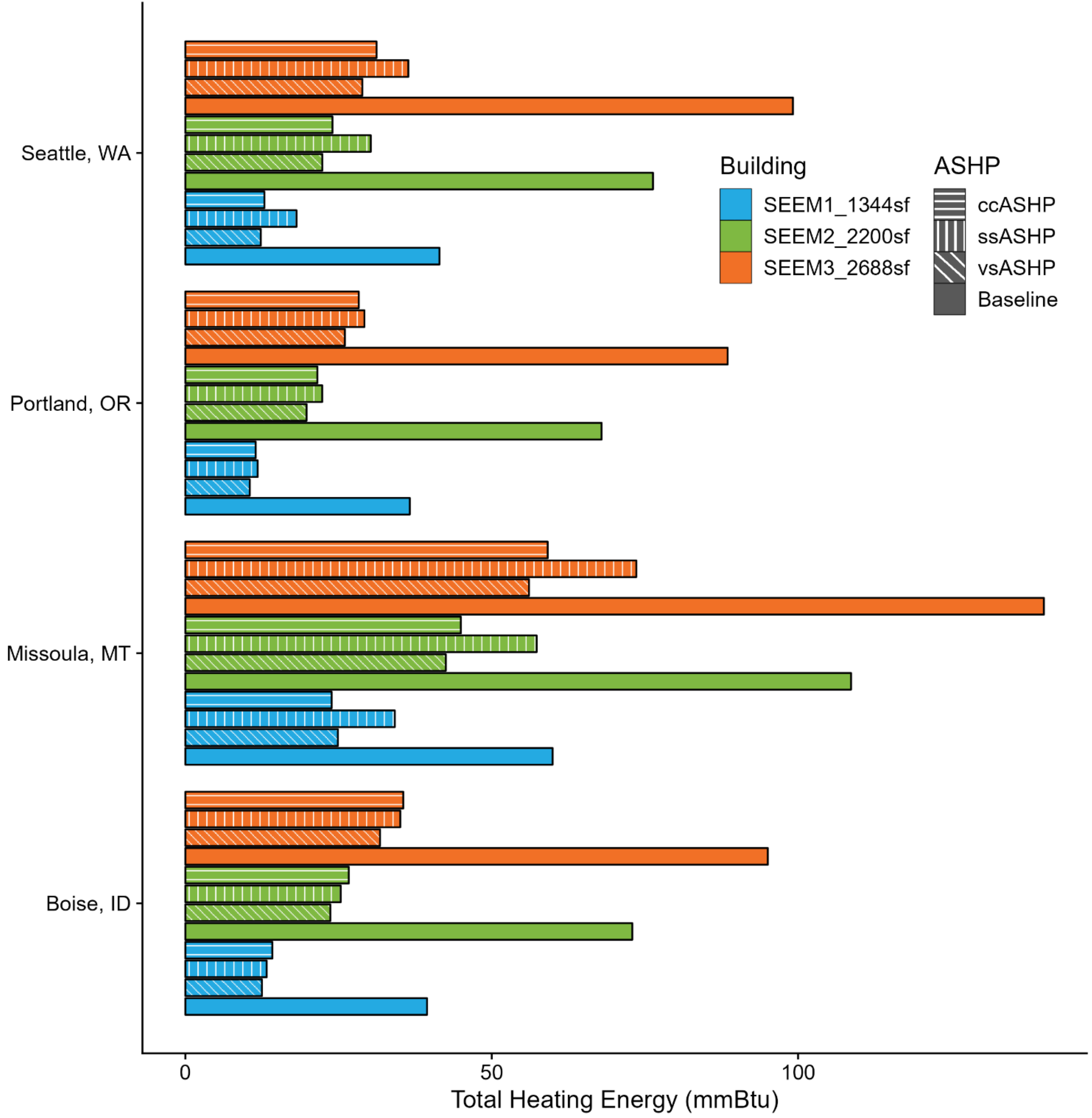


Location	Climate Zone	HDD	99.6% DB (°F)	CDD	0.04% DB (°F)
Portland, OR	4C	5657	26	481	92
Seattle, WA	4C	5967	27	211	86
Boise, ID	5B	6099	11	**1234**	**99**
Missoula, MT	6B	**7964**	**-2**	547	93

Site Cooling Energy



Site Heating Energy

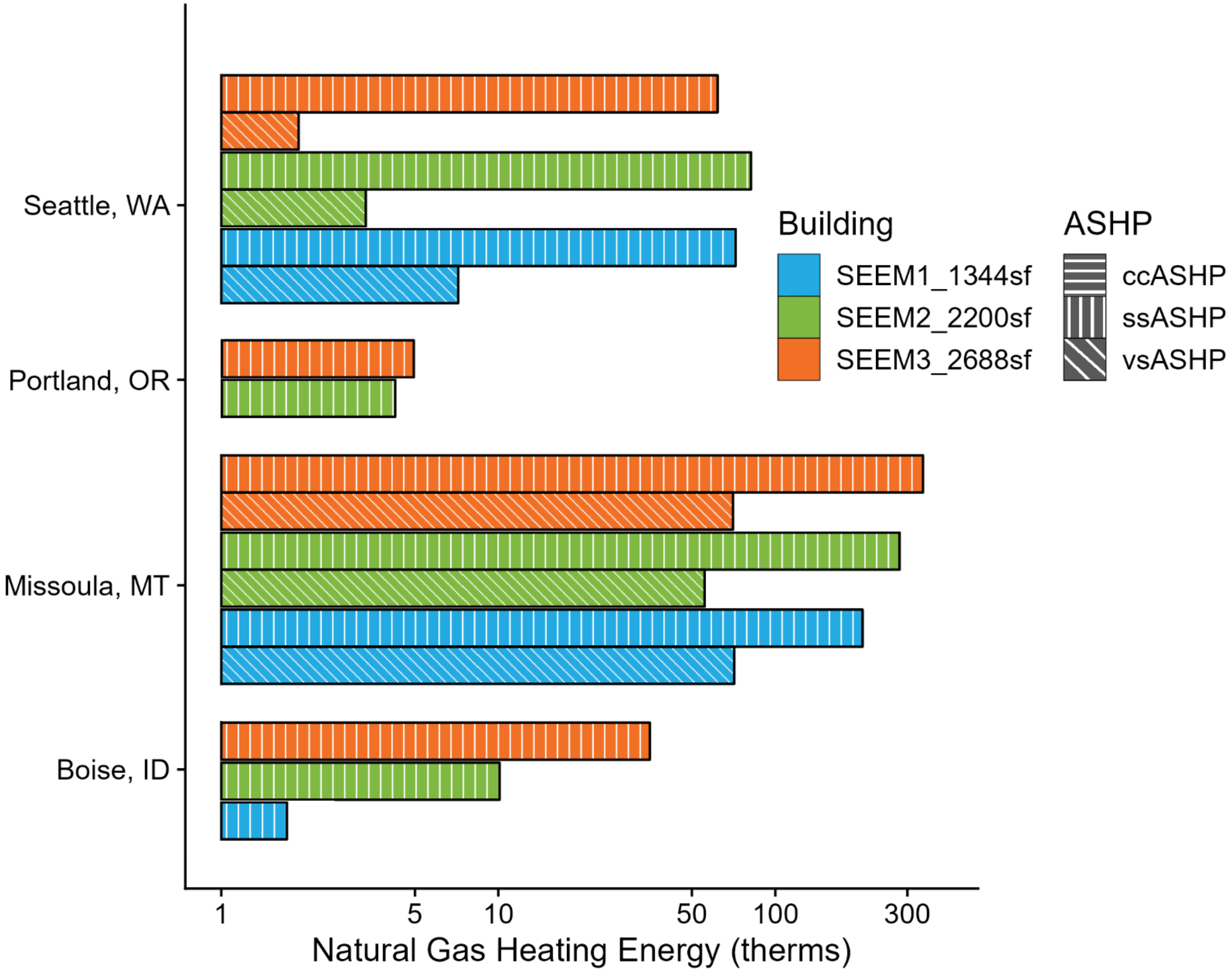


Backup Usage Assumptions

- The backup natural gas is used below the switchover temperature
- In all these energy results, this is the capacity switchover
- Maximizing heat pump may not be the most economic choice
- Model outputs are specific and very sensitive to assumptions

Backup Natural Gas Heating

- No backup heat needed for ccASHPs
- Negligible backup heat for vsASHP excluding Missoula (<10 therm)
- Negligible backup heat for ssASHP in Portland and smaller Boise homes (<10 therm)



Regional ASHP Requirements (Seattle)

- A 2-Ton ssASHP in Seattle runs out of capacity at 35-40 °F
  - Seattle's small cooling load limits the ssASHP sized for cooling
- The same size vsASHP needs has backup below 30-35F for the coldest 1%
- The ccASHP systems can meet the load

Heating Energy from ASHP - Seattle - 2200 sf			
Temperature	ssASHP	vsASHP	ccASHP
20	72%	99%	100%
25	72%	99%	100%
30	72%	99%	100%
35	72%	99%	100%
40	72%	98%	99%
45	68%	82%	82%
50	47%	55%	55%
55	27%	31%	31%
60	13%	14%	15%
65	6%	7%	7%

Regional ASHP Requirements (Portland)

- A 3-Ton ssASHP in Portland runs out of capacity at 30-35 °F
  - Portland requires larger CAC than Seattle
- The same size vsASHP and ccASHP systems can meet the load

Heating Energy from ASHP - Portland - 2200 sf			
Temperature	ssASHP	vsASHP	ccASHP
20	98%	100%	100%
25	98%	100%	100%
30	98%	100%	100%
35	98%	99%	99%
40	96%	97%	96%
45	80%	79%	78%
50	55%	53%	52%
55	32%	30%	31%
60	14%	13%	14%
65	7%	6%	6%

Regional ASHP Requirements (Boise)

- A 4-Ton ssASHP in Boise runs out of capacity at 10-15 °F
  - ssASHP benefits on the heating size when sized for Boise's large cooling load
- The same size vsASHP and ccASHP systems can meet the load

Heating Energy from ASHP - Boise - 2200 sf			
Temperature	ssASHP	vsASHP	ccASHP
10	95%	100%	100%
15	95%	99%	99%
20	92%	96%	95%
25	84%	86%	84%
30	74%	75%	73%
35	45%	44%	41%
40	28%	26%	24%
45	15%	14%	14%
50	7%	6%	6%
55	4%	3%	3%
60	1%	0%	0%
65	0%	0%	0%

Regional ASHP Requirements (Missoula)

- A 3-Ton ssASHP in Missoula runs out of capacity at 15-20 °F
  - Missoula has a large heating load at cold temperatures where the ssASHP can't keep up
- The same size vsASHP can meet load down to 5-10 ° F
- The ccASHP system can meet the load

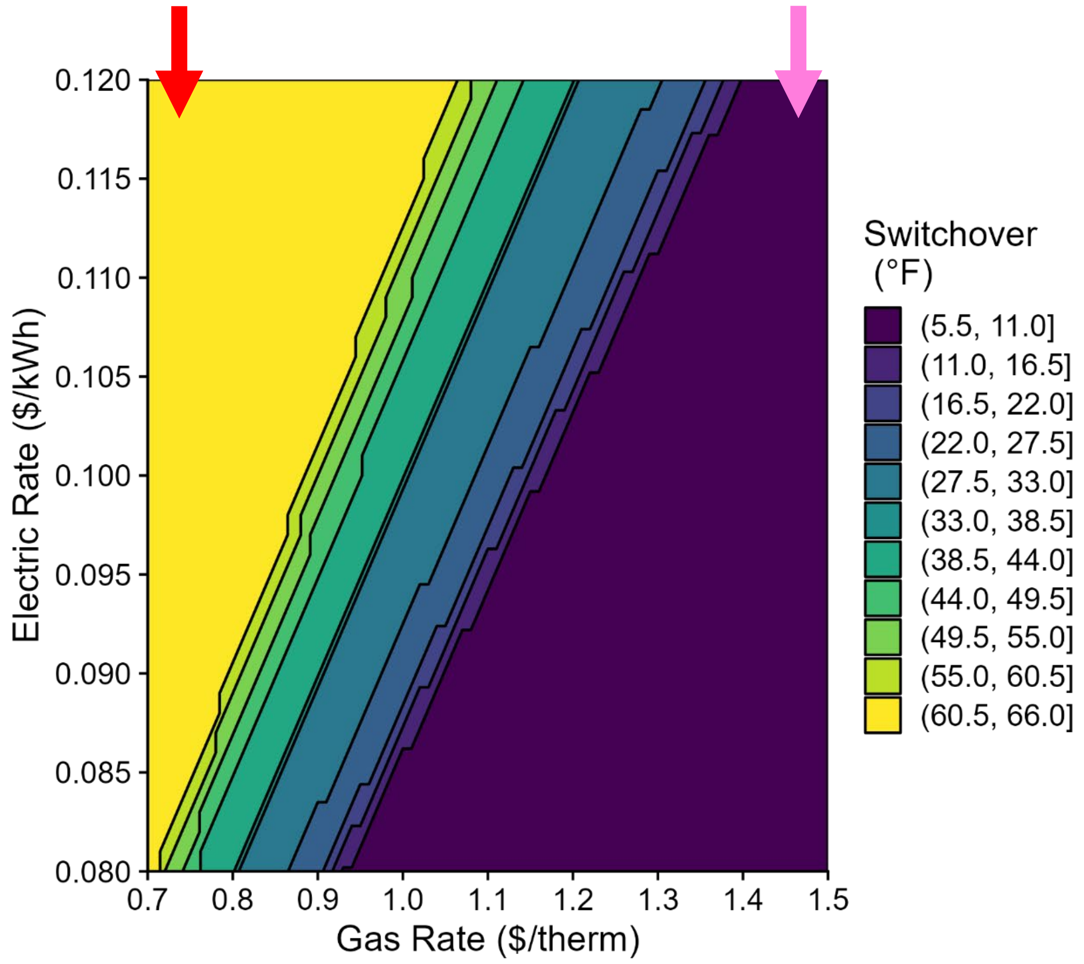
Heating Energy from ASHP - Missoula - 2200sf			
Temperature	ssASHP	vsASHP	ccASHP
0	48%	86%	100%
5	48%	86%	100%
10	48%	86%	99%
15	48%	85%	93%
20	48%	76%	81%
25	47%	62%	65%
30	39%	52%	54%
35	25%	33%	33%
40	15%	19%	19%
45	9%	12%	12%
50	5%	7%	7%
55	3%	4%	4%
60	1%	1%	1%
65	0%	0%	0%

