Evaluating the bulk power system implications of heat electrification through bottom-up building energy models

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MITEI Future Energy Systems Center

Spring Meeting

May 11, 2022

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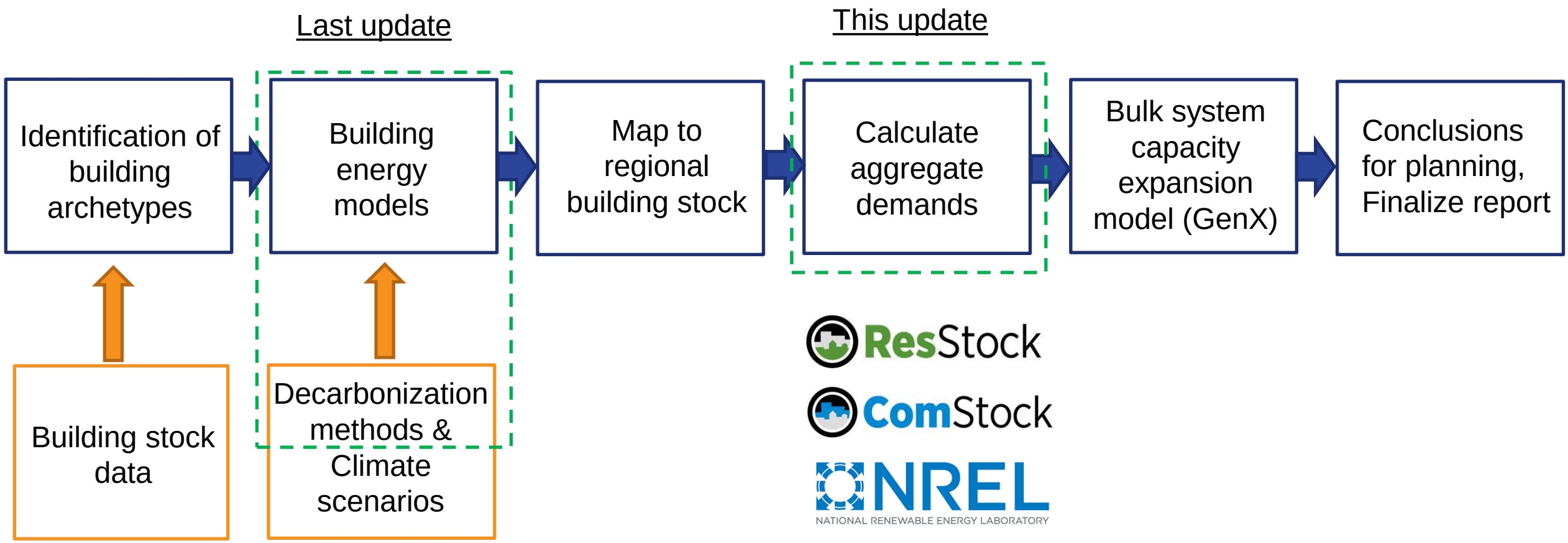
Presentation Outline

- Objectives & methodology
- Preliminary aggregated load profile examples for residential heat pump deployment in MA & MD
- Conclusions & future work

Project Objectives

- Determine implications for bulk power 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 grid-level aggregated impacts of different heating-related decarbonization methods made at the building level

Methodology – Bottom-Up Modeling

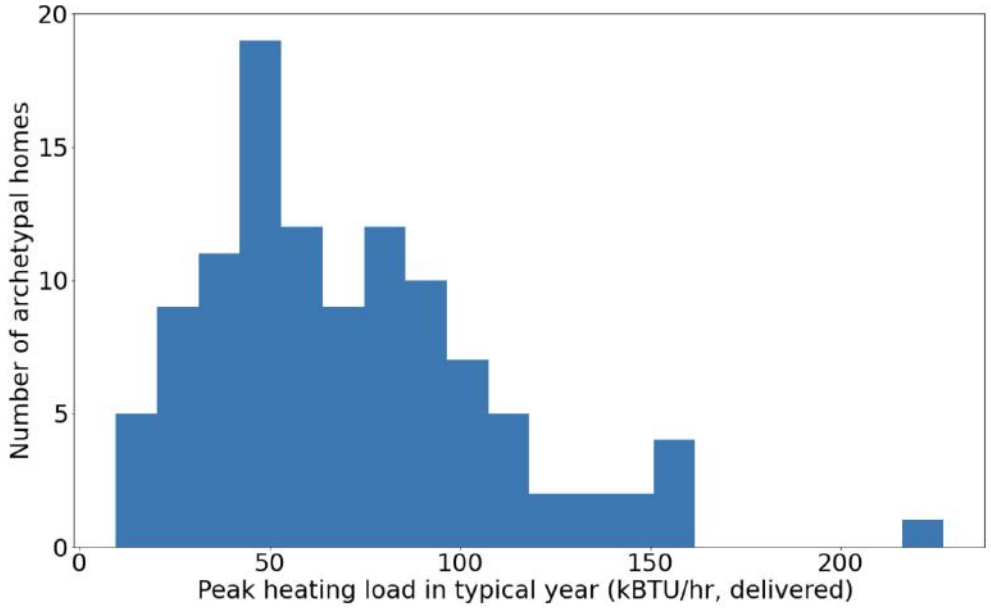


Building-Level Decarbonization Methods Currently at Interest in this Study

- Heat Pump:
  - Air-source heat pump (ASHP) of varying cold-climate performance levels
  - Ground-source heat pump (GSHP)
- Sizing:
  - Size heat pump for absolute peak heating load, or something less?
  - Type of backup heat: Gas (“hybrid”) or electric resistance
- Efficiency investments in building envelope
- Load flexibility measures (tentative)
  - Preheating / precooling
  - Thermal energy storage
  - Battery storage

Why Capturing the Heterogeneity of the Building Stock Matters

- Load behavior of individual buildings is very diverse
  - Strong effect on aggregated profiles
  - Project seeks to capture this through leveraging large number of archetypes – today, ~100 for each example state



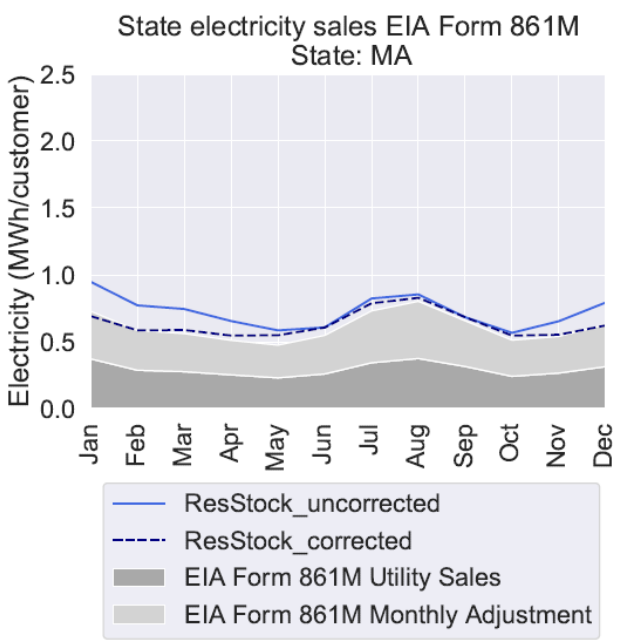
- Beyond load effects, heterogeneity in building stock has significant effect on retrofit costs
  - Discussed in previous workshop

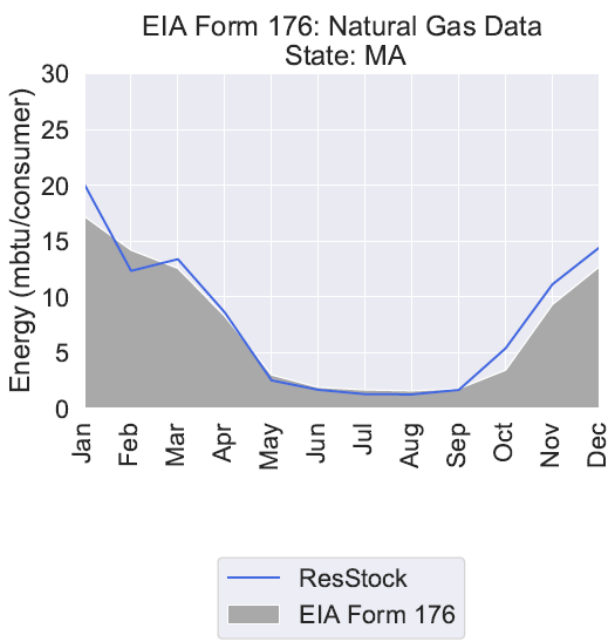
Preliminary example residential aggregated load profiles: Massachusetts & Maryland

