Bulk power system implications of heat pump deployment in commercial and residential buildings

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Electric Power Systems Fall Workshop

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Presentation Outline

- Overview, objectives & methodology
- Case study of a commercial building heat pump retrofit
  - Effects on heating & cooling demand profiles
  - Discussion of retrofits in reality
- Conclusions & future work

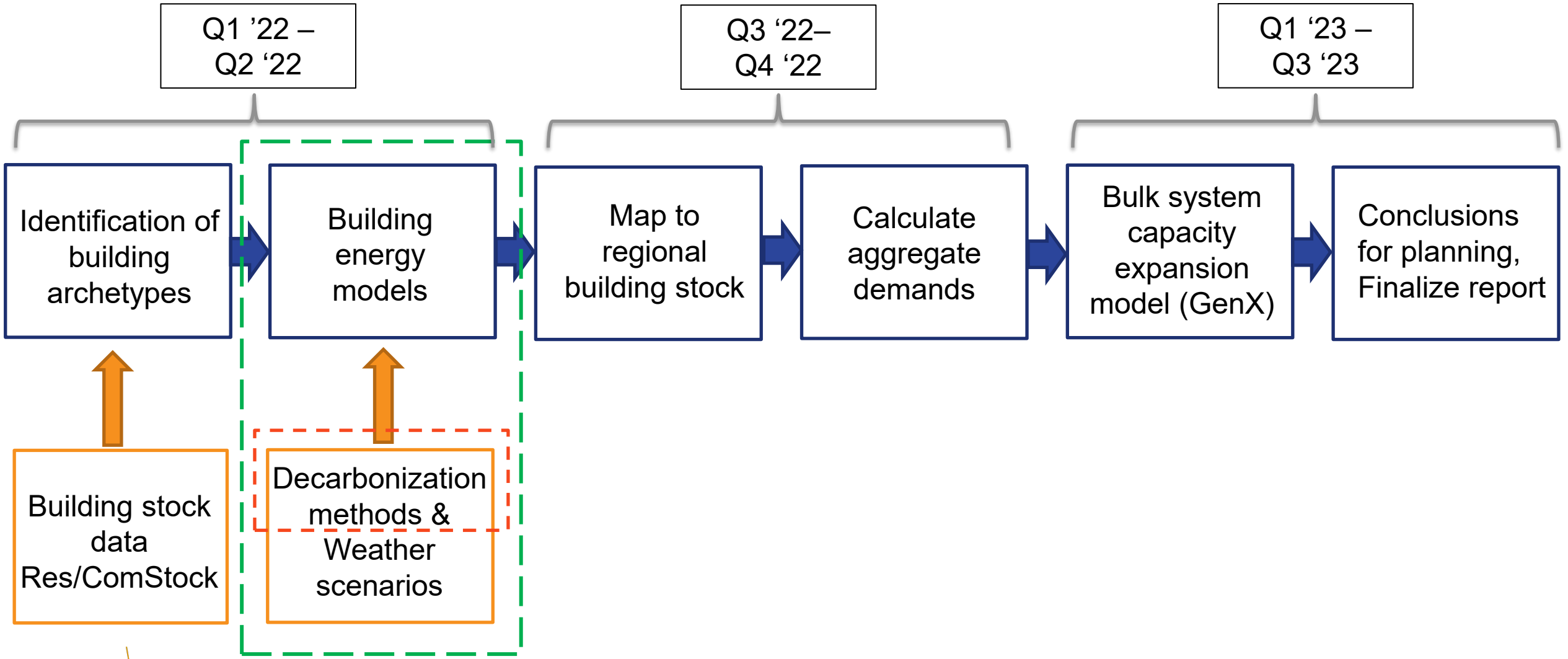
Project Overview

- Climate action plans require decarbonization of building energy end uses
- Natural gas is a widespread fuel for space heating in the Northeast United States
- Heat pumps, which evaporate and condense a refrigerant in a compressor-driven loop to move heat up a thermal hill from low to high temperatures, merit careful consideration
  - In the many buildings that have central air-conditioning, two-way heat pumps are a plug-in option
  - Ductless refrigerant flow systems are viable but require air distribution
  - Peak electrical loads operating costs argue for consideration of hybrid gas-electric systems and flexible time of use of electricity for heating

Project Objectives

- Determine implications for bulk system planning as a result of widespread heat pump deployment in the Northeast and Mid-Atlantic
- Analyze residential and commercial buildings
  - Capture the diversity of the building stock
- Investigate the aggregated impacts of different heating-related decarbonization methods at the building level
  - Heat pump systems, including hybrid gas-electric systems
  - Efficiency improvements (especially to the envelope)
  - Flexibility measures that can provide ancillary services to system operators