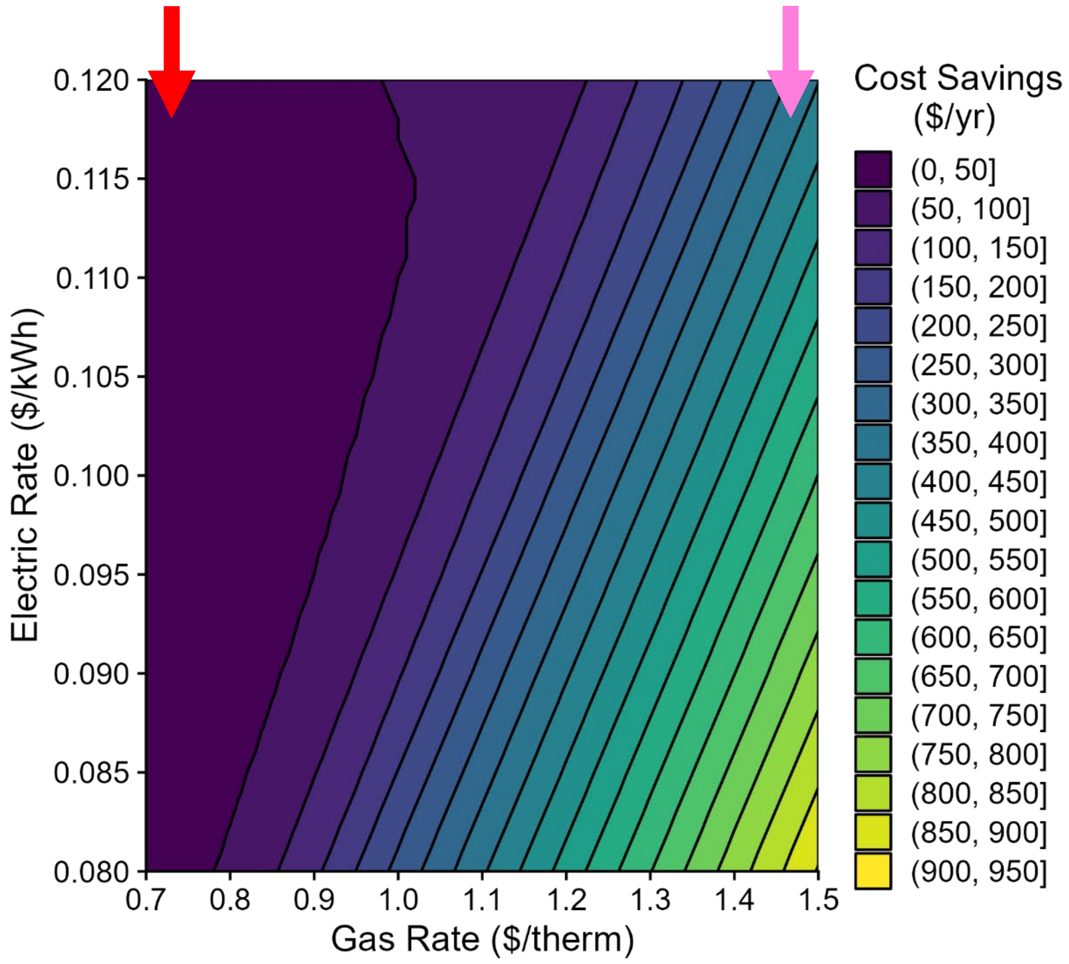
Model Results - Economics

Customer HVAC Energy Bill Impacts

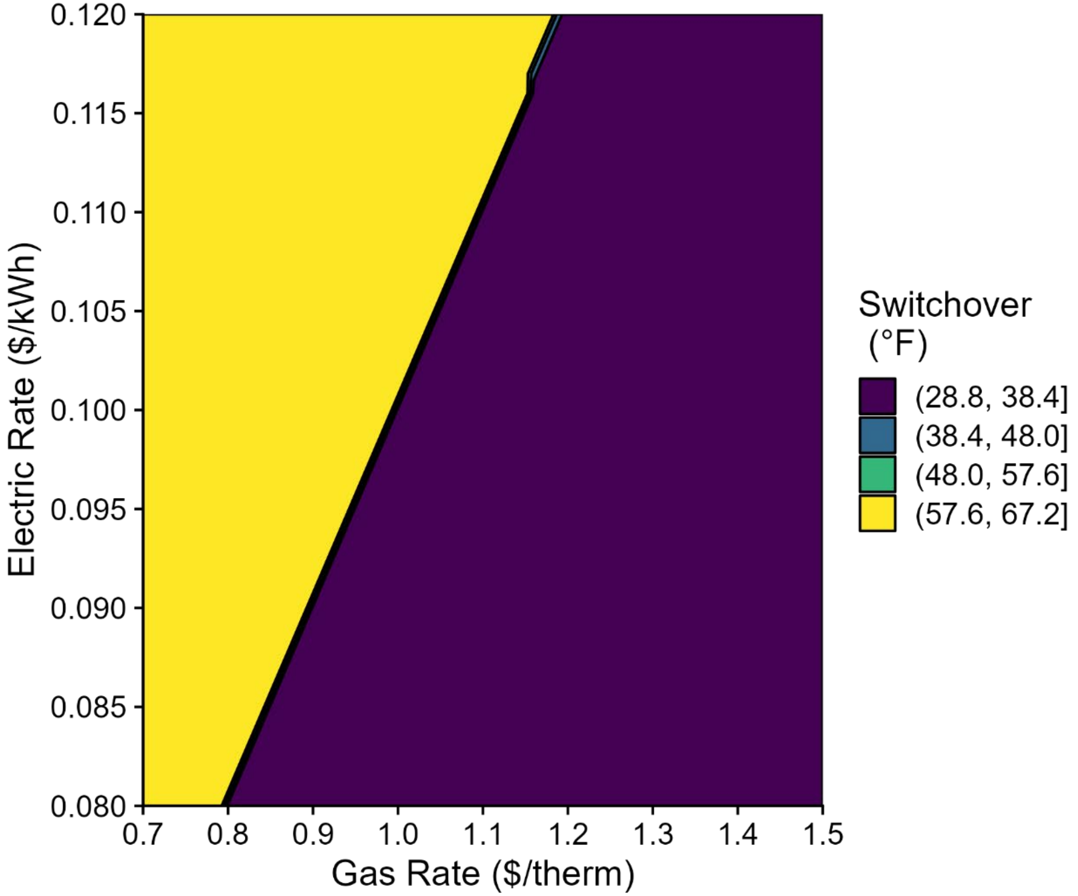
- All scenarios yield some bill reductions (although many are very close to zero) because the system can be operated in CAC-only mode and all ASHP systems have higher efficiency than the baseline CAC
- Switchover temperature can be adjusted to values above the capacity-based switchover to affect HVAC energy bill impacts
  - ASHP performance decreases with outside temperature
  - Combination of ASHP and switchovers produce different costs due to differences in heating hours at each temperature and the cost of natural gas and electricity
- This model yields about 500 scenarios each representing a climate, ASHP type, building model, replacement type. Each of these scenarios can be optimized to identify the switchover temperature that maximizes costs savings at specific electricity and gas rates.
- Examples of these results follow