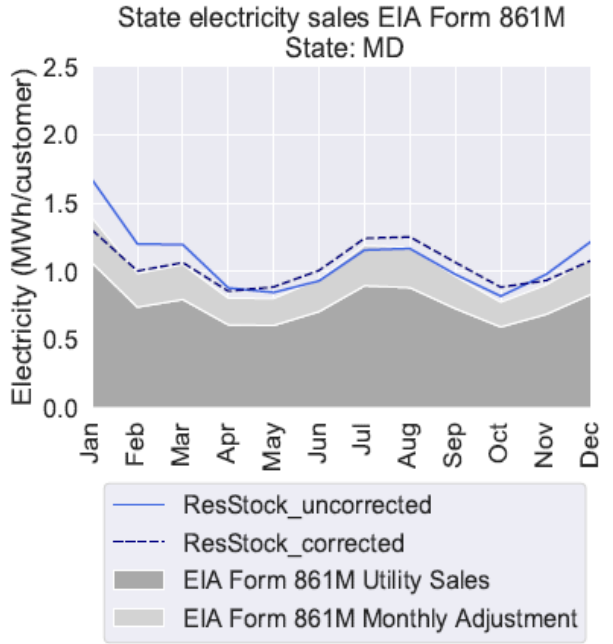
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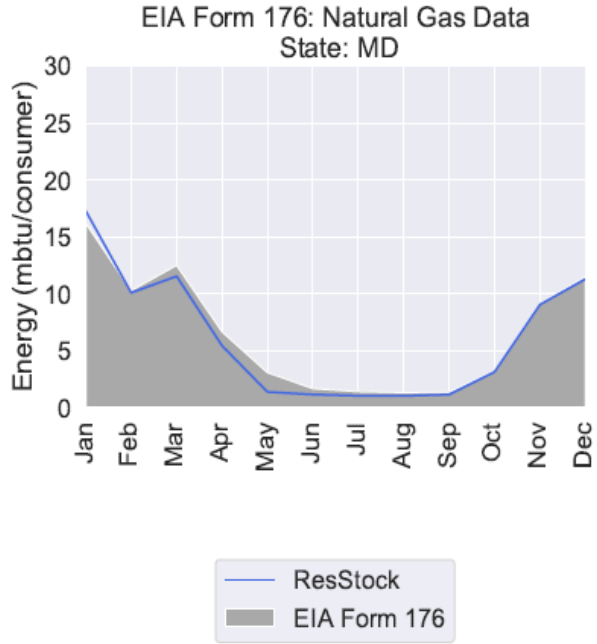
ResStock vs. Empirical Data

- For MA and MD, baseline results are more or less in alignment with reality
- Model results must be evaluated in light of their basis in synthetic data and likely deviation from empirical data









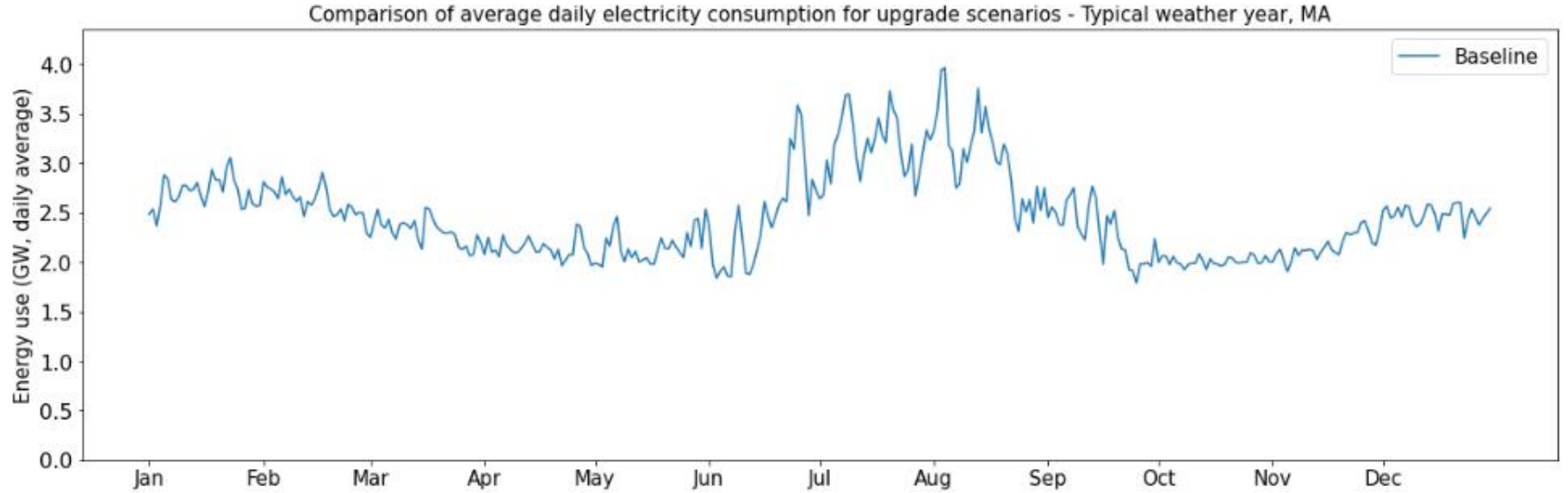
Images from NREL Report – “End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification”

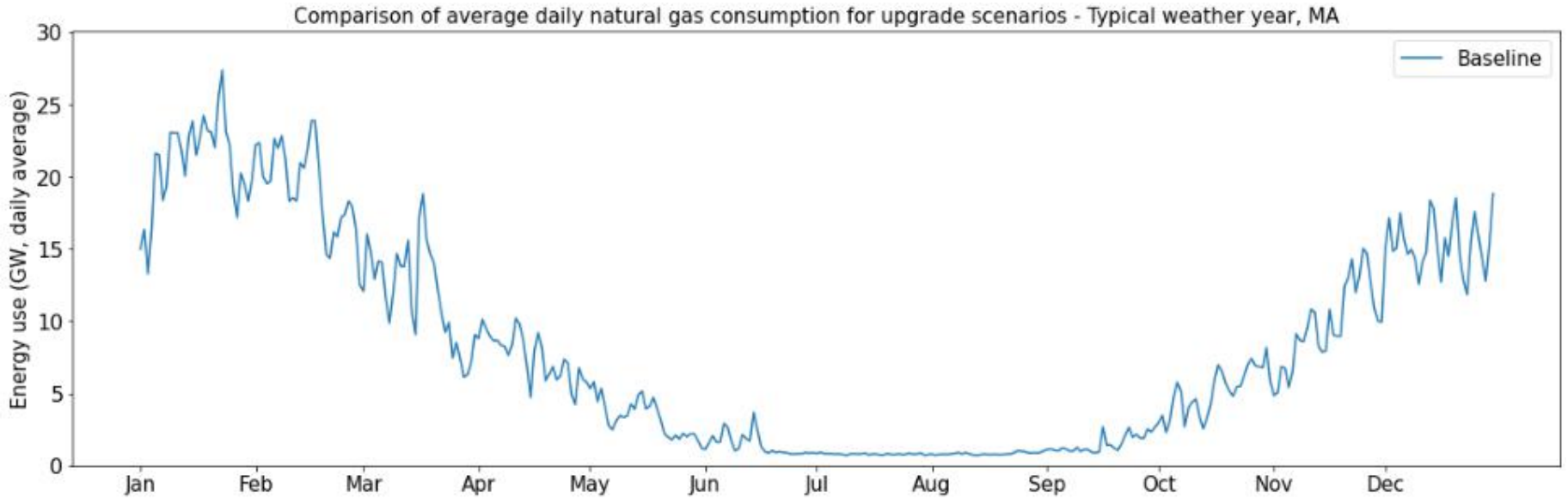
Preliminary Residential Aggregated Load Profiles: Massachusetts

- Massachusetts Clean Energy and Climate Plan: ~ 1 million households w/ heat pumps by 2030 (approx. 1/3 of the housing stock)
- Potential load impacts are appreciated by system stakeholders, especially peak impacts
- Scenarios we show today:
  - Baseline
  - Penetration of ASHP to 1/3 of housing stock
    - ASHP specs: SEER 22, HSPF 11
  - Penetration of ASHP + building envelope improvements to 1/3 of housing stock
    - Envelope improvements according to MA Decarbonization Roadmap “Low Efficiency” (Level 2) energy conservation measures[1]

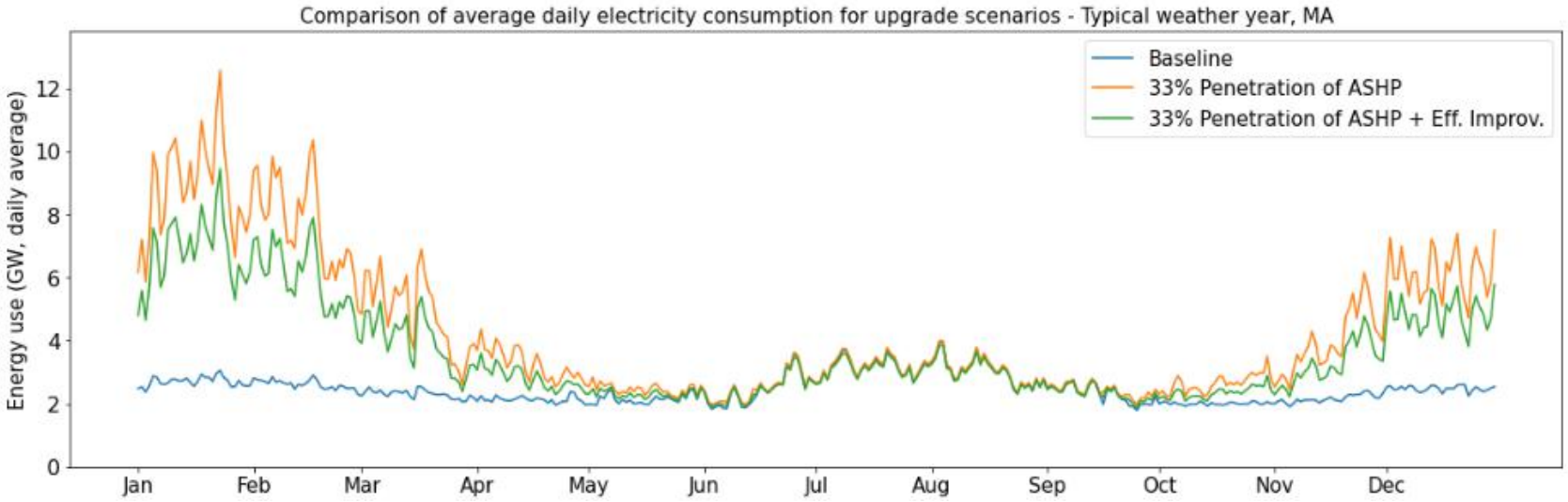
1. https://www.mass.gov/doc/building-sector-technical-report/download