Methodology – Bottom-Up Modeling



Case Study of a Retrofit for a Commercial Building

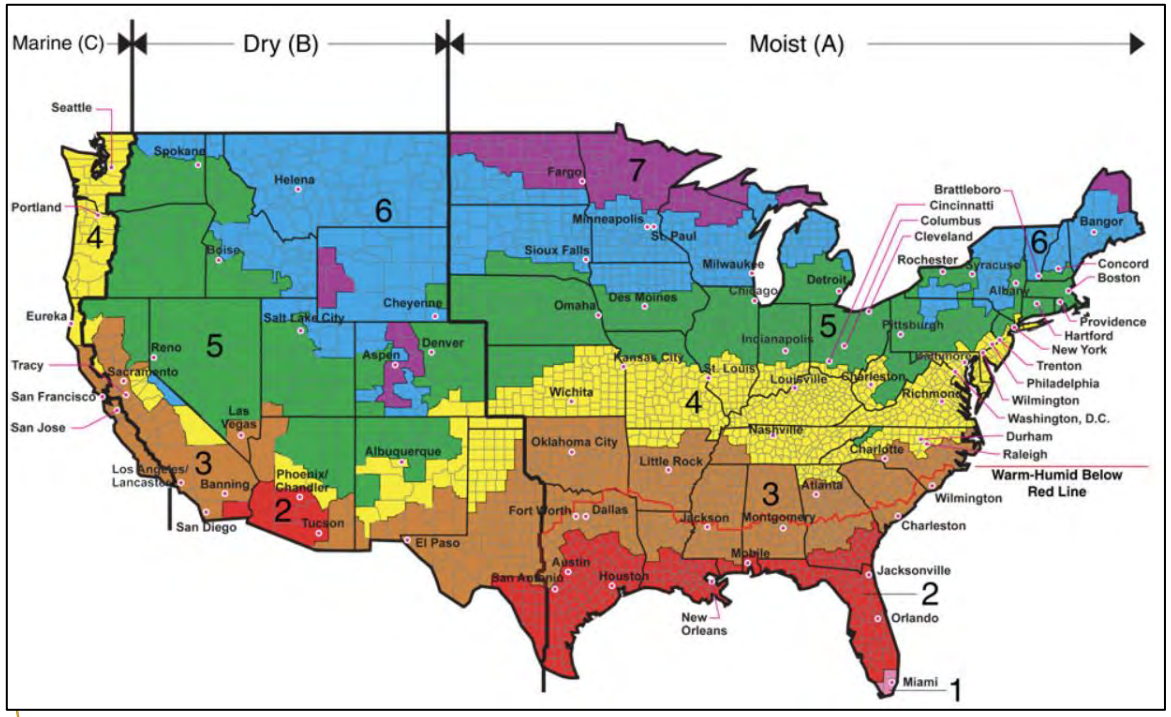
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Case Study of a Retrofit for a Commercial Building

- Most buildings in 2050 have already been built, therefore retrofits are important
- Base model: DOE Reference Medium Office Building for ASHRAE Climate Zone 5A (Boston, MA)
  - 54k sqft.
  - Pre-1980 construction
  - Ducted w/ existing air conditioning & gas boiler heating