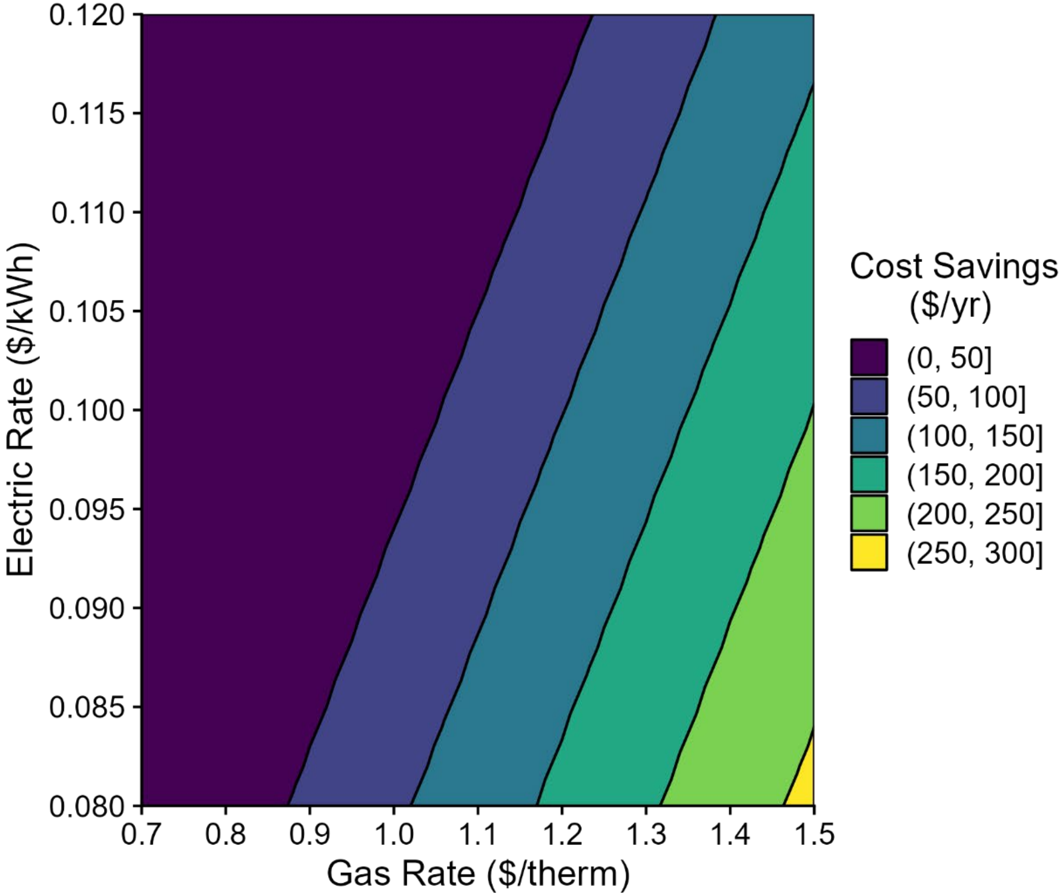
How to Interpret Contour Plots



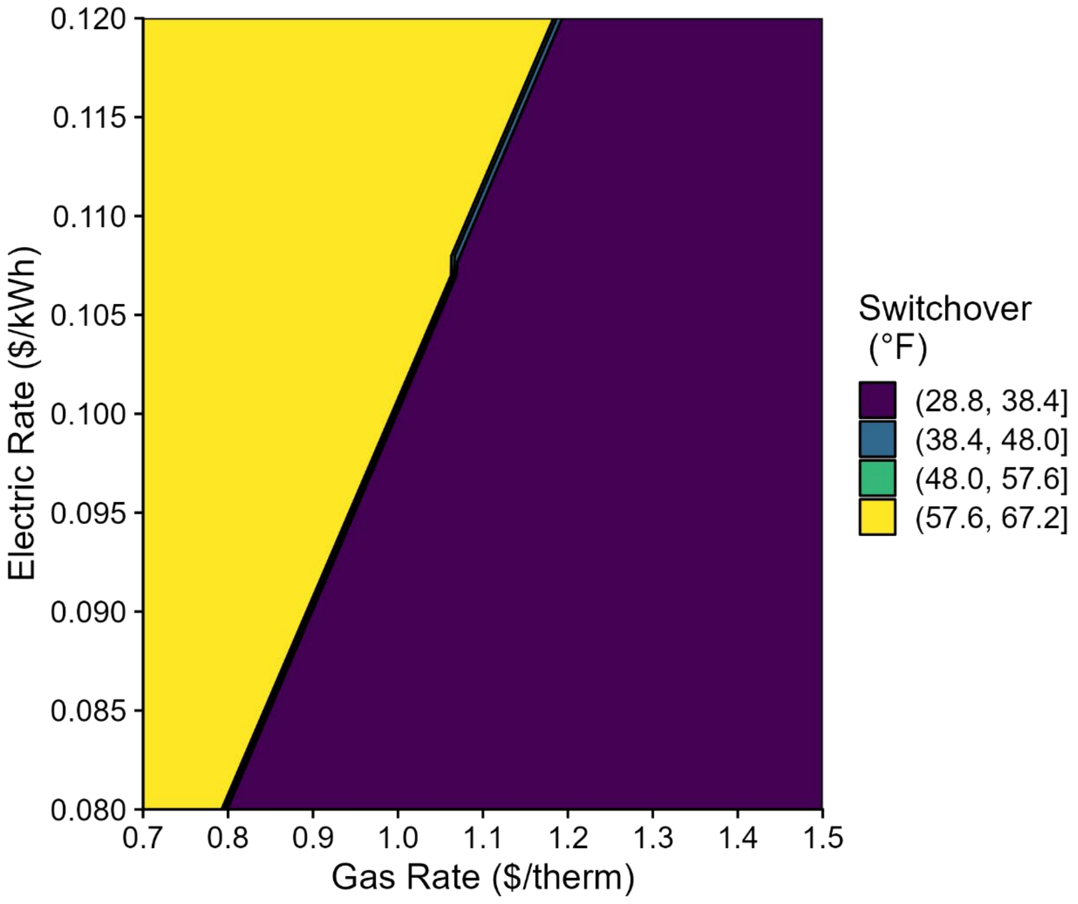


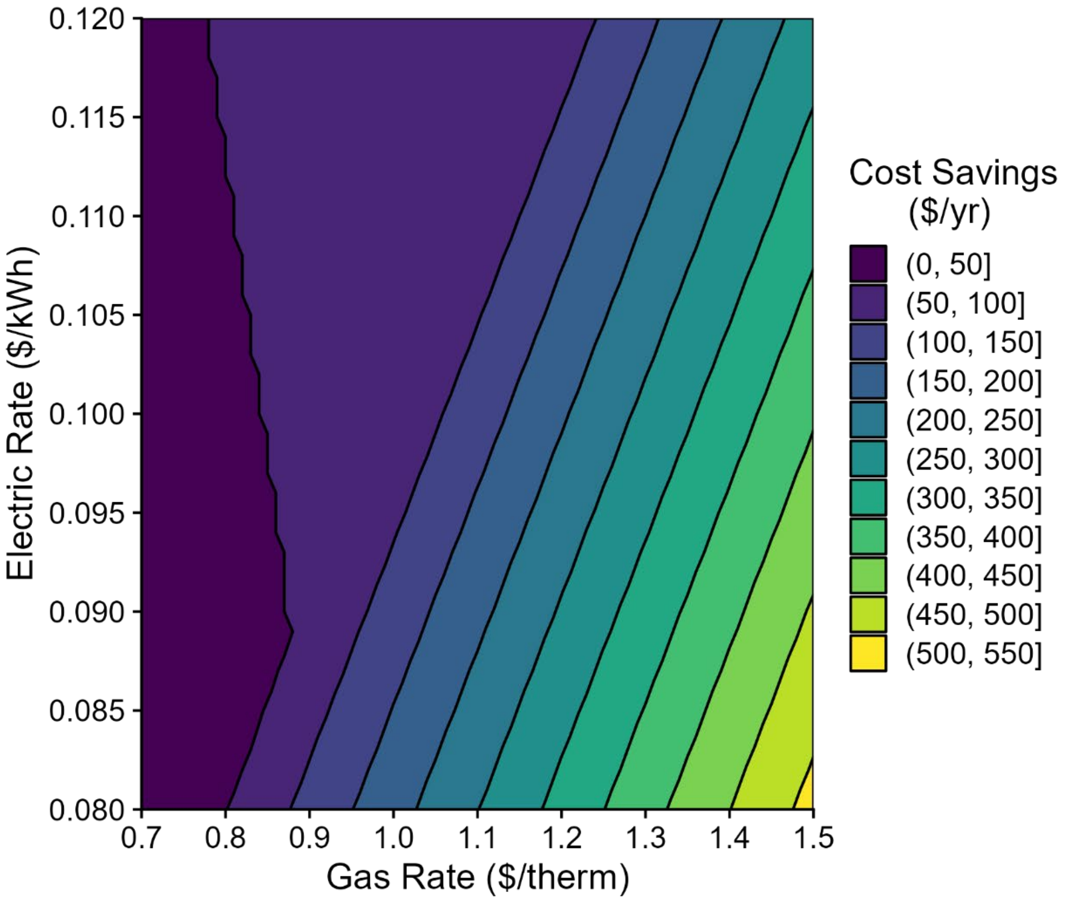
ssASHP on SEEM1_1344sf in Seattle



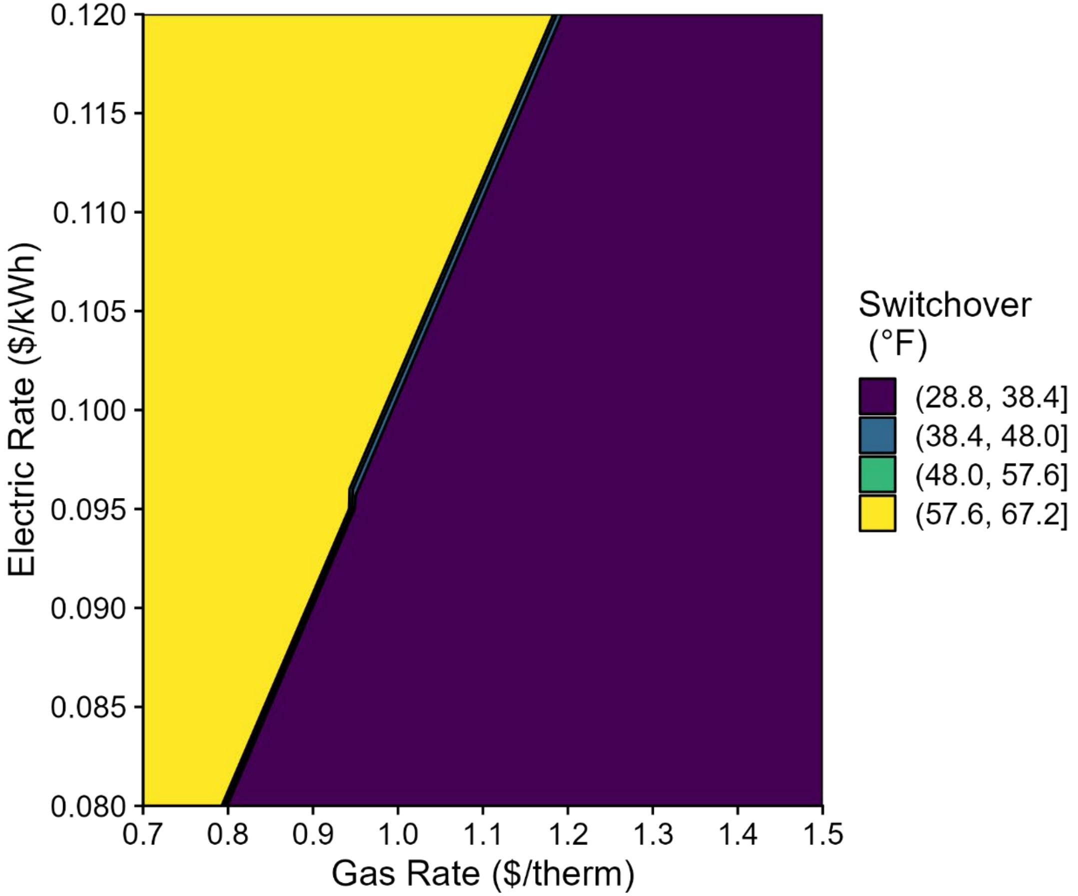


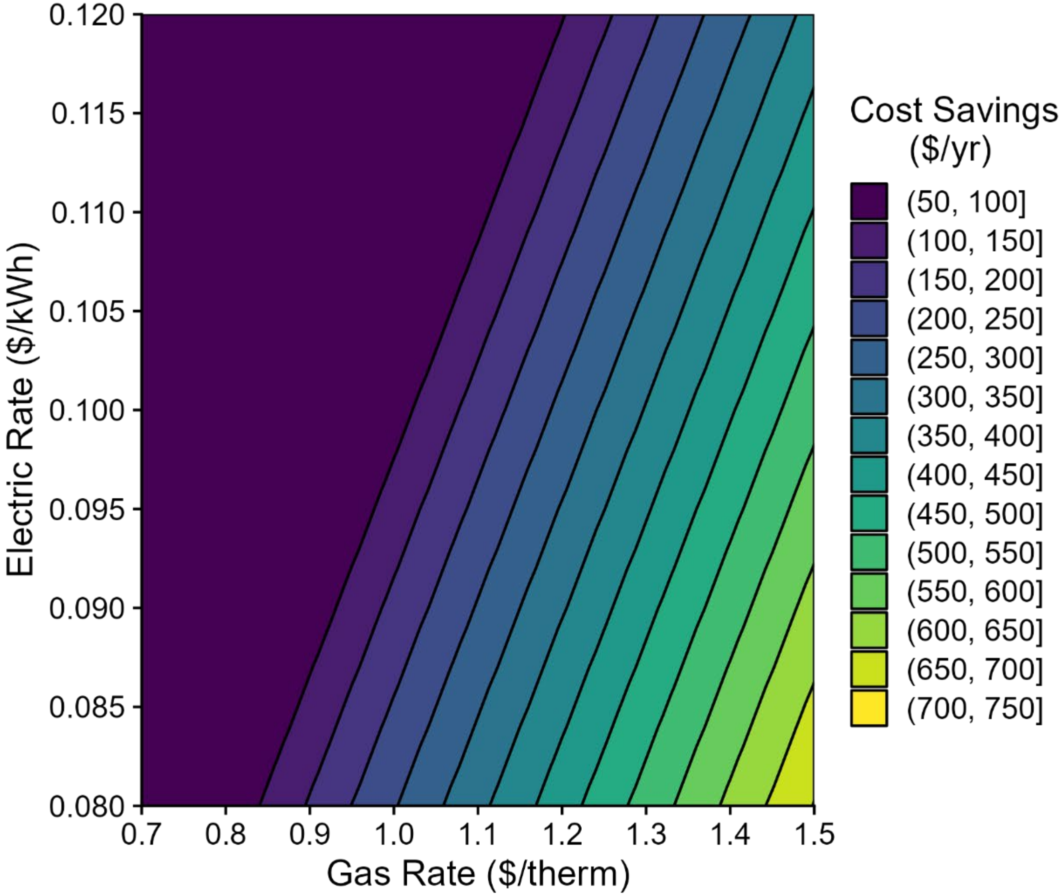
ssASHP on SEEM2_2200sf in Seattle



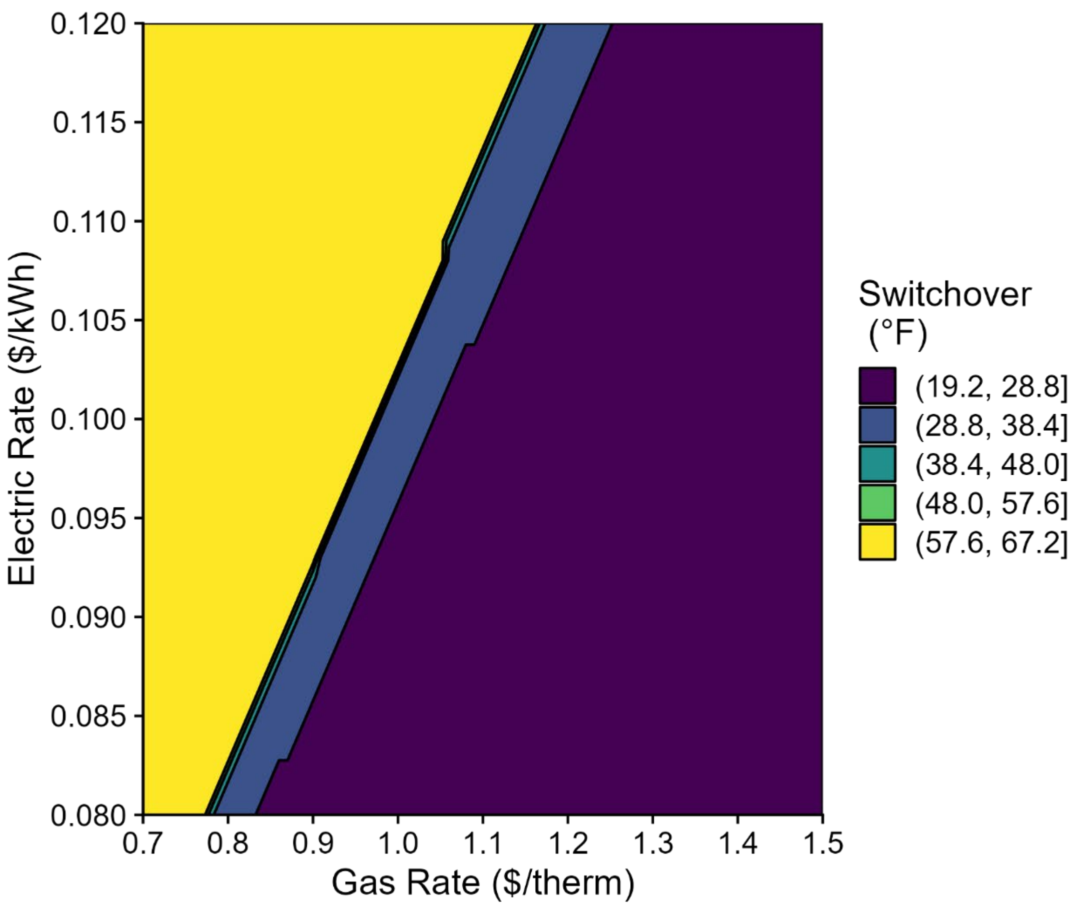


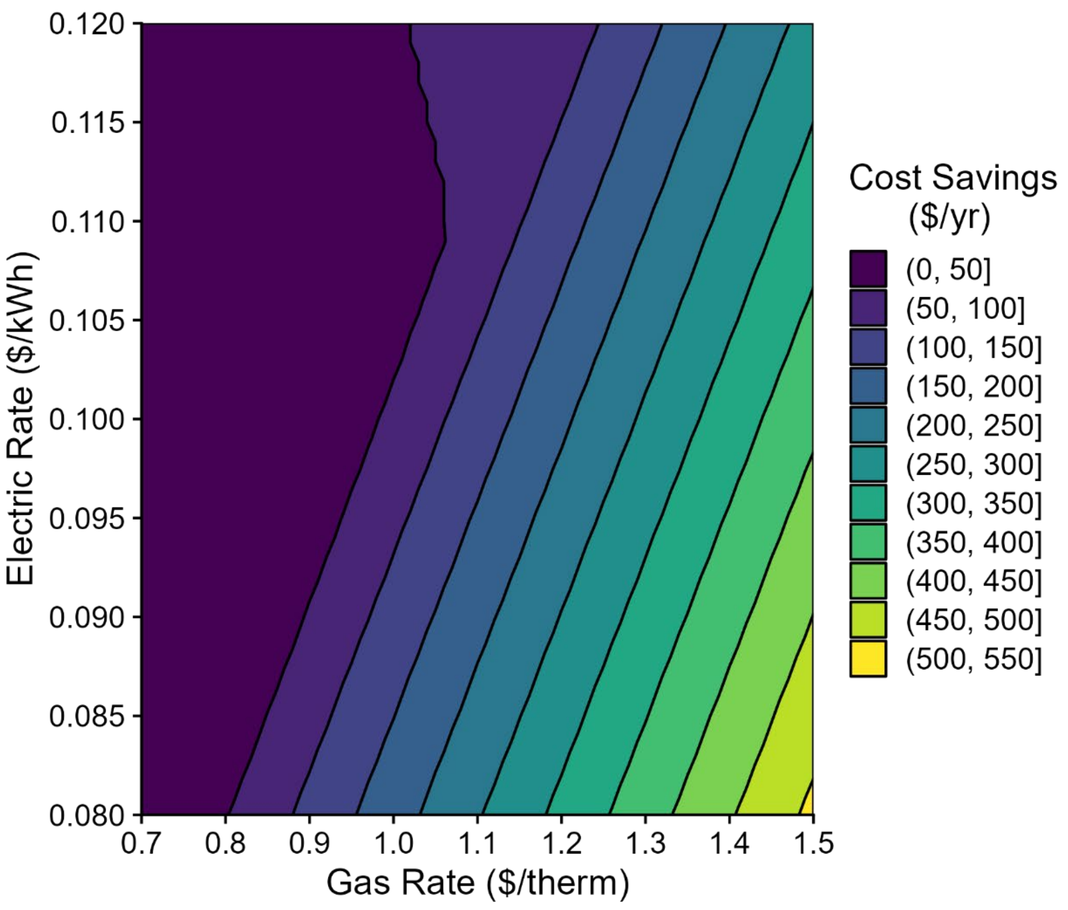
ssASHP on SEEM3_2688sf in Seattle



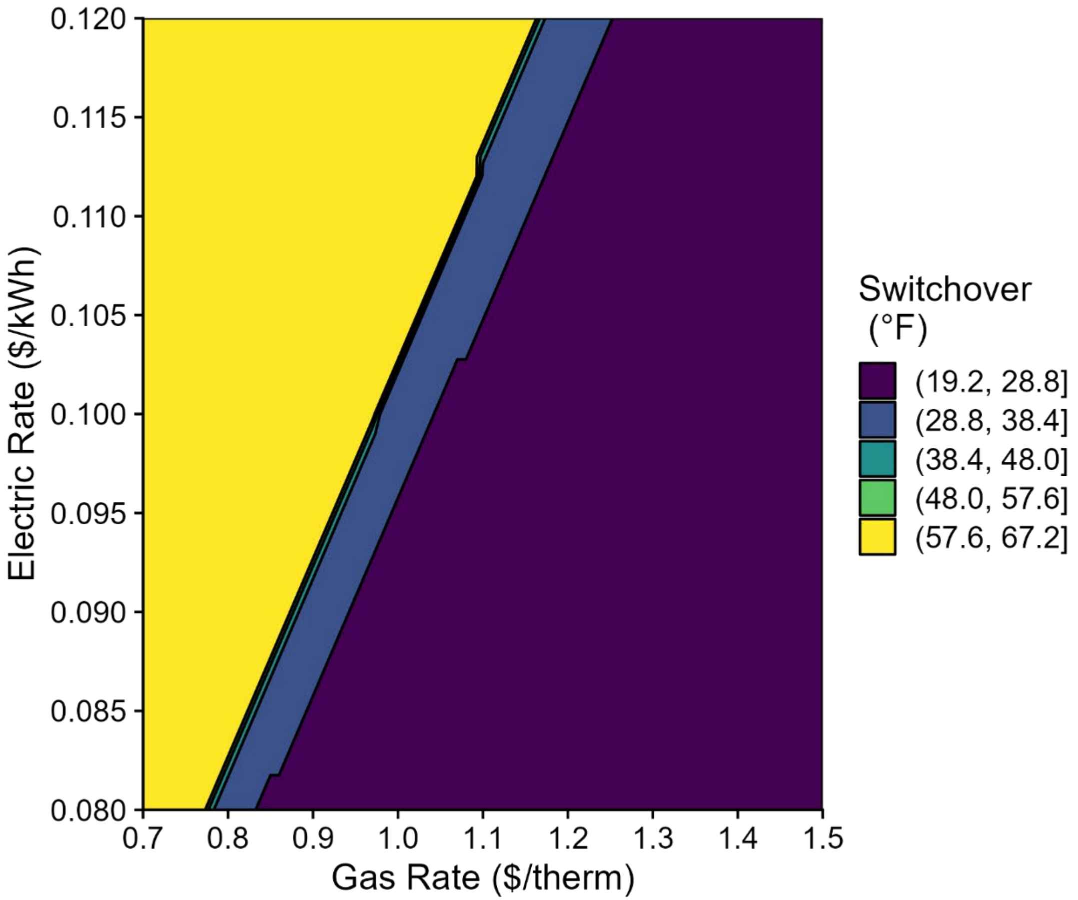