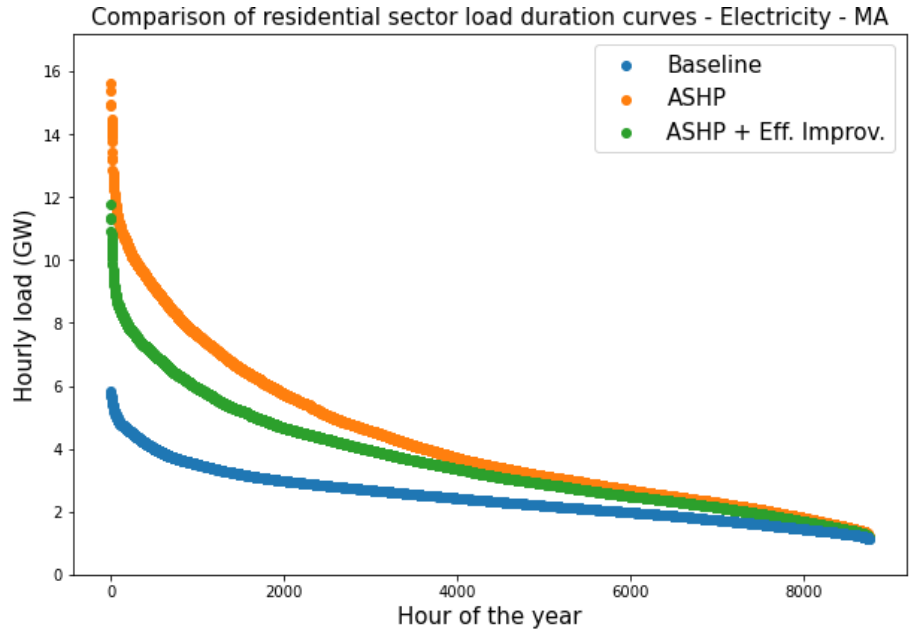
MA: Baseline, No Improvements





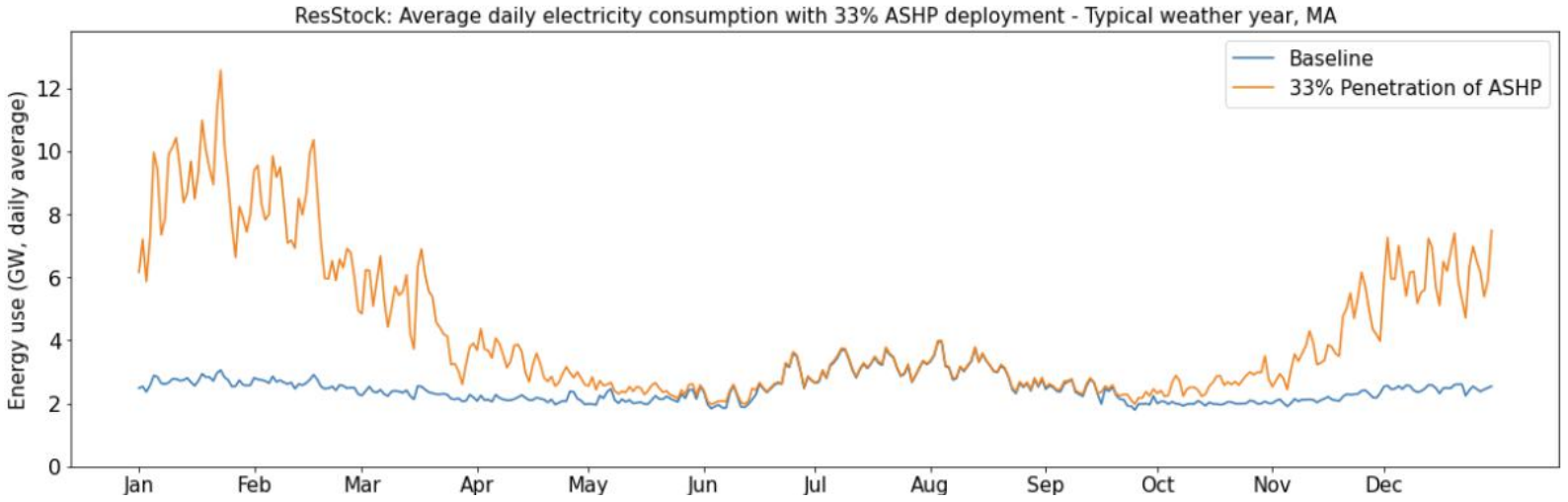
MA: ResStock Results from All Scenarios – Electricity Loads

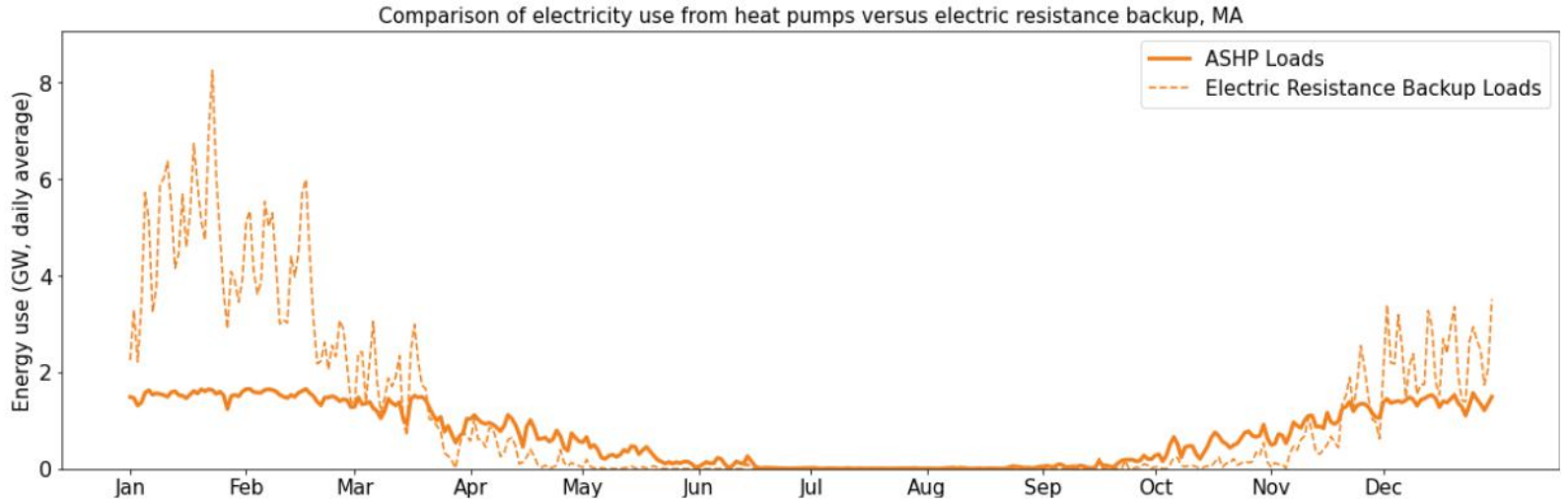




- Drastic winter-peaking behavior with 33% ASHP penetration
- Peak increase between ~6-10 GW depending on the scenario