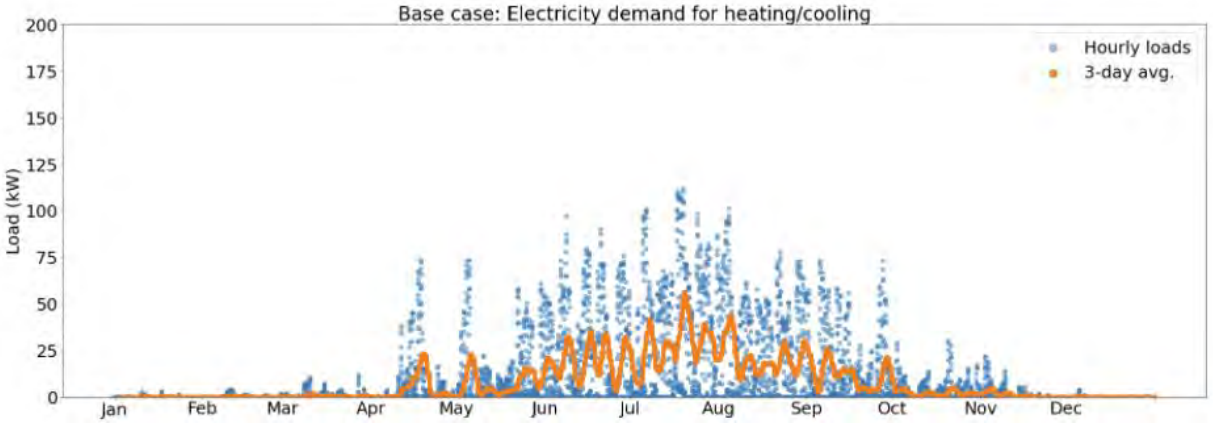


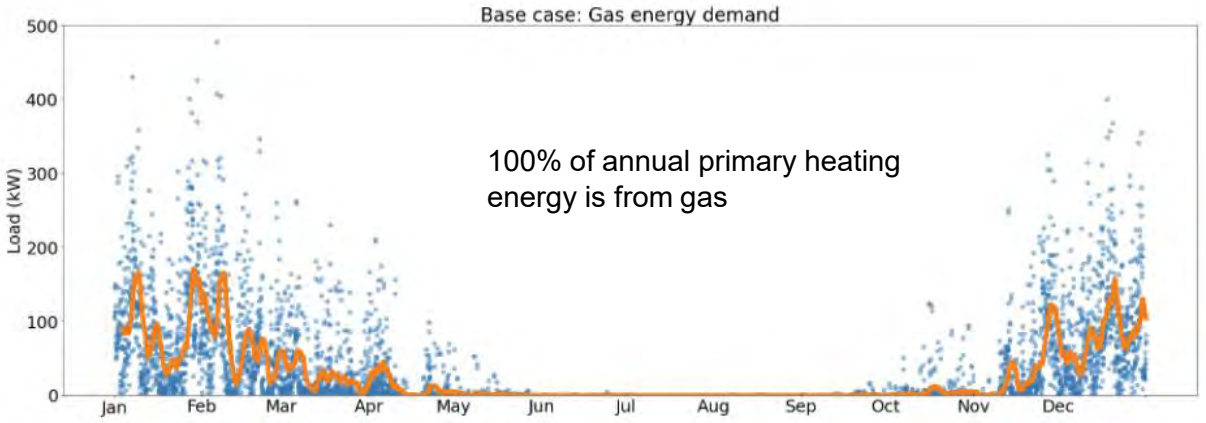


Retrofit Case Study - Technical Decisions

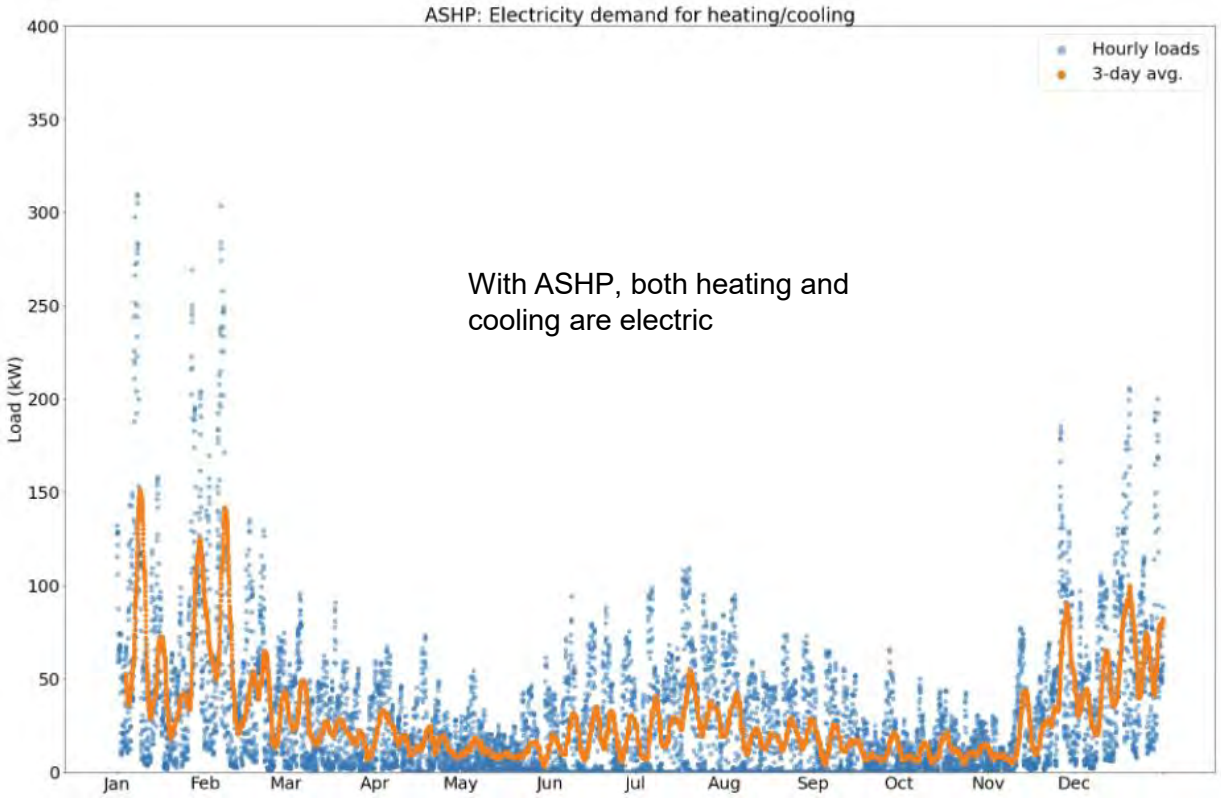
- Heat Pump:
  - Air-source heat pump (ASHP)
  - Cold-climate air-source heat pump (CCHP)
  - Ground-source heat pump (GSHP)
- Sizing:
  - Size heat pump for absolute peak load, or something less?
  - Type of supplemental heat: Gas (“hybrid”) or electric resistance
- Efficiency investments in building envelope

Base Case vs. Typical Air-Source Heat Pump (ASHP)





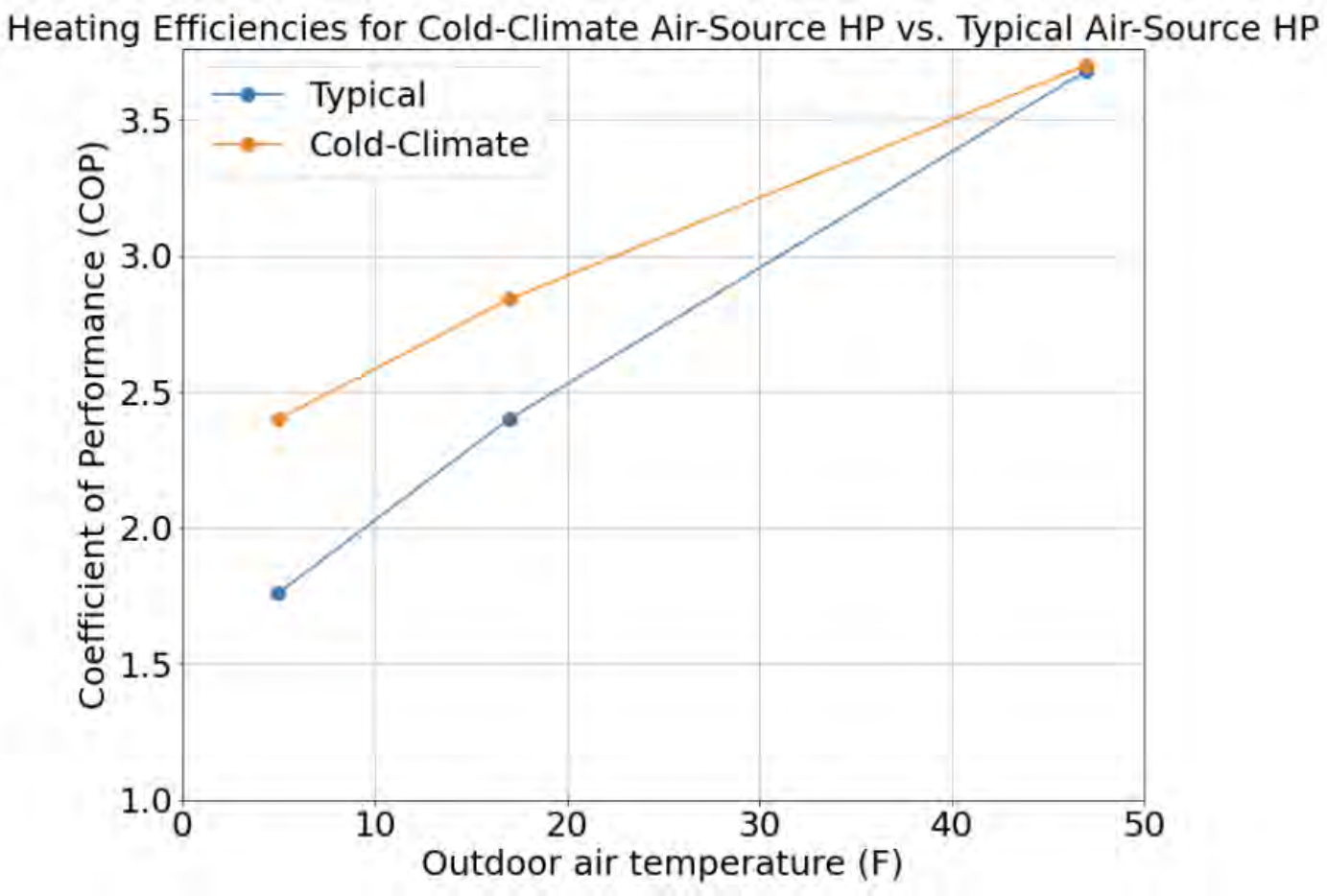
100% of annual primary heating energy is from gas