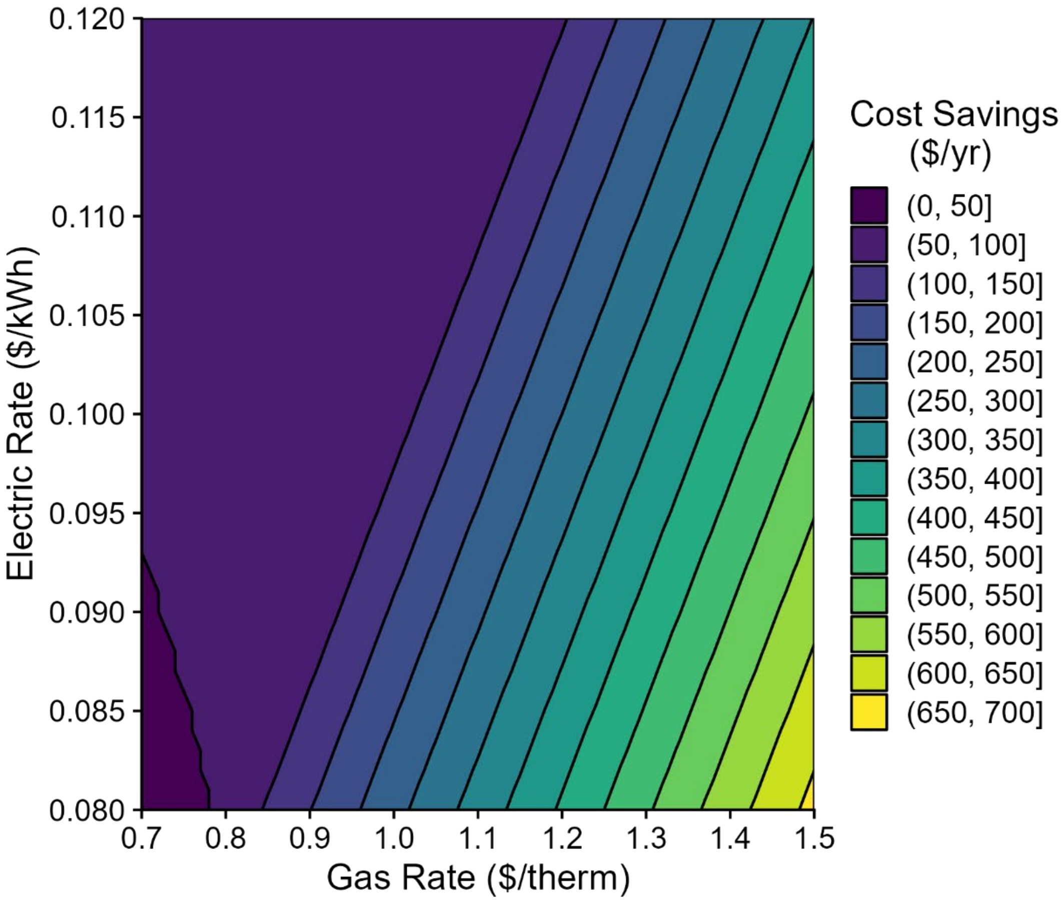
ssASHP on SEEM2_2200sf in Portland



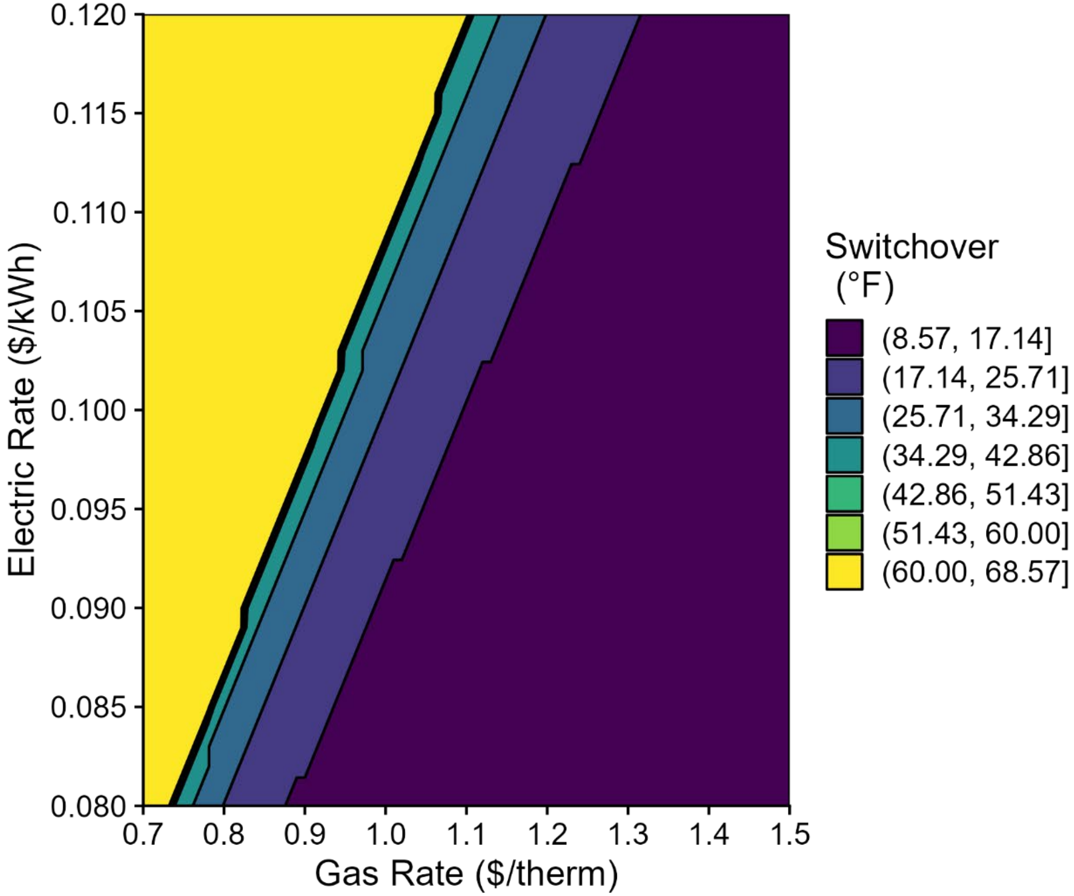


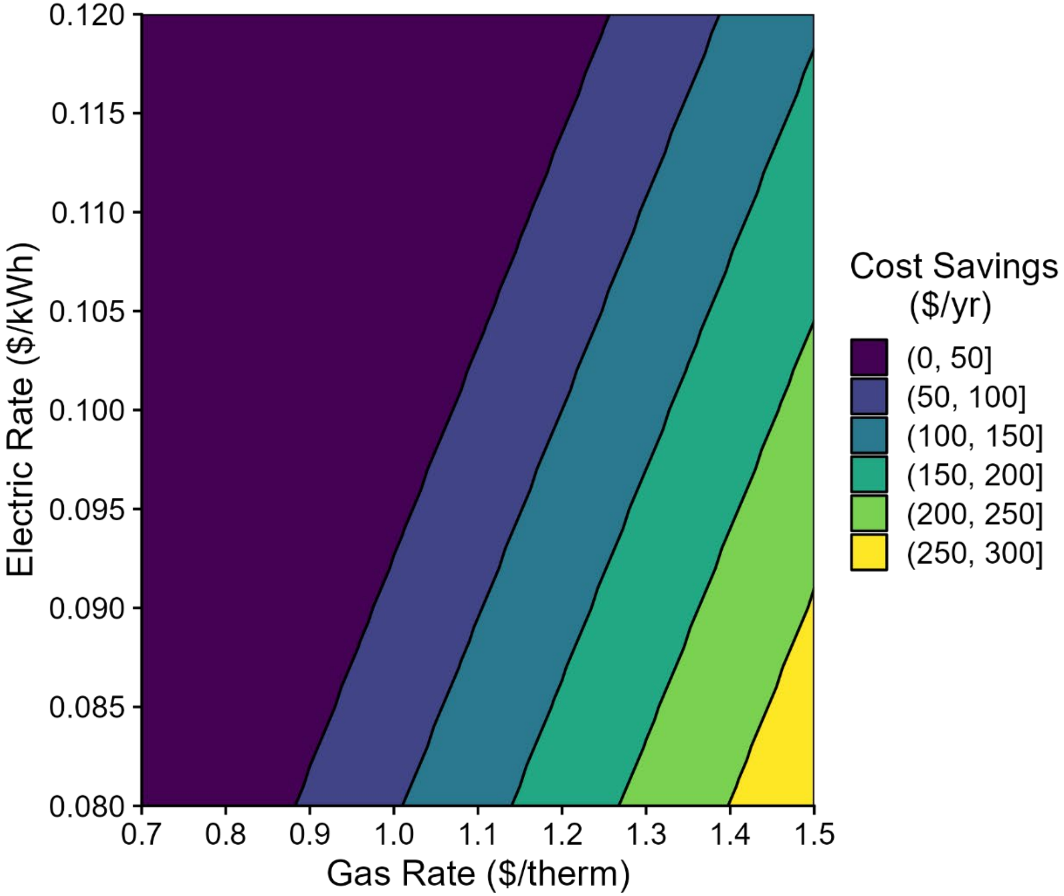
ssASHP on SEEM3_2688sf in Portland



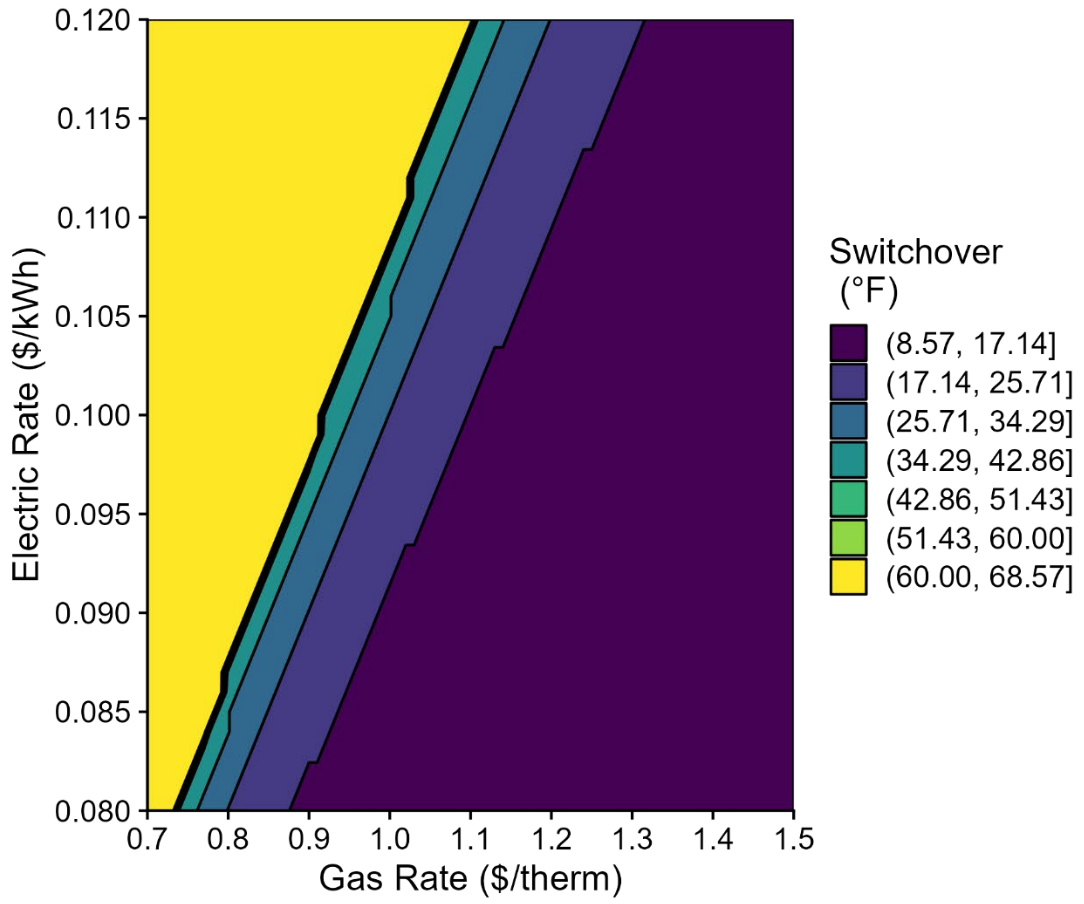


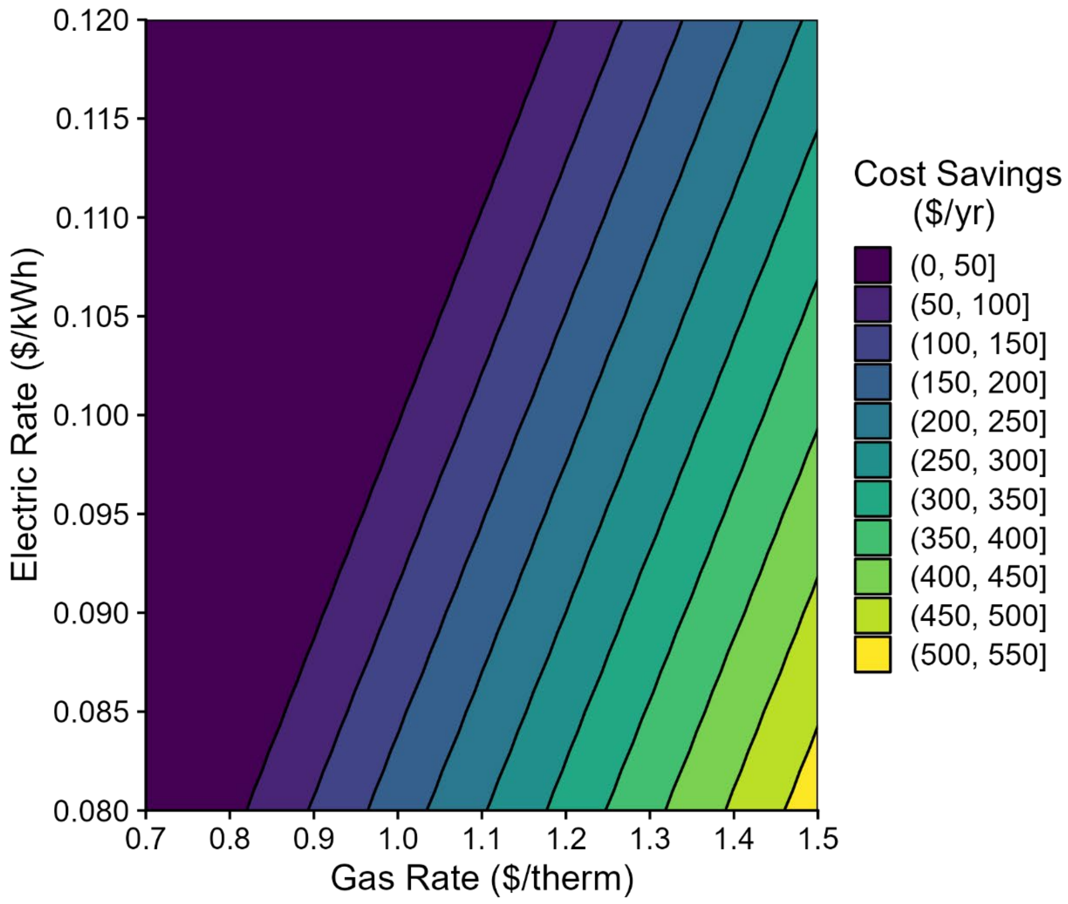
ssASHP on SEEM1_1344sf in Boise



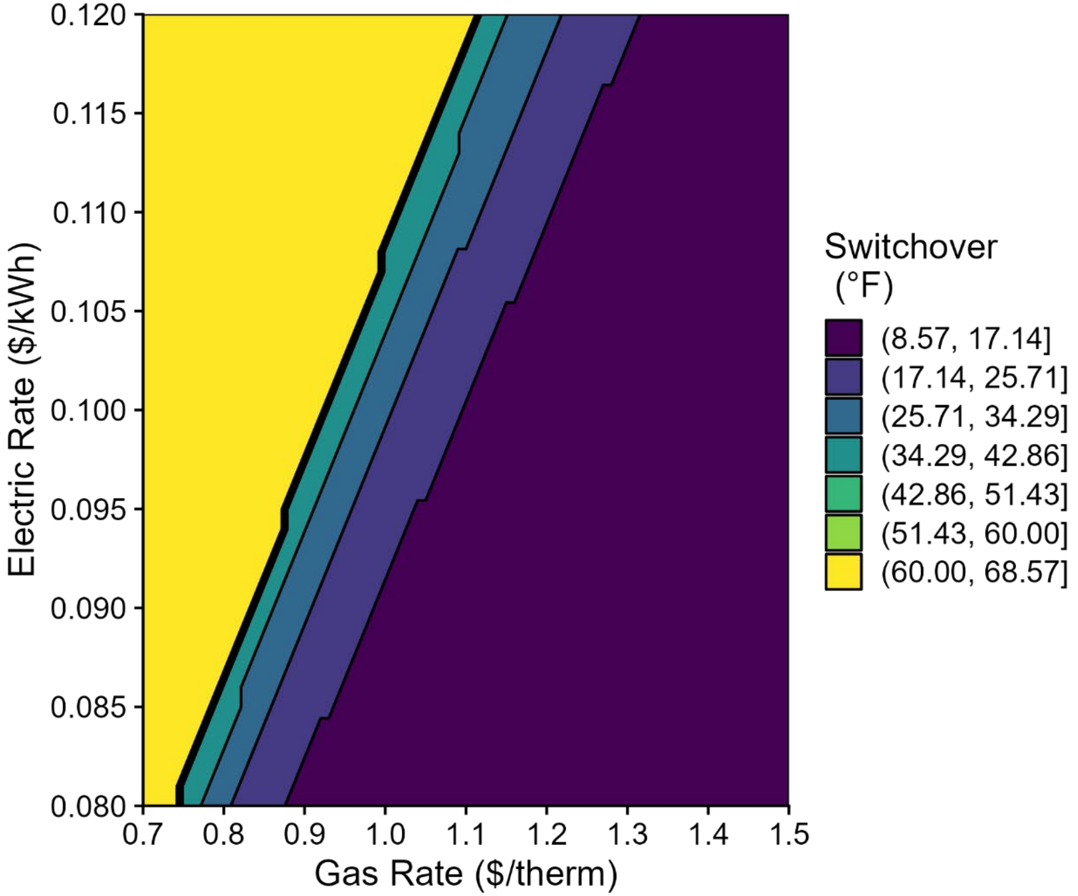


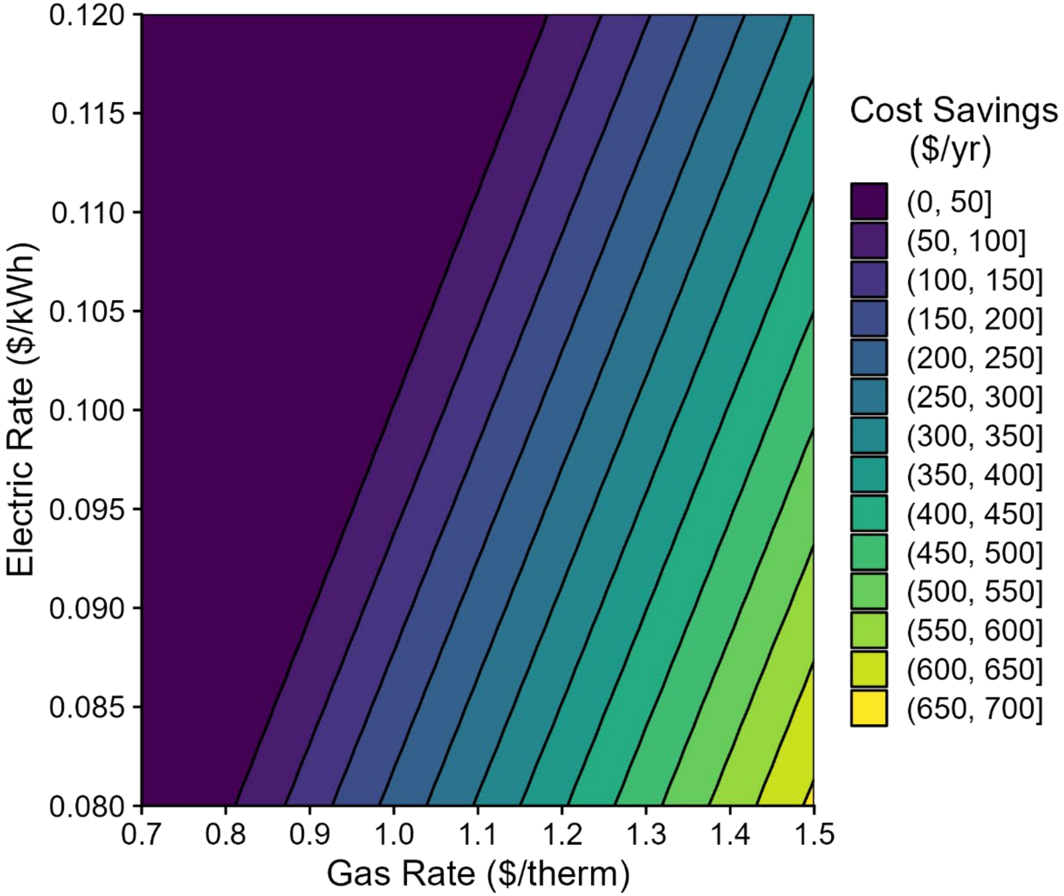
ssASHP on SEEM2_2200sf in Boise