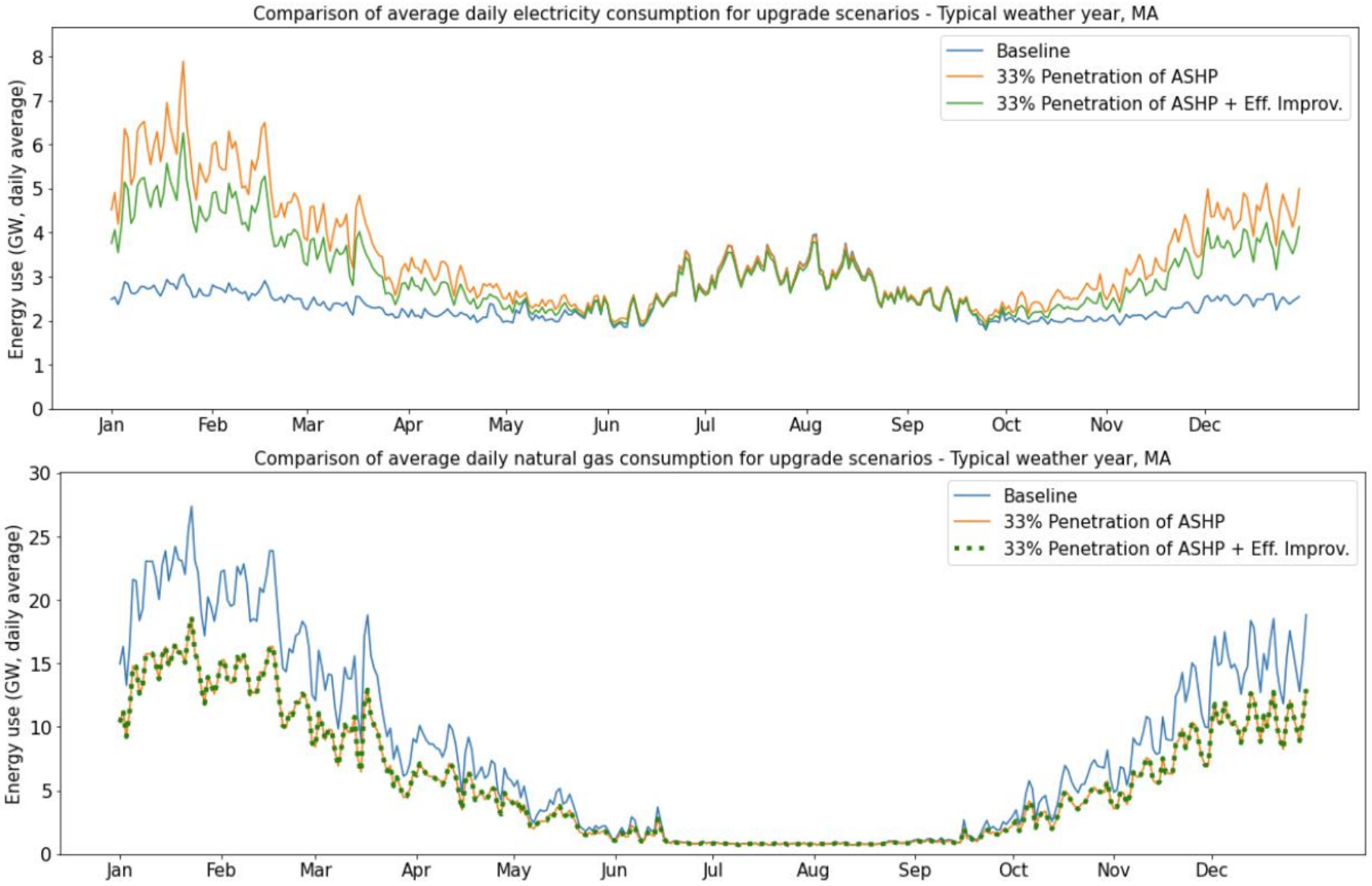
ResStock ASHP models rely heavily on electric resistance backup heating



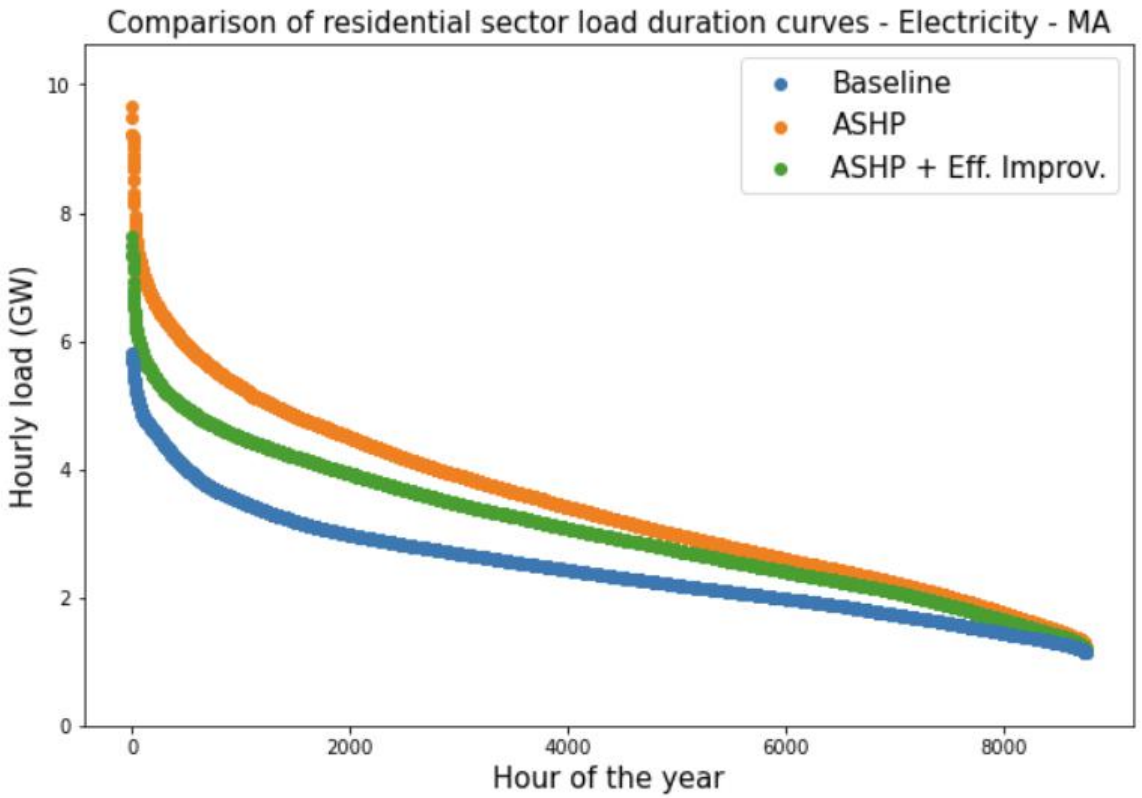


- ResStock assumes ASHP are sized for summer
- In heating season, heavy reliance on electric backup results in drastic and unrealistic peaking behavior
- Interim solution: Create our own linear ASHP models
  1. ASHP sized to meet all loads
  2. ASHP sized to meet 95% of heating loads + gas backup

MA: All Scenarios Using Our ASHP Models – Sized to Meet All Loads



MA: Sized to Meet All Loads - Implications for Electricity Peaking

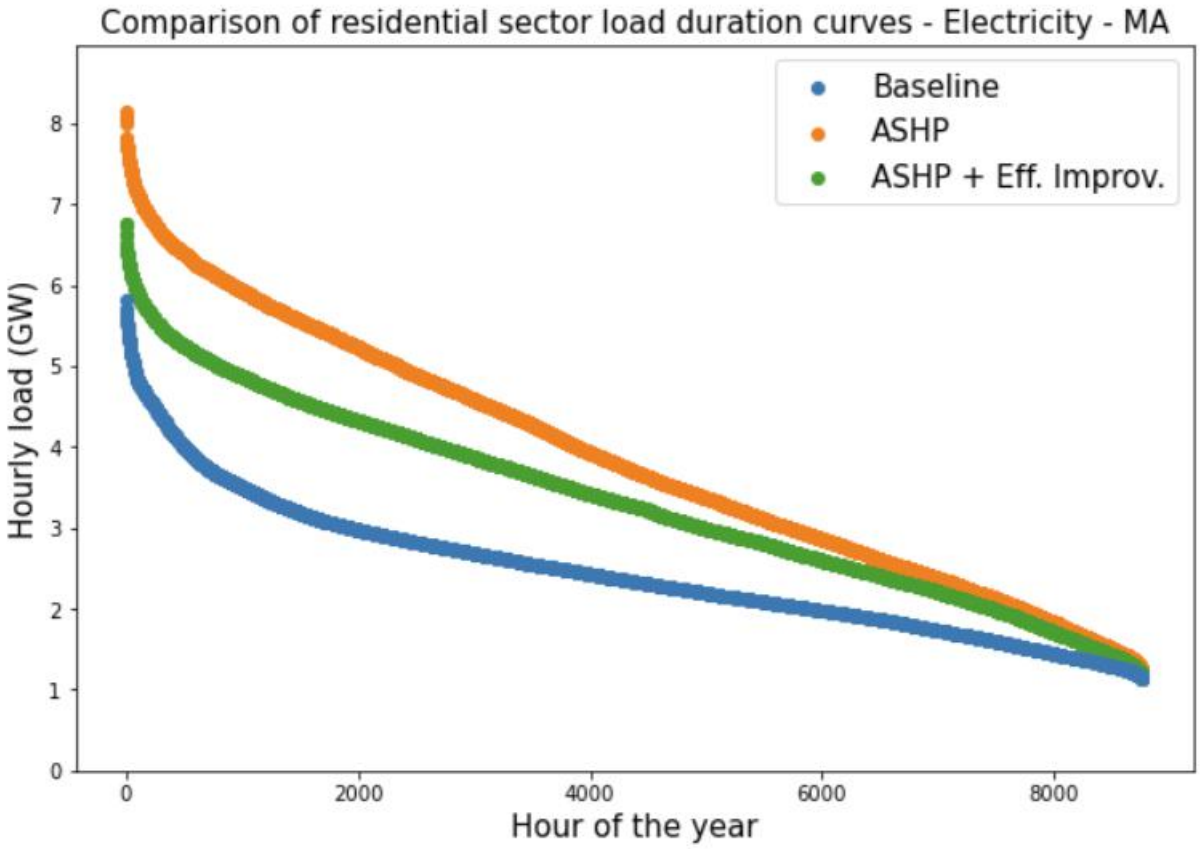


Scenario	Peak Load
Baseline	5.8 GW (Summer)
33% ASHP	9.7 GW (Winter, +67%)
33% ASHP + Eff. Improv.	7.6 GW (Winter, +31%)