With ASHP, both heating and cooling are electric

All profiles created using EnergyPlus + additional Python models.

Typical ASHP vs. Cold-Climate ASHP (CCHP)

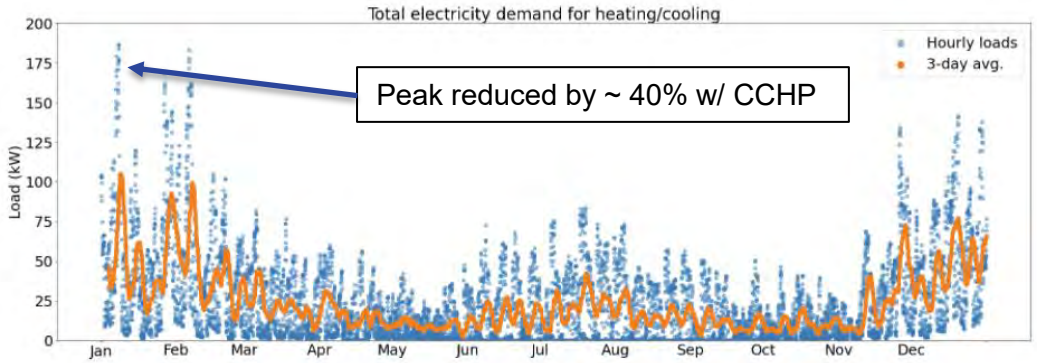


- CCHP is an ASHP designed for cold climates
- Uses methods such as “enhanced vapor injection” (EVI) to improve efficiency at low outdoor air temperatures

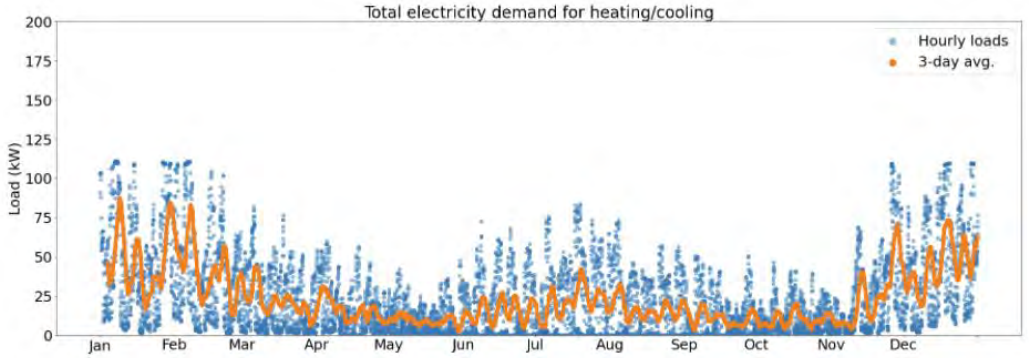
Data from Northeast Energy Efficiency Partnerships (NEEP) for Trane/Mitsubishi Models NTXMPH20A122A and TUMYP0601AK43
Example of heat pump using EVI: https://www.arcticheatpumps.com/evi-dc-inverter-for-heat-pumps.html