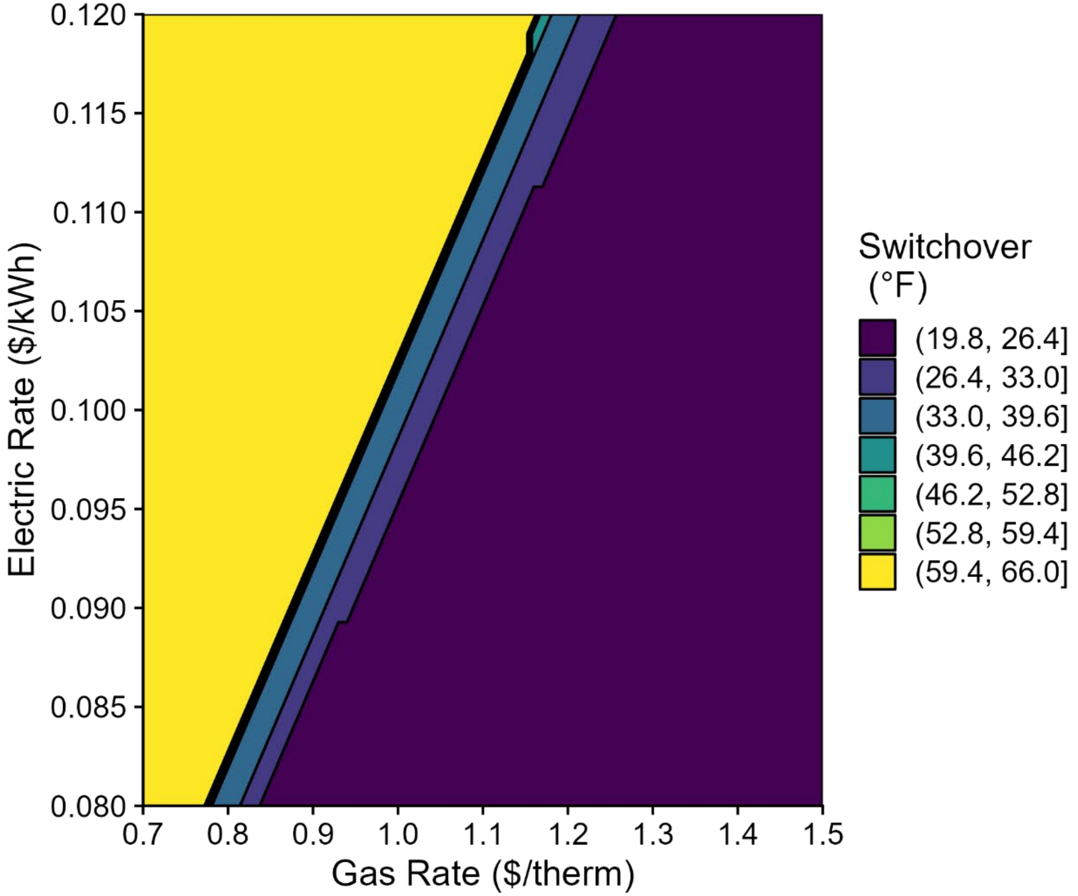


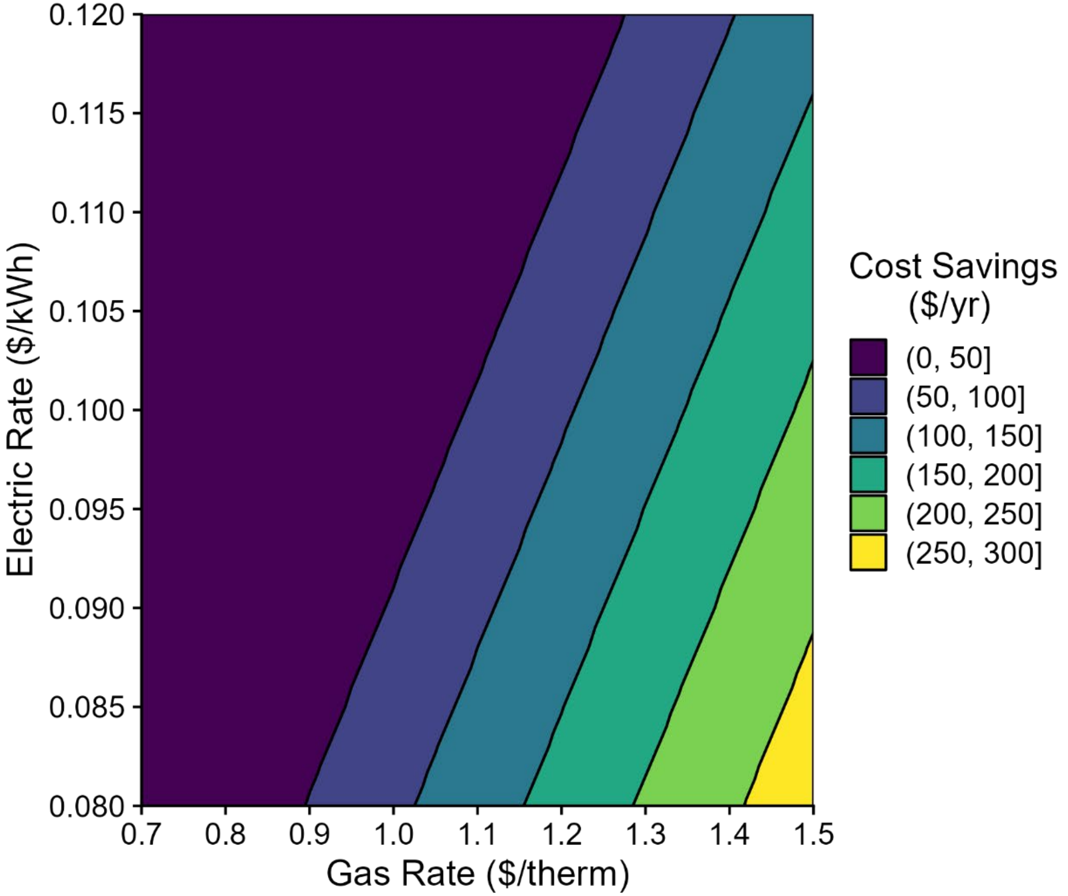
ssASHP on SEEM3_2688sf in Boise



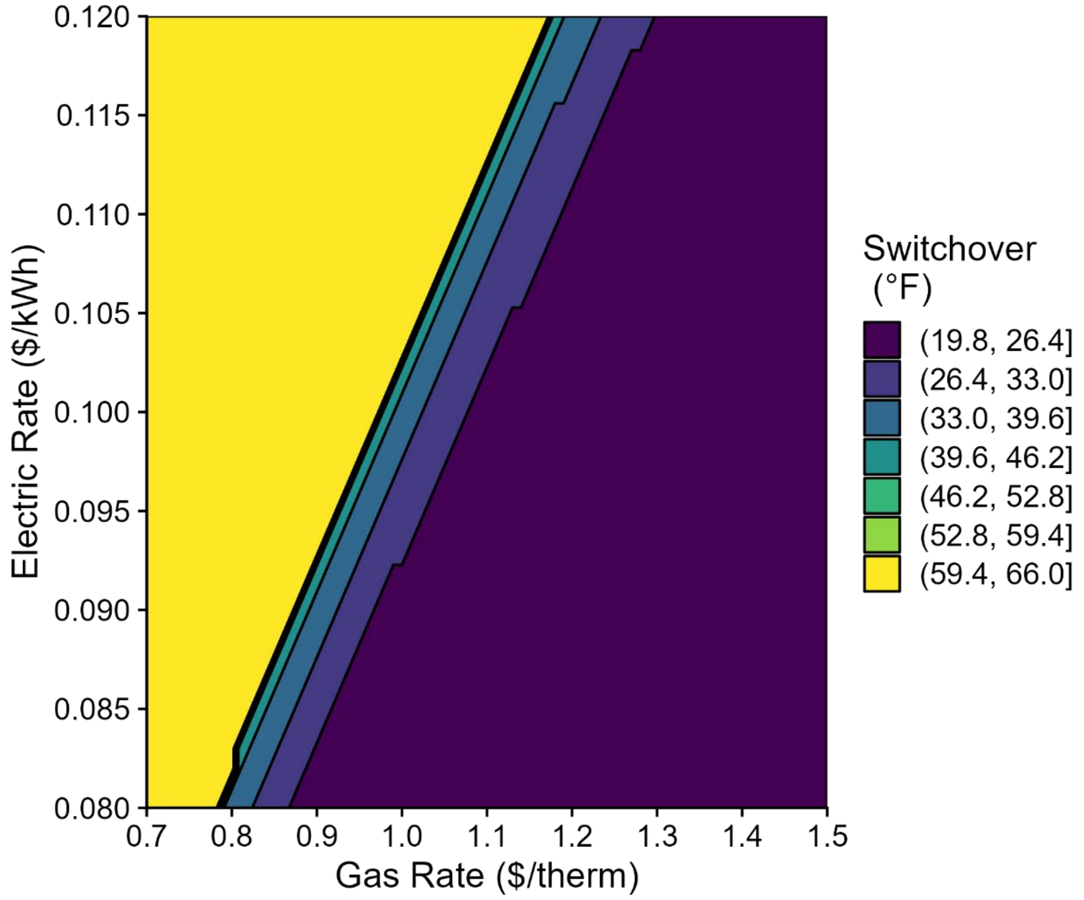


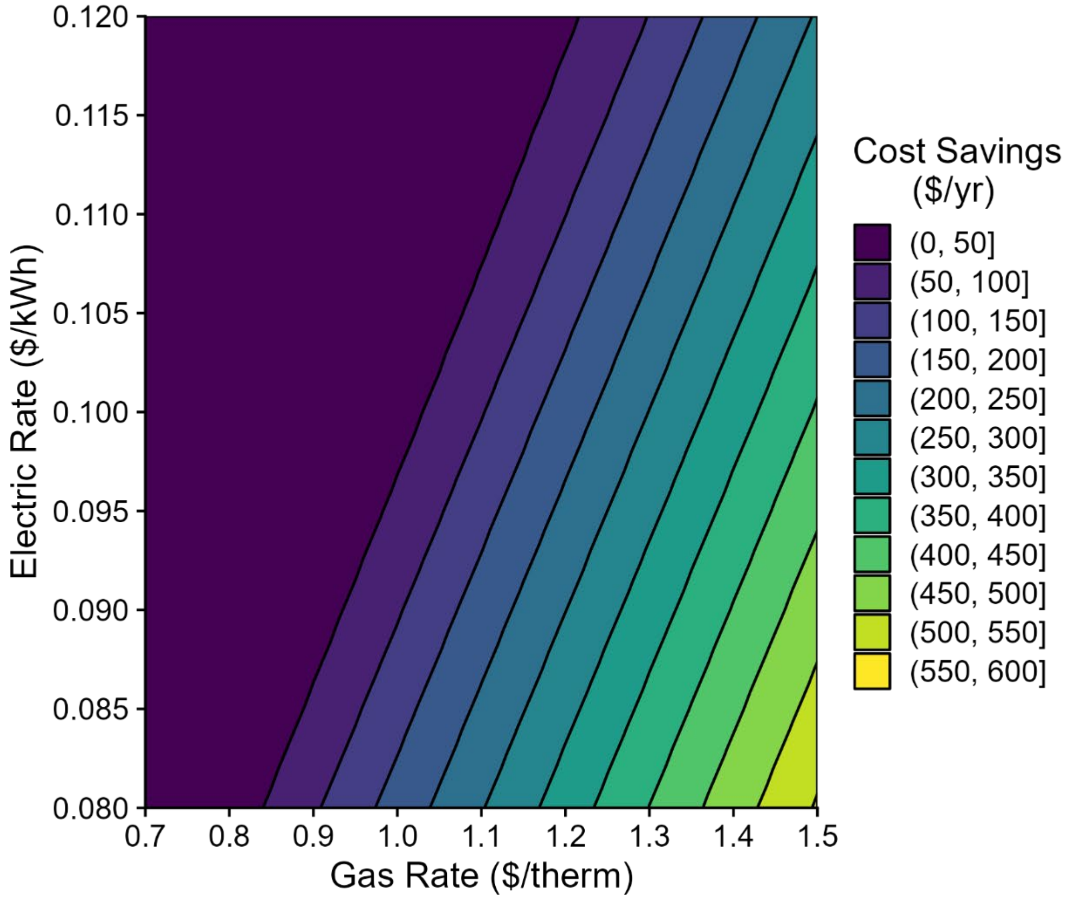
ssASHP on SEEM1_1344sf in Missoula



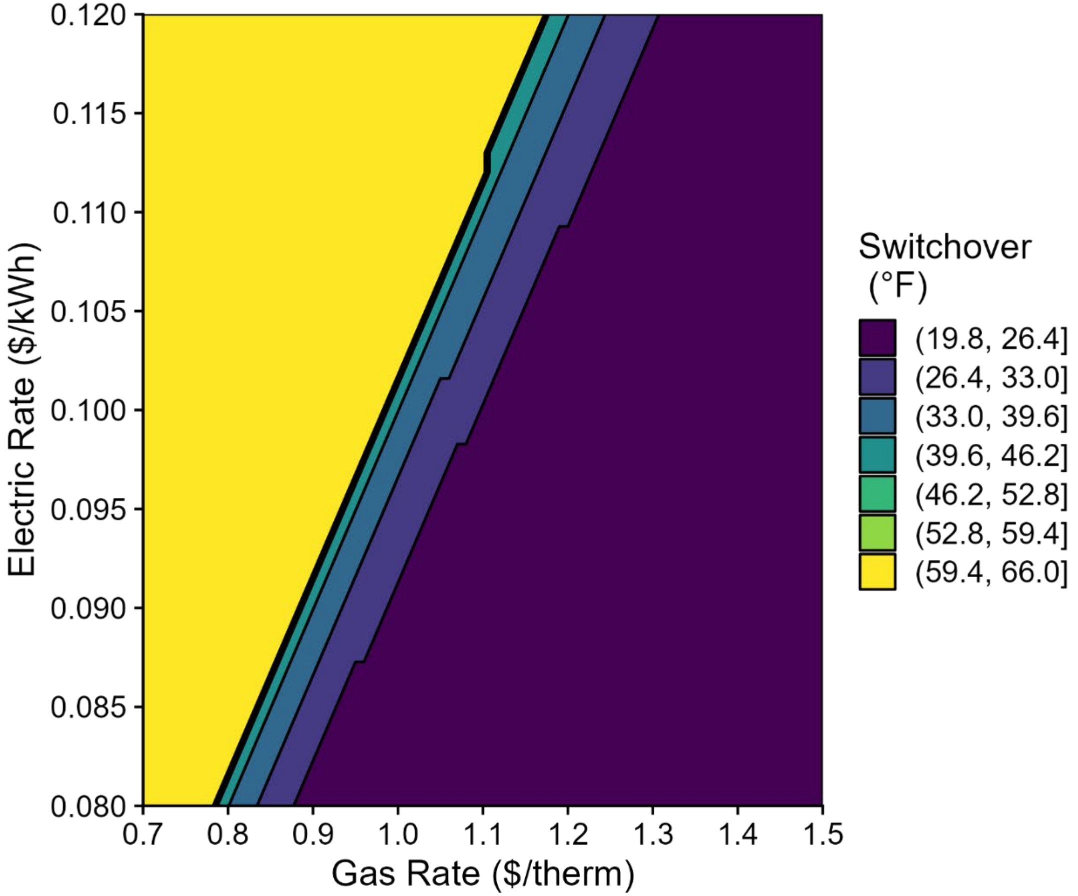


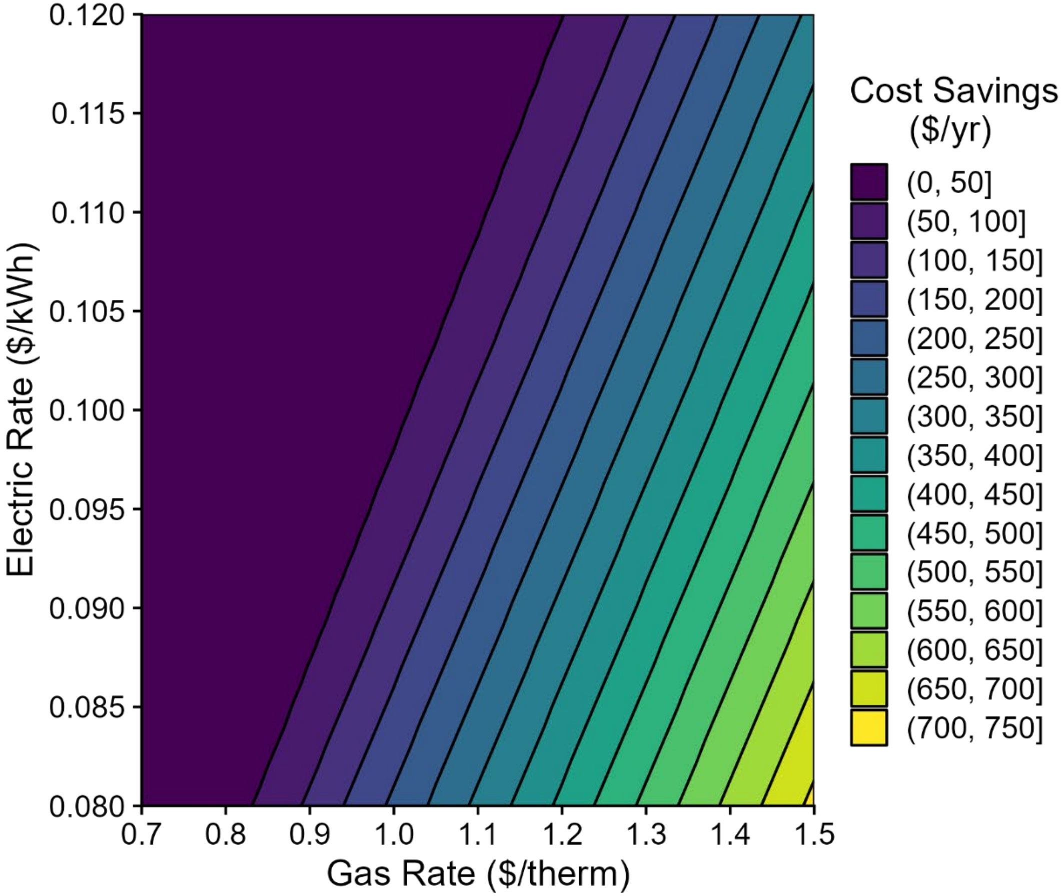
ssASHP on SEEM2_2200sf in Missoula



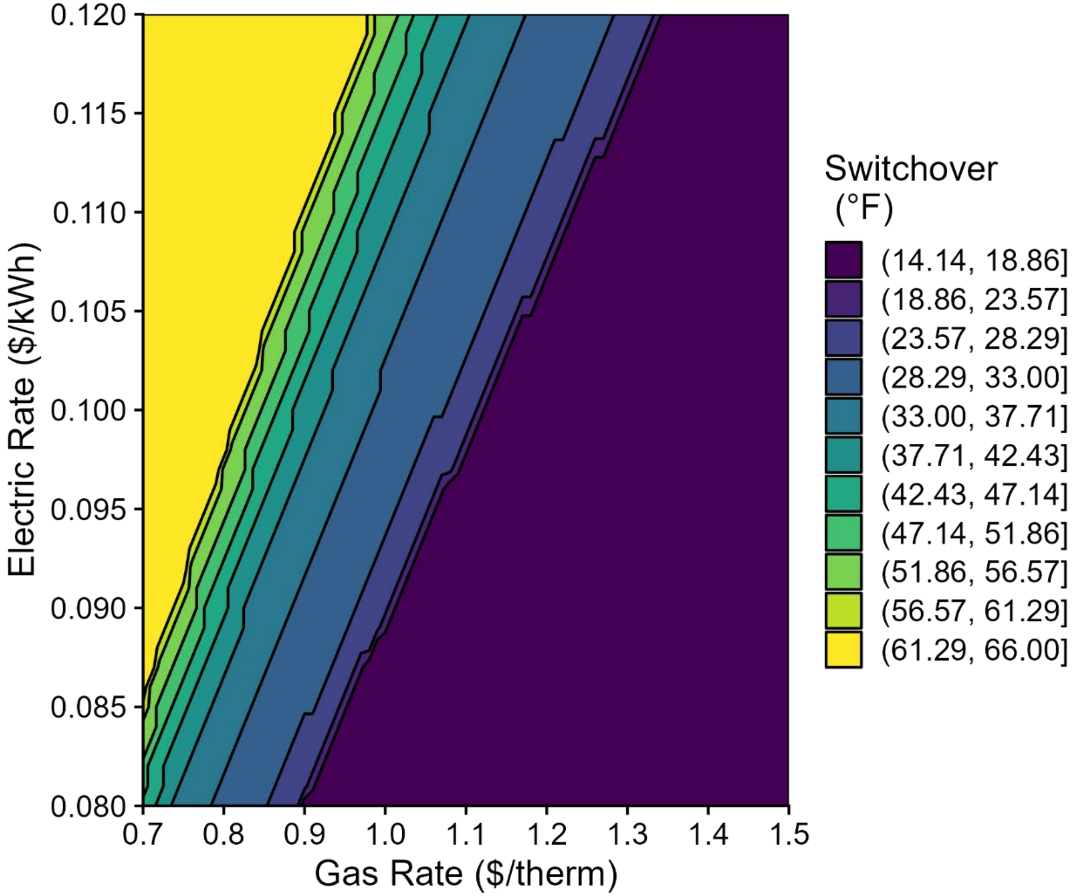


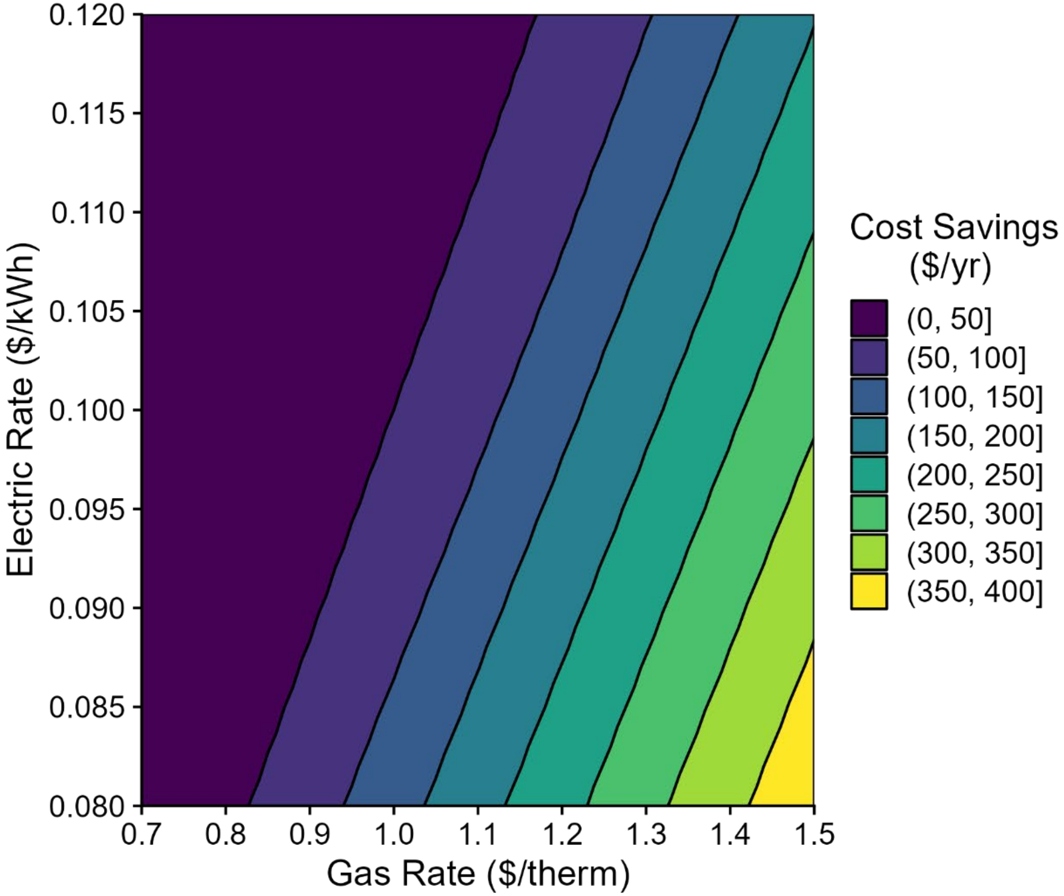
ssASHP on SEEM3_2688sf in Missoula