- Efficiency improvements significantly reduce peak load impacts
- MA current net capacity: ~13 GW (Summer)[1]

1. Data from EIA https://www.eia.gov/electricity/state/massachusetts/
All results are preliminary and subject to revision

MA: Sized for 95% of Loads + Backup Gas Heating – Implications for Electricity Peaking

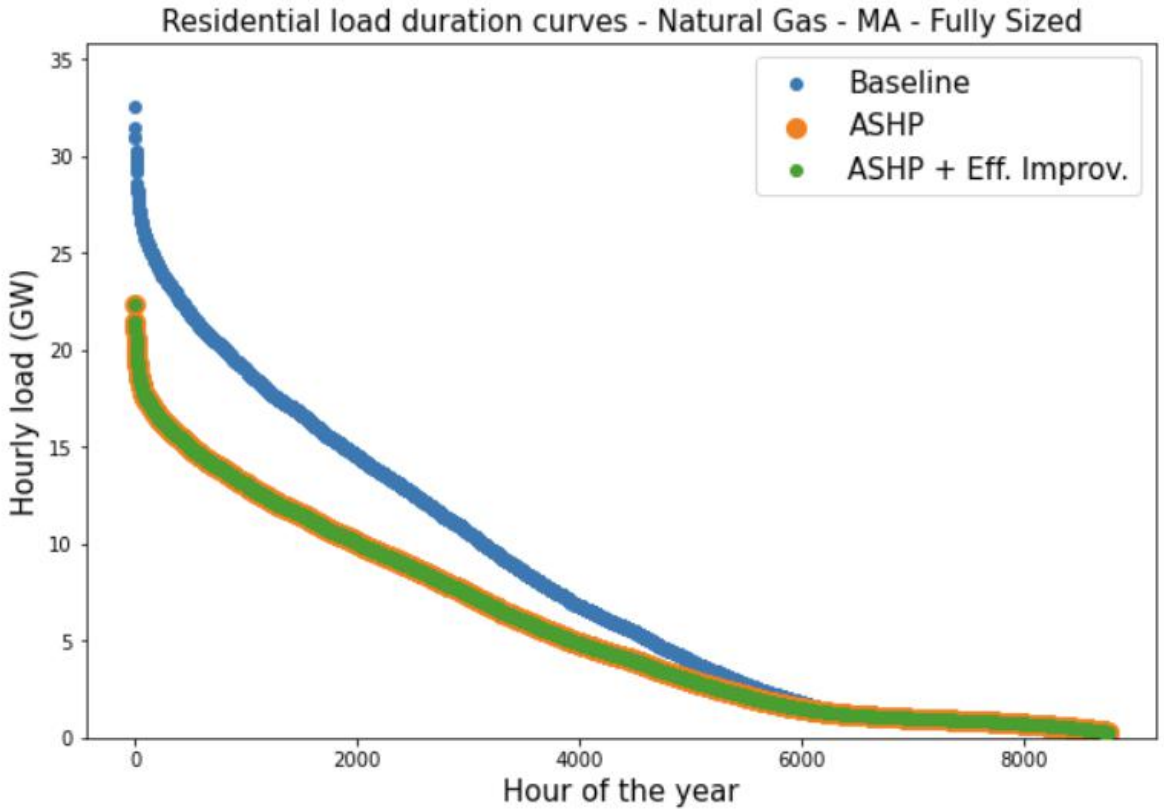


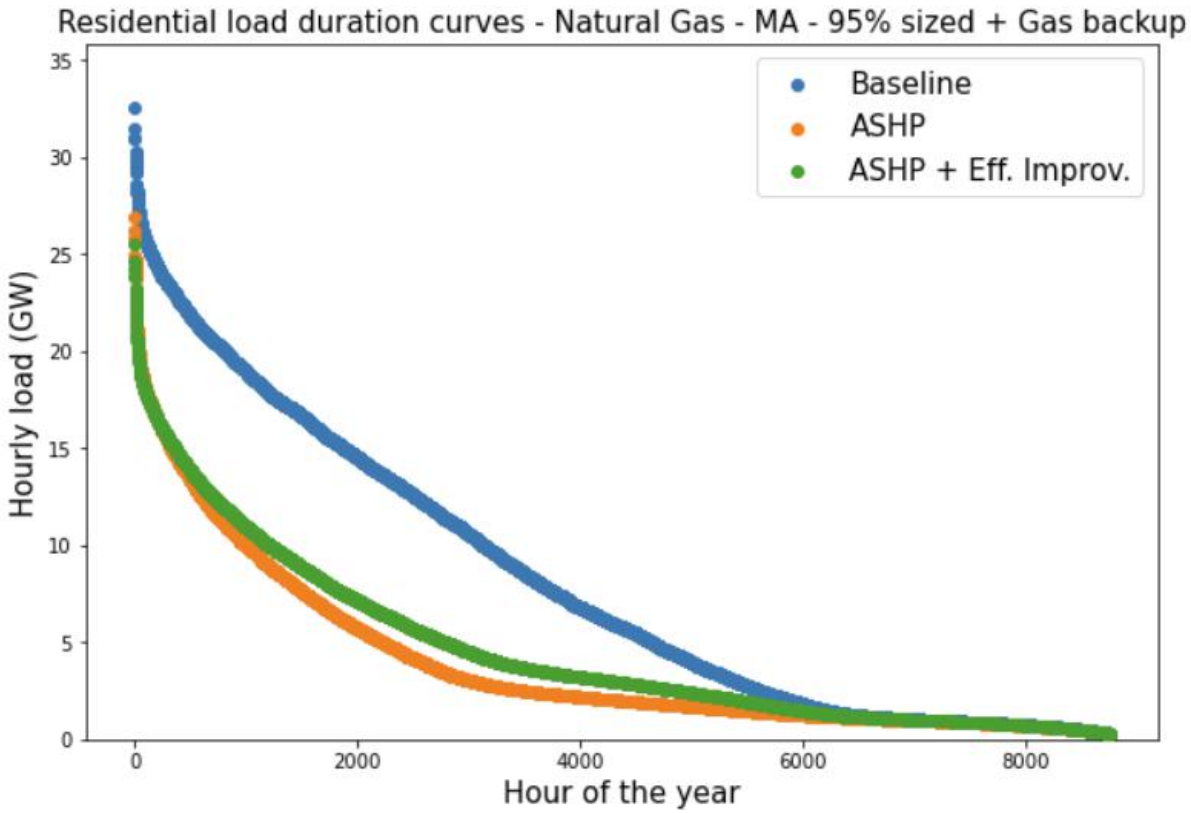
Scenario	Peak Load
Baseline	5.8 GW (Summer)
33% ASHP	8.2 GW (Winter, +41%)
33% ASHP + Eff. Improv.	6.8 GW (Winter, +17%)

- Peak electricity load reduced by 1-1.5 GW compared to full electrification, depending on whether the ASHP are deployed in parallel with efficiency improvements
- MA current net capacity: ~13 GW (Summer)[1]

1. Data from EIA https://www.eia.gov/electricity/state/massachusetts/
All results are preliminary and subject to revision

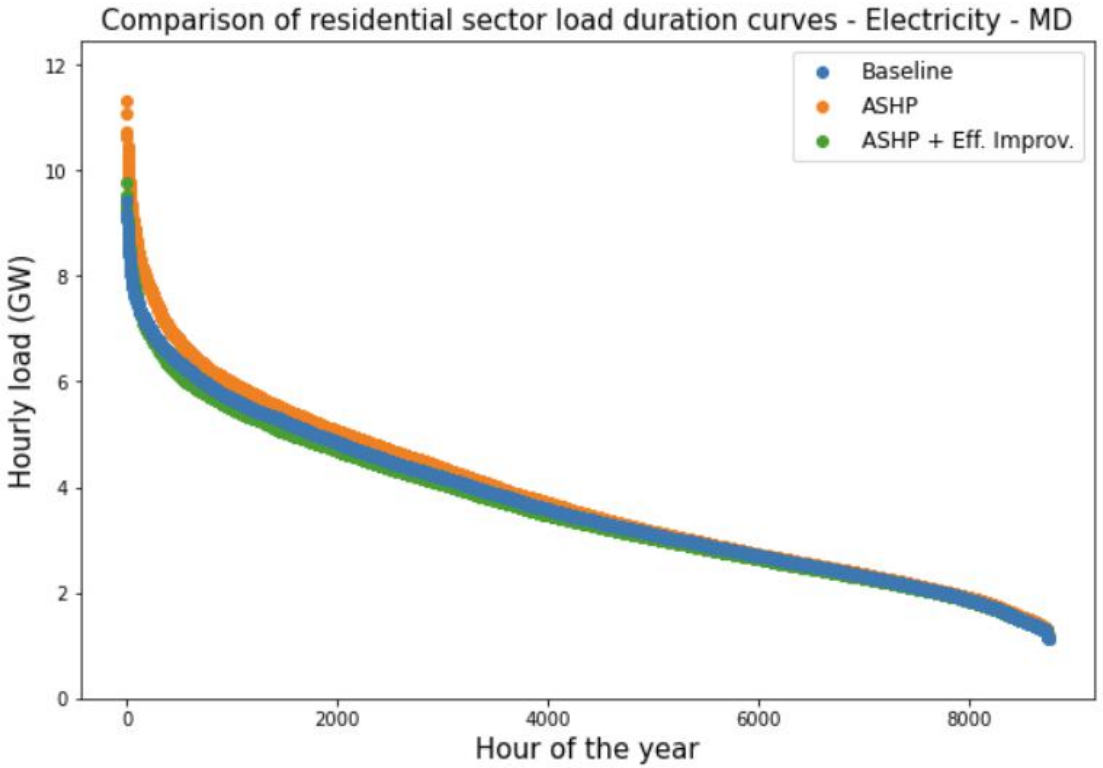
MA: Natural Gas Load Duration Curves for Both Sizing Methods