Cold-Climate HP (CCHP) - Comparison of Winter Sizing Criteria

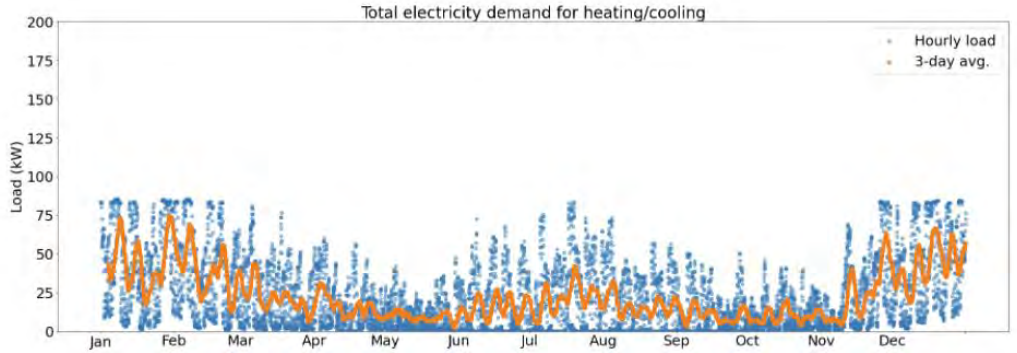
Sized for 100th Percentile Heating Load

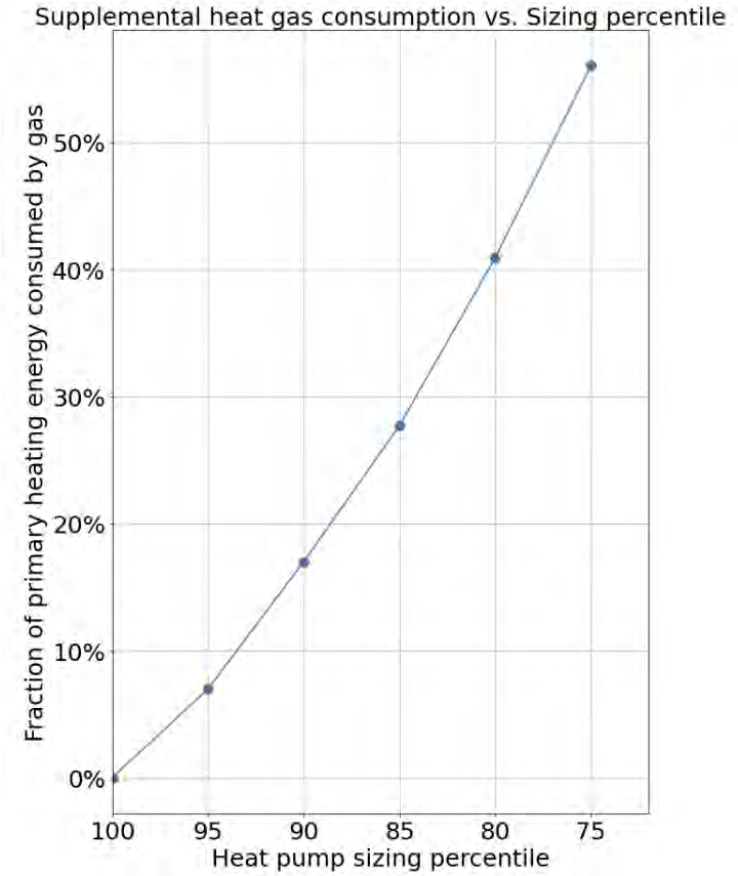


95th Percentile



90th Percentile





Commercial Retrofit Decisions Are Not Simple

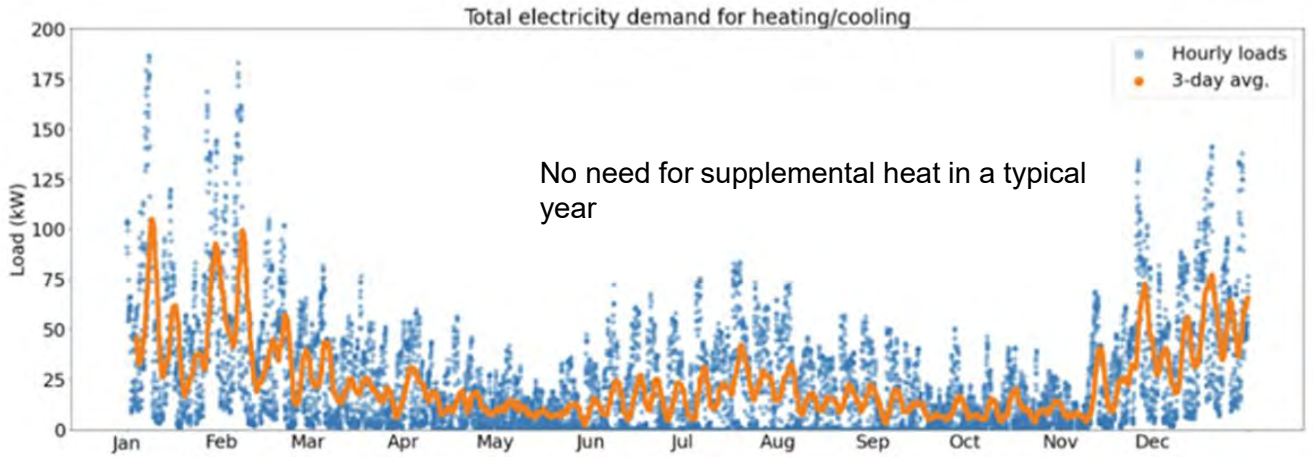


- E.g., with a preexisting rooftop unit system:
  - New unit connections may not be compatible with preexisting
  - New unit may be too large for roof space

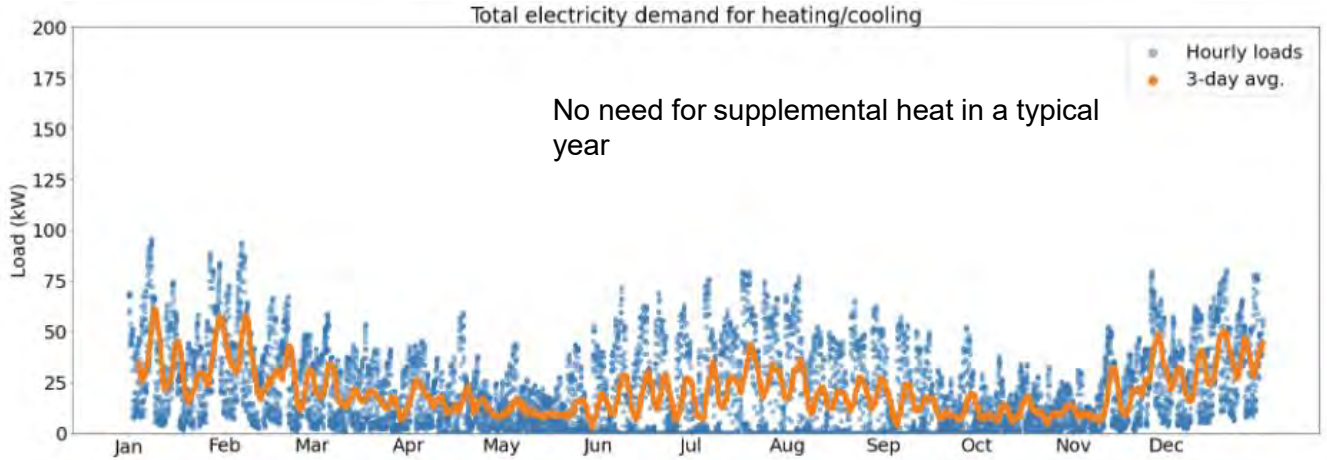
Image source: https://en.wikipedia.org/wiki/Heating,_ventilation,_and_air_conditioning