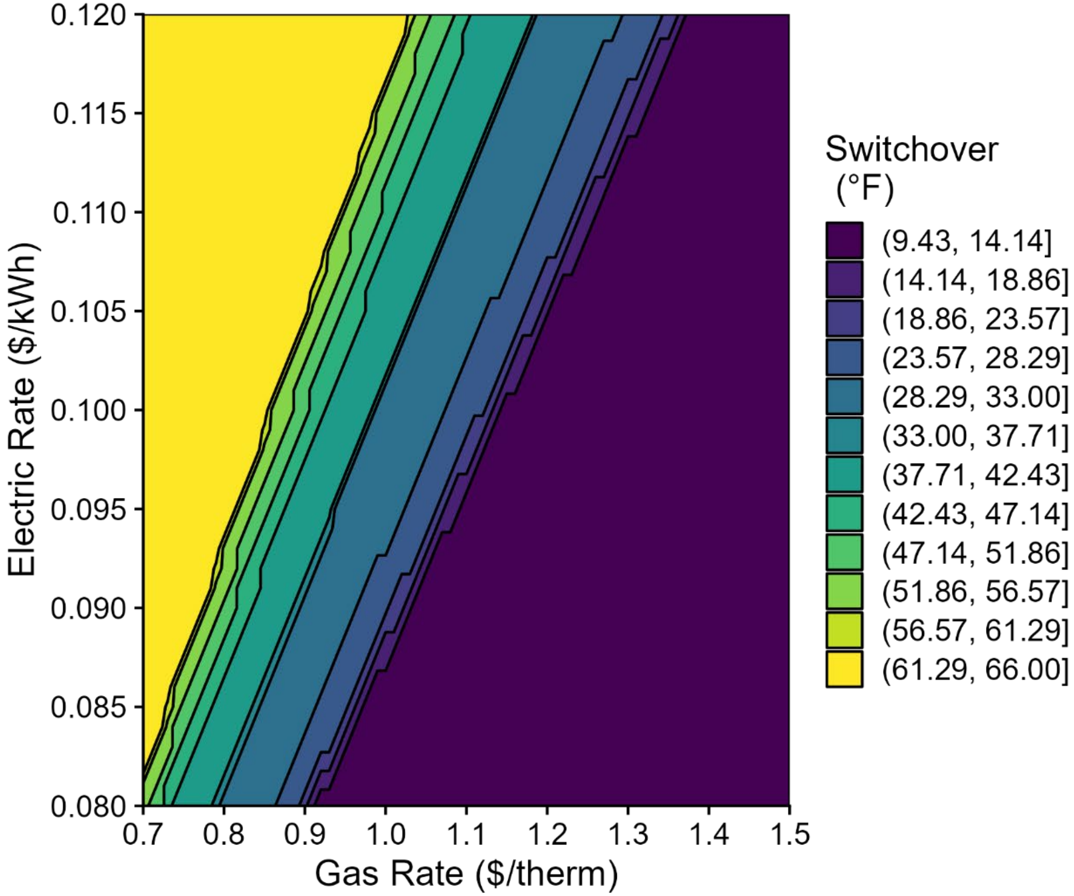


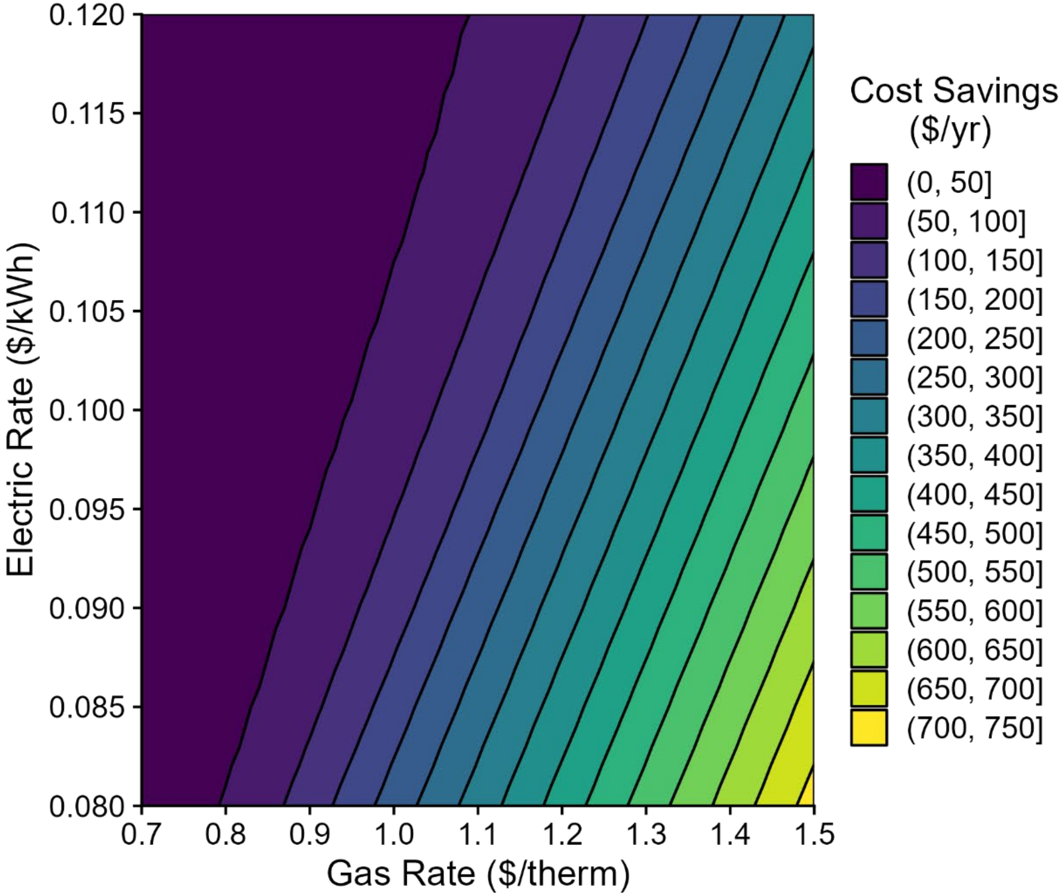
vsASHP on SEEM1_1344sf in Missoula



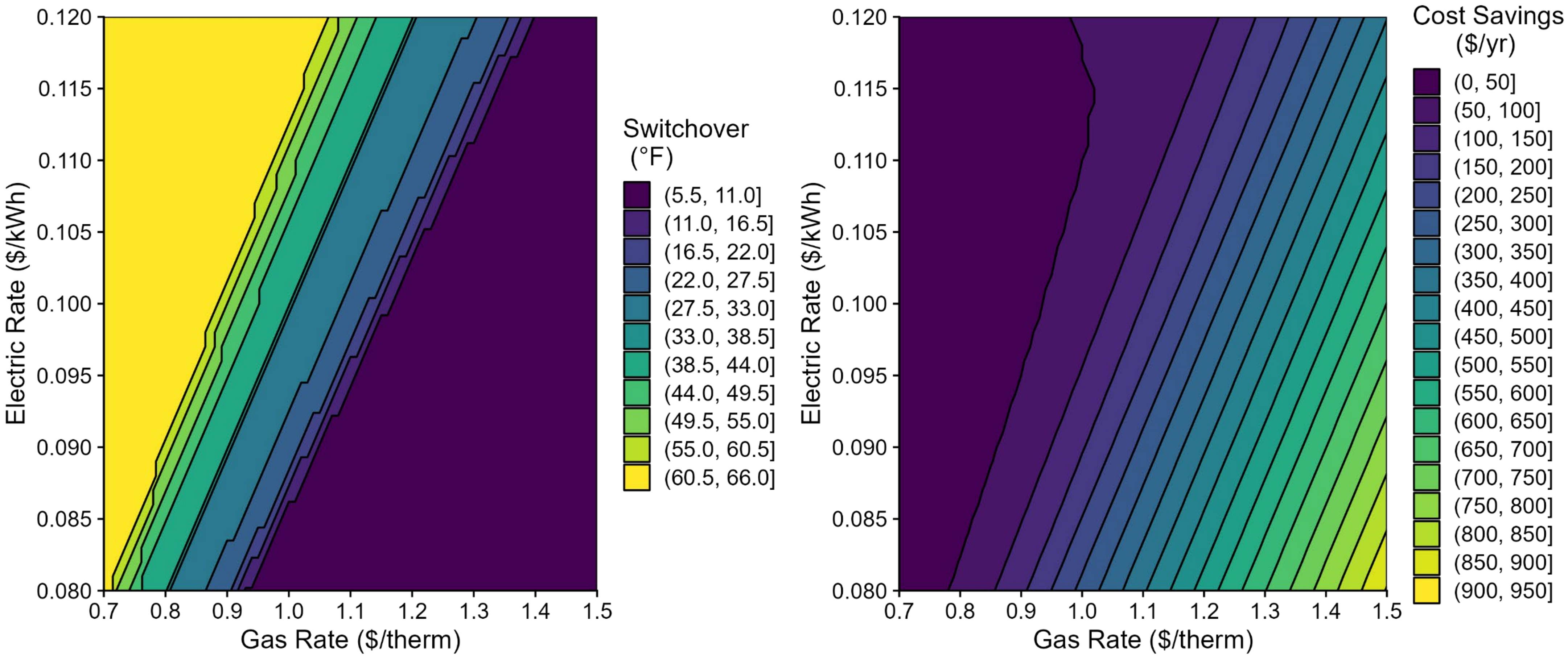


vsASHP on SEEM2_2200sf in Missoula





vsASHP on SEEM3_2688sf in Missoula



Overall Trends

- Single speed offers minimal flexibility compared to variable speed options
  - Worse capacity retention
  - Lower efficiency in colder weather
- The amount of cooling required governs how much we can electrify heating
  - Climates with large cooling needs will see more room to electrify with larger ASHPs
- The heating load scales heating bill impacts
  - Scenarios that reduce energy bills will see larger reductions with a larger load in similar weather
- Technical potential may not be the design limitation
- There is a lot of sensitivity to site-specific details

Open Questions

- How much backup heating is necessary to justify dual-fuel?
- How do we quantify the benefit of a gas backup for resiliency or extreme weather?
- How do we select the right heat pump depending on the above answers?

THANK YOU!

cee
Center for Energy and Environment

Contact Information

Ranal Tudawe – Research Analyst
Center for Energy and Environment
rtudawe@mncee.org

Josh Quinnell – Senior Research Scientist
Center for Energy and Environment
jquinnell@mncee.org

Noe Contreras – Senior Project Manager
NEEA
ncontreras@neea.org