- In either case, peak need for natural gas is still significant –
  - Only 33% of housing stock was retrofitted with ASHP
  - Scenarios did not consider other forms of electrification (water heating, cooking, etc.)

MD: Sized to Meet All Loads - Implications for electricity peaking



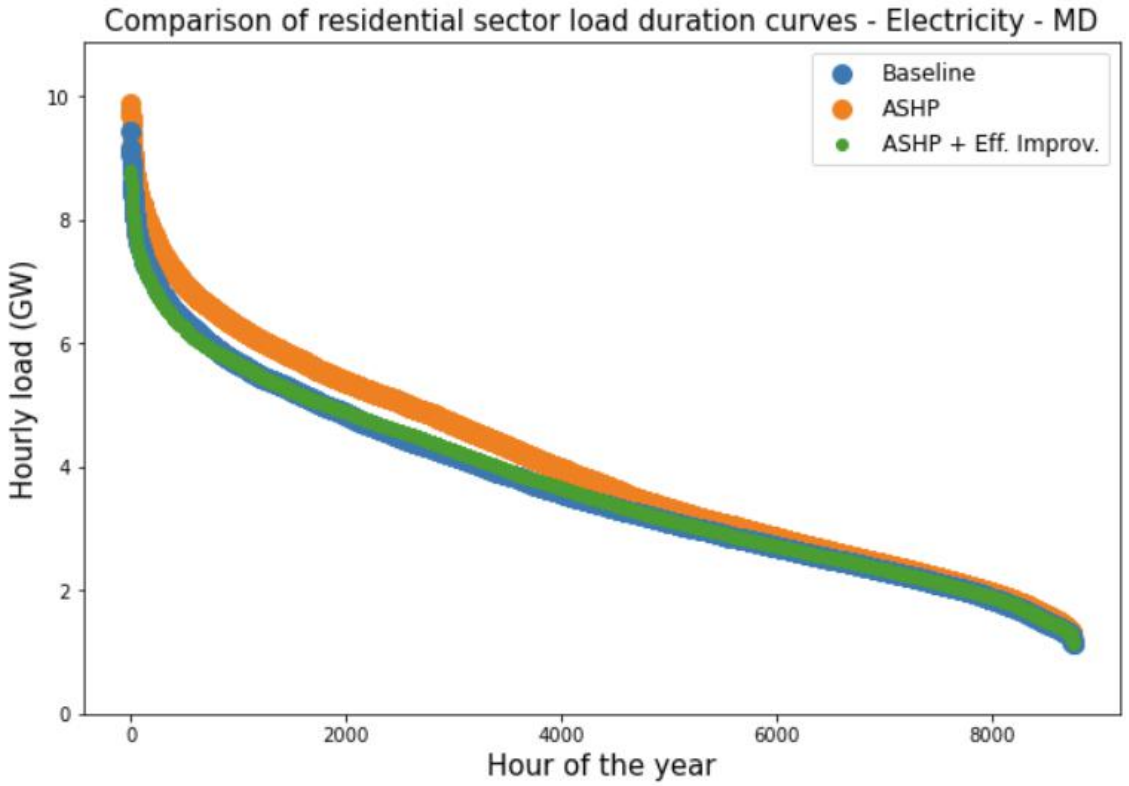
Scenario	Peak Load
Baseline	9.4 GW (Winter)[1]
33% ASHP	11.3 GW (Winter, +20.2%)
33% ASHP + Eff. Improv.	9.8 GW (Winter, +4%)

- Efficiency improvements nearly negate modest peak load impacts
- MD current net capacity: ~13.8 GW (Summer)[2]

1. MD being winter-peaking is not in agreement with current empirical data, but likely to be within the next few years (See https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/MWG/Building%20Decarbonization%20Study%20Update%209.21.21.pdf)
2. Data from EIA https://www.eia.gov/electricity/state/maryland/

All results are preliminary and subject to revision

MD: Sized for 95% of loads + Backup gas heating- Implications for electricity peaking



Scenario	Peak Load
Baseline	9.4 GW (Winter)[1]
33% ASHP	9.9 GW (Winter, +5%)
33% ASHP + Eff. Improv.	8.8 GW (Winter, -6%)

- Both deployment scenarios result in loads close to baseline
- MD current net capacity: ~13.8 GW (Summer)[2]

1. MD being winter-peaking is not in agreement with current empirical data, but likely to be within the next few years (See https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/MWG/Building%20Decarbonization%20Study%20Update%209.21.21.pdf)
2. Data from EIA https://www.eia.gov/electricity/state/maryland/

All results are preliminary and subject to revision

Conclusions

- Heat pump adoption in cold climates has significant impact on demand profiles at the regional level
  - Assumptions about sizing and role of electric resistance backup heat are critical to load shapes
  - Envelope improvements have valuable role in reducing peak load
  - Winter peaking effects are less pronounced in milder climates
- Flexibility measures warrant particular interest for shaving narrow peaks

Future Work & Questions

- Summer ‘22:
  - Refine our ASHP modeling representation
  - Roadmap aggregative modeling methodology for commercial sector
- Fall ’22:
  - Implement aggregative modeling for commercial sector
  - Create models for impact of flexibility measures at stock level
- Question for sponsors:
  - What role have you been foreseeing for ASHP sizing & backup heating?
    - Specifically, what is being done on the ground in your service territory?

Thank you

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Supplemental Information

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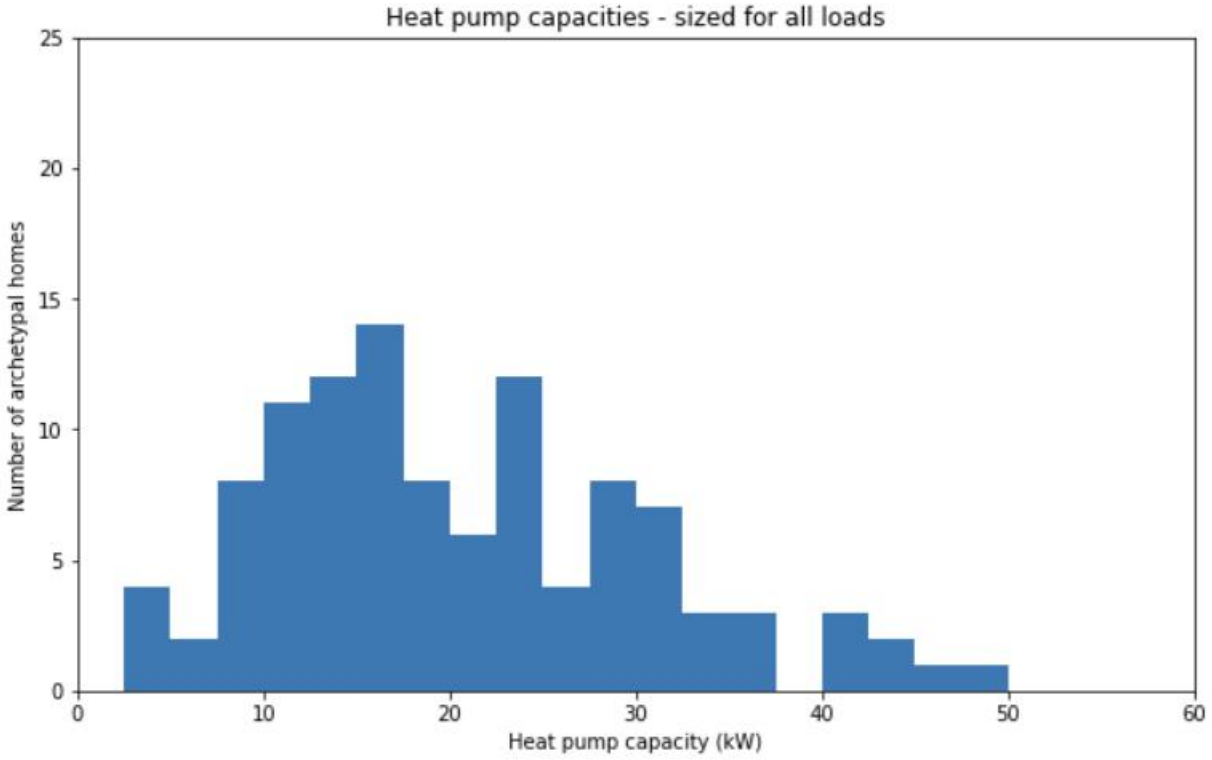
Electric Power Systems Fall Workshop