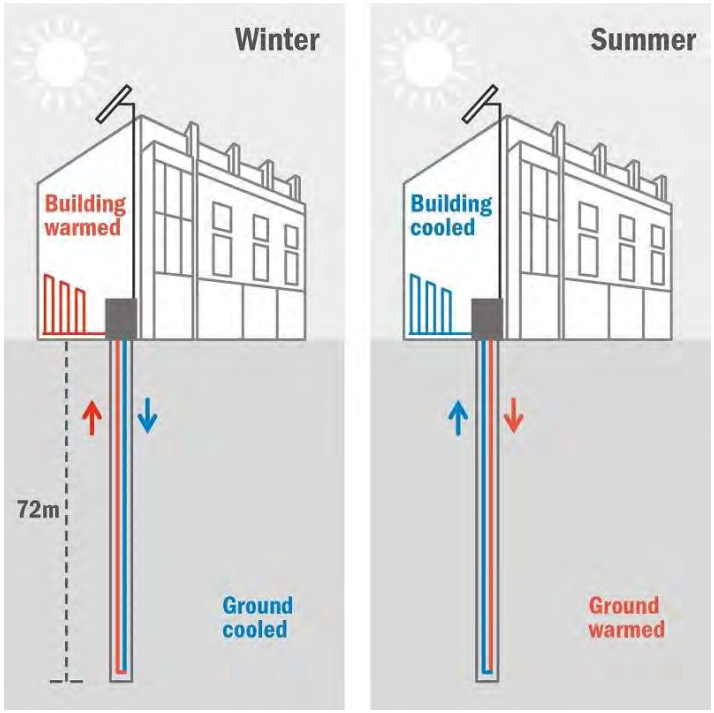
CCHP vs. GSHP: Sized for 100th Percentile Heating Load

Cold Climate HP (CCHP)



Ground Source HP (GSHP)





Significant space is needed for GSHP heat exchanger

Graphs by author. GSHP diagram source: https://www.iop.org/explore-physics/sustainable-building-design/ground-source-heat-pump

Effect of Efficiency Investments

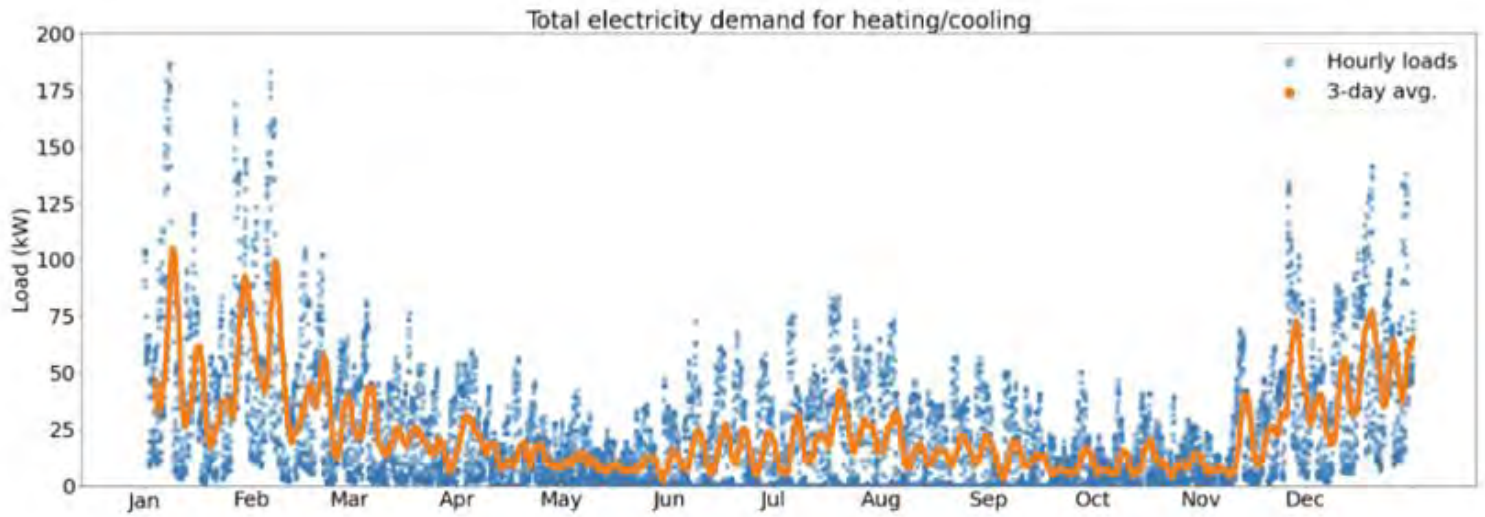
Office (Small), Office (Medium), Retail, Supermarket			
ECM 1 Electrification	ECM 2 Low Efficiency	ECM 3 Medium Efficiency	ECM 4 High Efficiency
	ECM 1 plus:	ECM 2 plus:	ECM 3 plus:
Systems			
Heat Pump Cooling SEER: 15	ECM 1	Heat Pump Cooling SEER: 20	Heat Pump Cooling SEER: ECM 3
Heat Pump Space Heating HSPF: 9		Heat Pump Space Heating HSPF: 10	Heat Pump Space Heating HSPF: ECM 3
Heat Pump DHW Heating UEF: 2.73		Heat Pump DHW Heating UEF: 3.2	Heat Pump DHW Heating UEF: 3.45
Envelope			
None	R-30 Roof/Attic	Window U-value: 0.38	R-40 Roof/Attic
	R-15 Walls	Window SHGC: 0.35	R-30 Walls
	Airtightness to 0.4 CFM/sf at 0.3 in. wc.	Airtightness to 0.2 CFM/sf at 0.3 in. wc.	Window U-value: 0.22
			Window SHGC: 0.25
			Airtightness to 0.1 CFM/sf at 0.3 in. wc.
Controls			
Setbacks to 70°F and 75°F in heating and cooling, respectively	**ECM 1**	ECM 1	ECM 1
Demand-Control Ventilation			
70% Effective Energy Recovery			
Appliances			
Electric conversion	ECM 1	ECM 1	ECM 1

From:
"Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study: Buildings Sector Report" (December 2020)

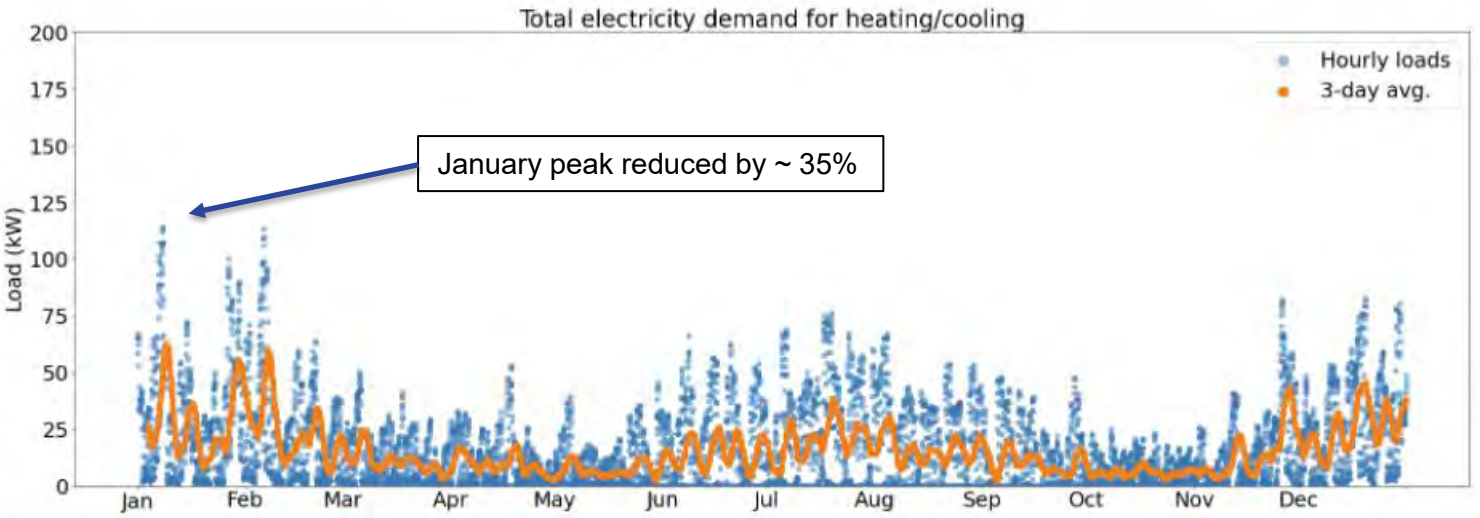
https://www.mass.gov/doc/building-sector-technical-report/download

Effect of Efficiency Investments: CCHP For 100th Percentile Heating Load

CCHP w/out Envelope Improvements



CCHP w/ Envelope Improvements



Realities of Heating Retrofits in Commercial Buildings

- Commercial building retrofit circumstances are highly heterogenous
- Challenges from a technical standpoint:
  - Individual buildings are suitable for different types of retrofits
  - Some emerging technologies have ill-defined performance metrics
- Challenges from a financial standpoint:
  - Some systems are more expensive than others
  - Some technologies have ill-defined costs

Conclusions & Future Work

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Conclusions

- Technical decisions have significant effect on building-level electricity for heating/cooling demand profiles
  - System type
  - System sizing criteria
  - Efficiency investments in envelope
- Per-building “optimal” technical decisions often depend on operational priorities, site constraints, and financial factors
- Modeling scenarios will reflect assumptions about key candidates for building-level decarbonization methods

Future Work

- Short term (~1mo):
  - Sensitivity analysis of building-level models to extreme weather years
  - Implement flexibility/demand intervention measures within building-level models
    - Thermal energy storage
    - Preheating

- Longer term (~3mo):
  - Clustering ResStock/ComStock data to determine appropriate amount and kinds of building archetypes