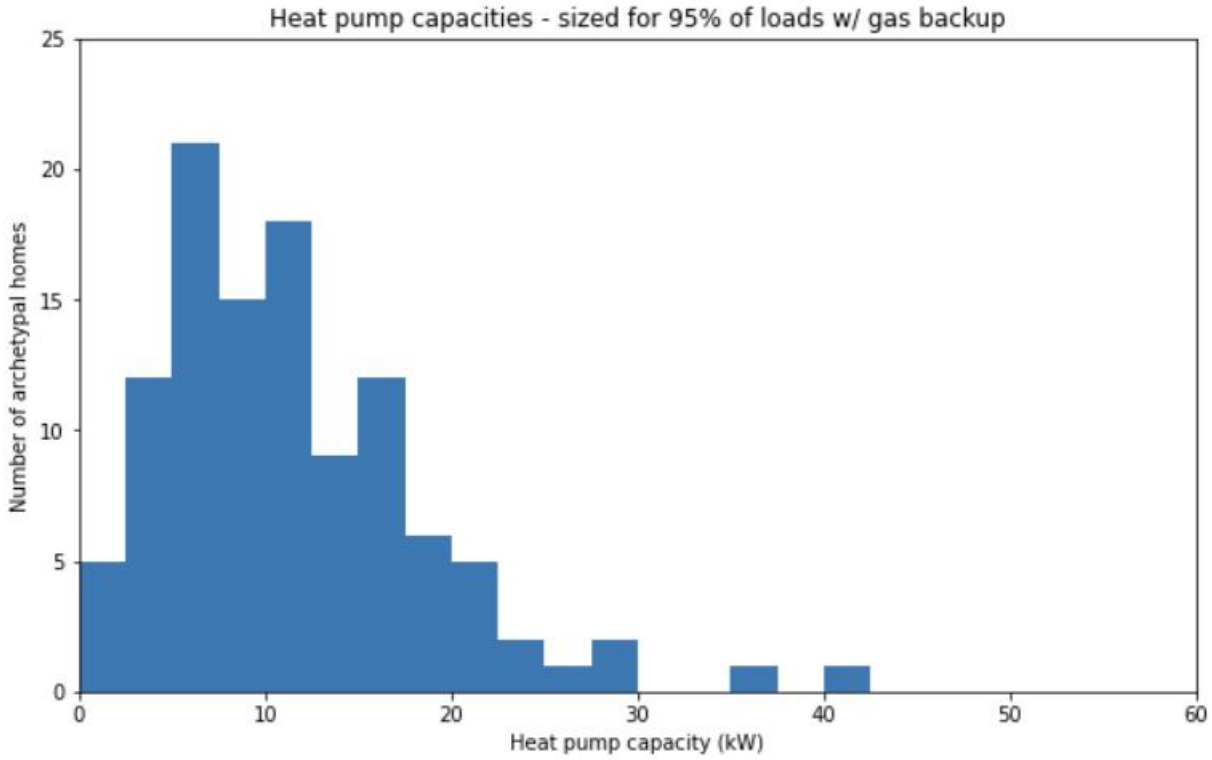
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MA Decarbonization Roadmap – Building Efficiency Criteria

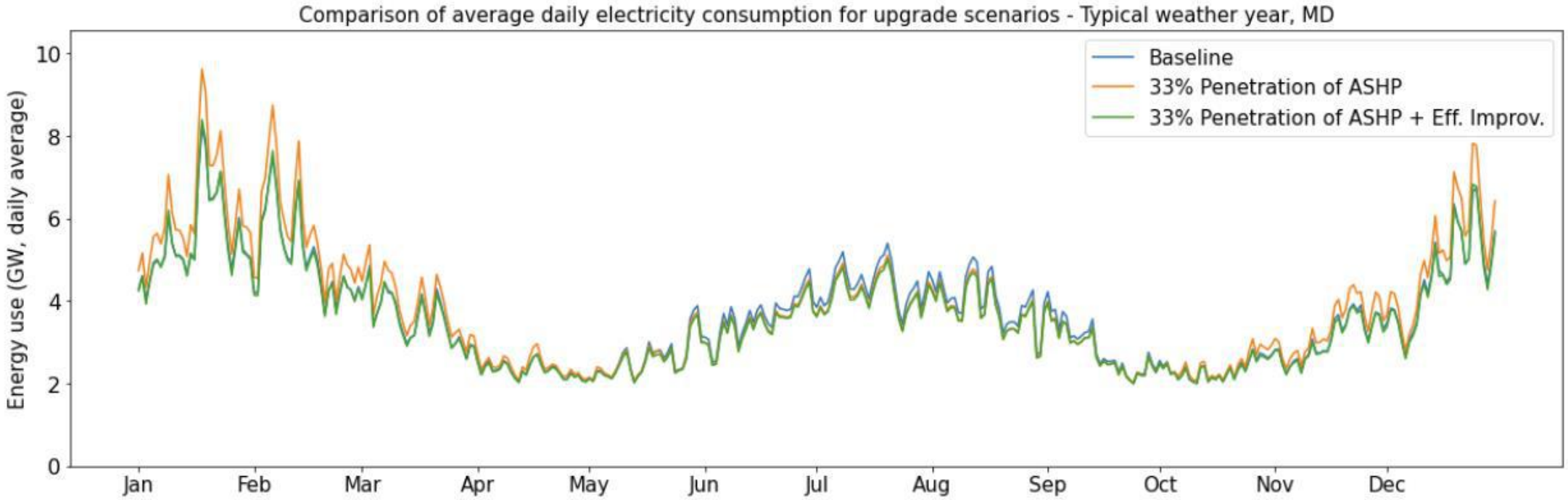
Single Family and Small Multifamily			
ECM 1 Electrification	ECM 2 Low Efficiency	ECM 3 Medium Efficiency	ECM 4 High Efficiency
	ECM 1 plus:	ECM 2 plus:	ECM 3 plus:
Systems			
Heat Pump Cooling SEER: 15	ECM 1	Heat Pump Cooling SEER: 20	Heat Pump Cooling SEER: ECM 3
Heat Pump Space Heating HSPF: 9		Heat 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-60 Roof/Attic	Window U-value: 0.25	R-30 Walls
	R-15 Walls	Window SHGC: 0.32	Window U-value: 0.21
	Airtightness to 0.4 CFM/sf at 0.3 in. wc.	Airtightness to 0.2 CFM/sf at 0.3 in. wc.	Window SHGC: 0.24
			Airtightness to 0.1 CFM/sf at 0.3 in. wc.
Controls			
Setbacks to 70°F and 75°F in heating and cooling, respectively	**Demand-Control Ventilation**	ECM 2	ECM 2
	70% Effective Energy Recovery		
Appliances			
Electric conversion	ECM 1	ECM 1	ECM 1

Heat pump sizing – variation across housing stock





MD: All Scenarios Using Our ASHP Models – Sized to Meet All Loads



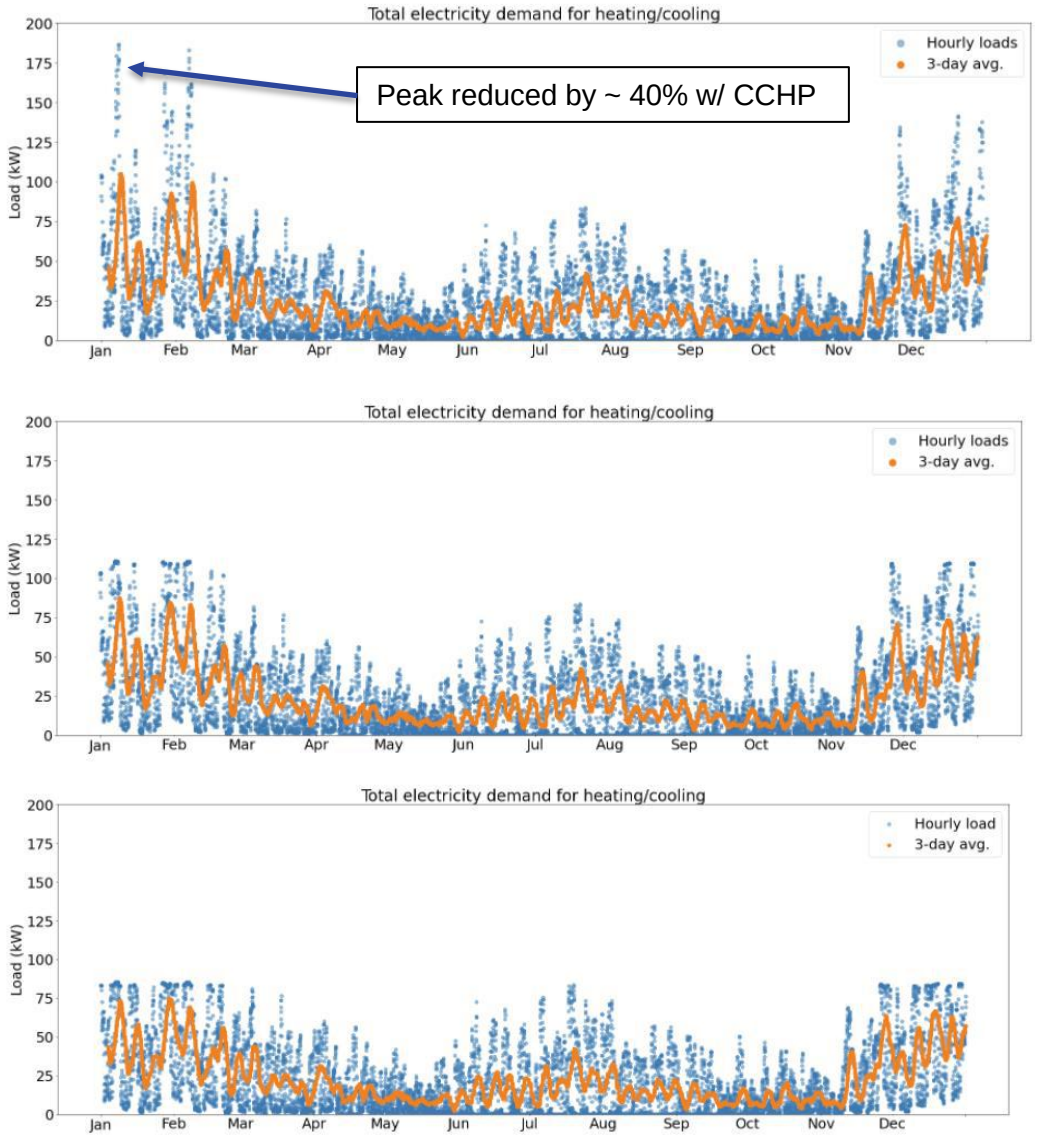
Supplemental Info – Example Office Building Retrofit