Thank you

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Supplemental Information

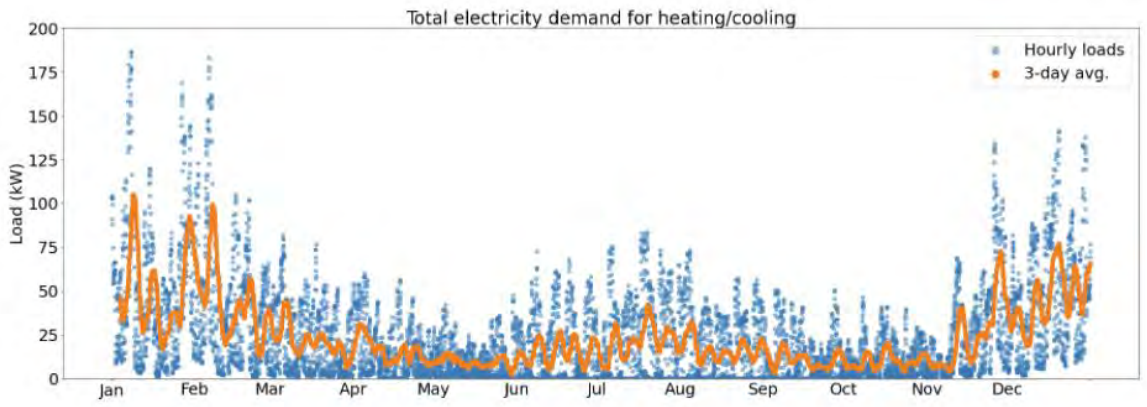
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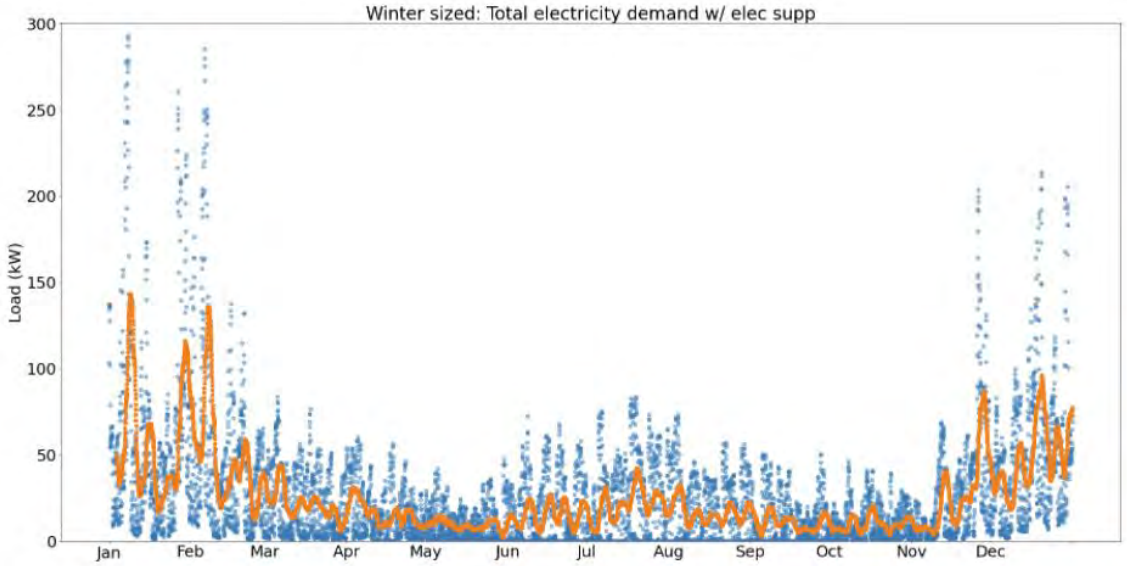
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Example of CCHP profiles with/without electric supplemental heat

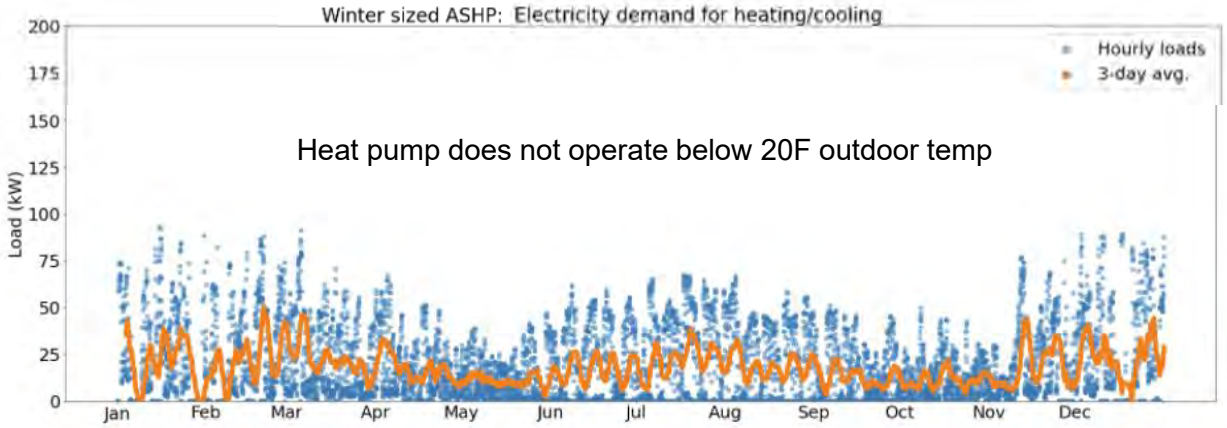
100th-percentile sized CCHP



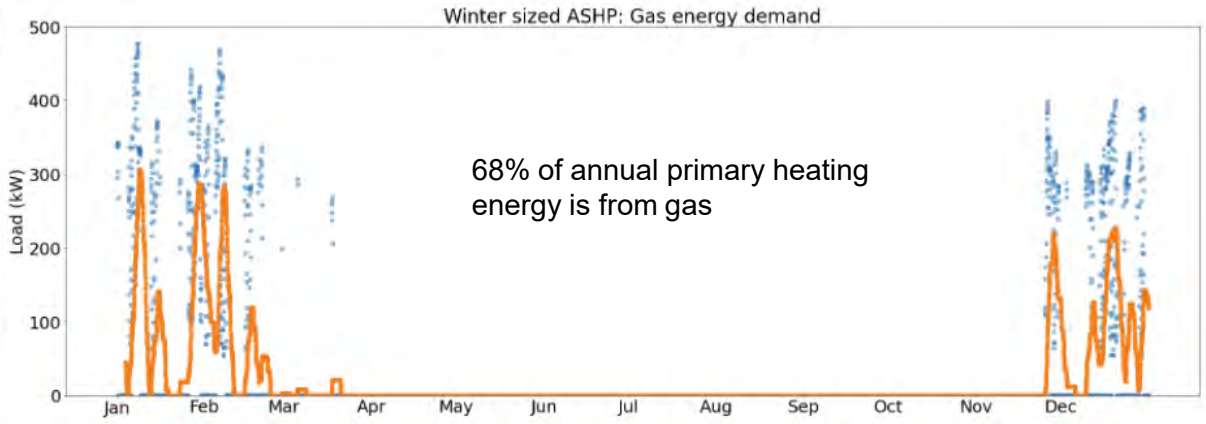
90th-percentile sized CCHP w/ electric supplemental heat



Example of Typical ASHP w/ Low-Temperature Cutoff



Heat pump does not operate below 20F outdoor temp



68% of annual primary heating energy is from gas