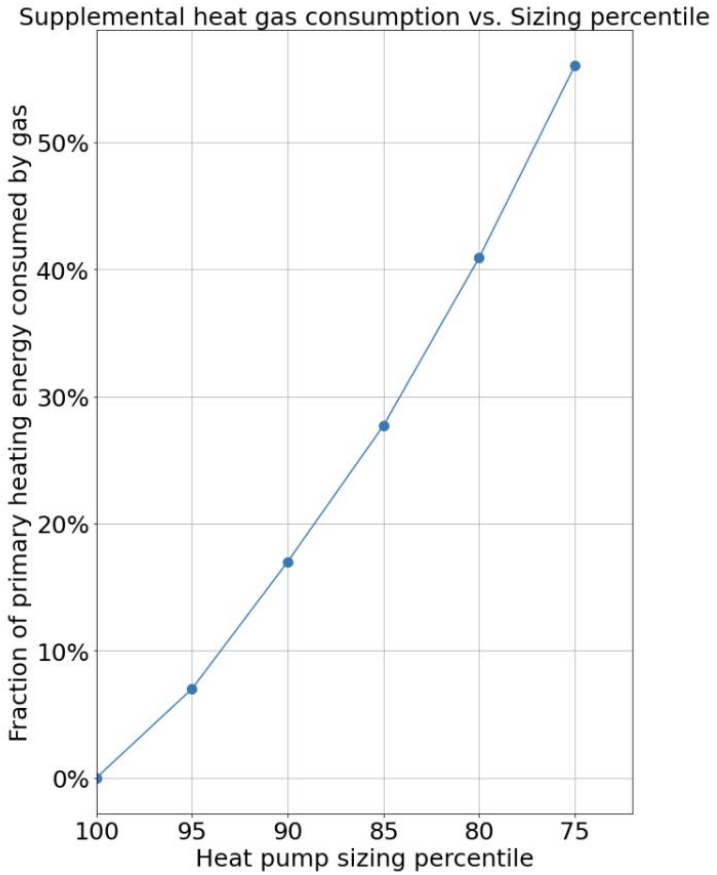
Cold-Climate HP (CCHP) - Comparison of Winter Sizing Criteria

Sized for 100th Percentile Heating Load

95th Percentile

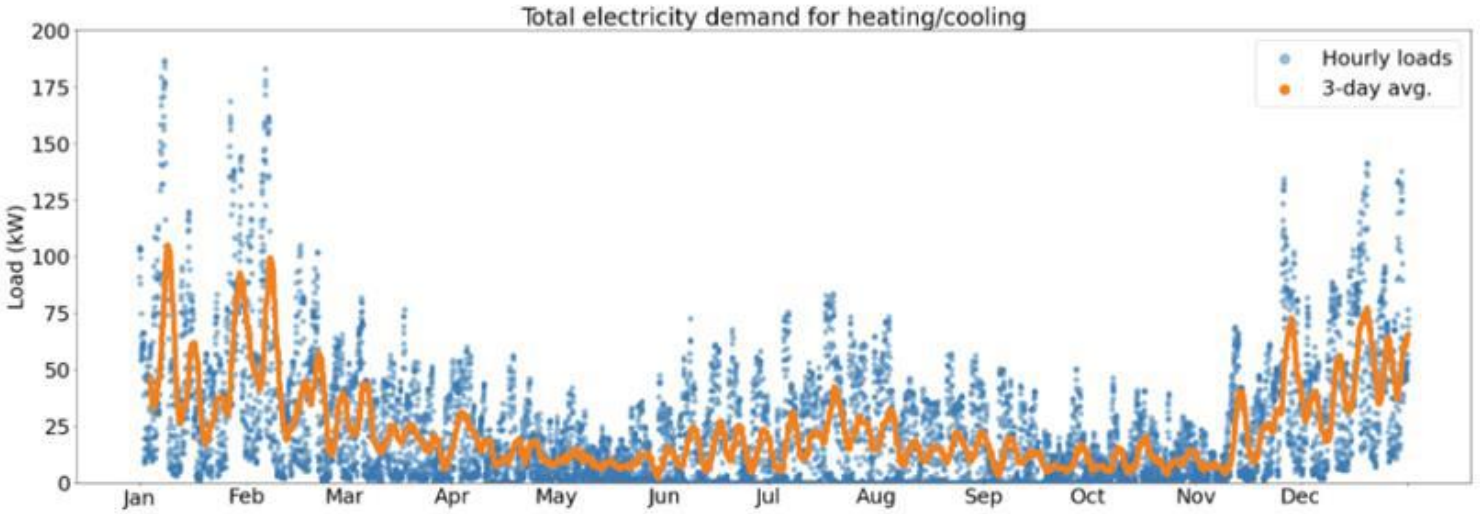
90th Percentile



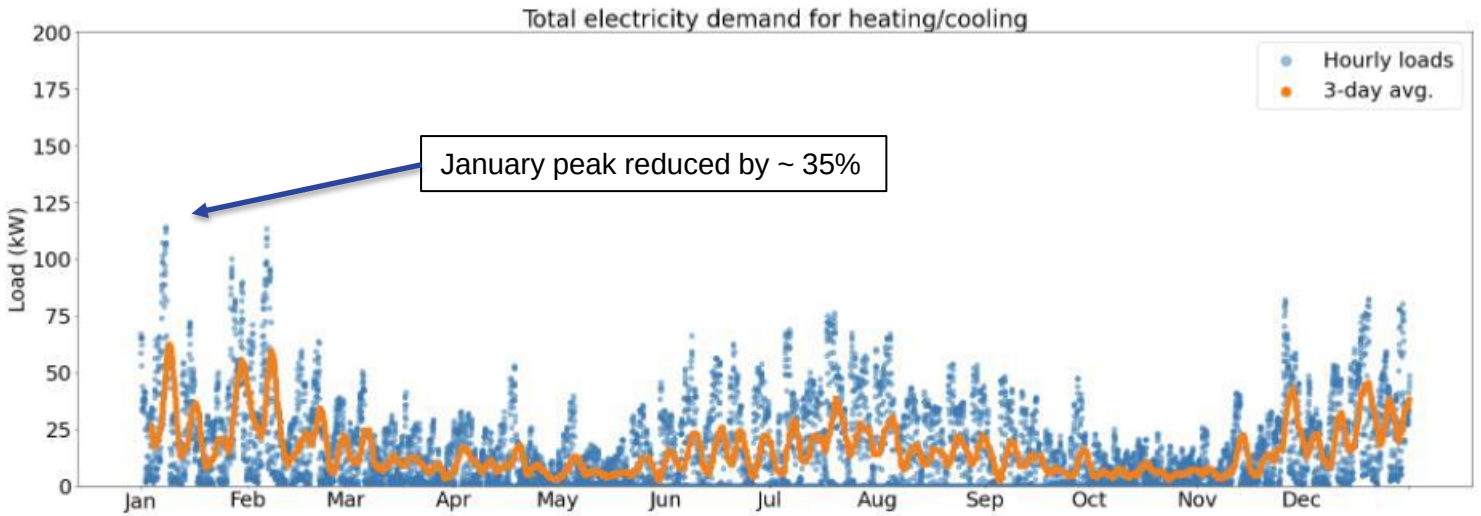


Effect of Efficiency Investments: CCHP For 100th Percentile Heating Load

CCHP w/out Envelope Improvements

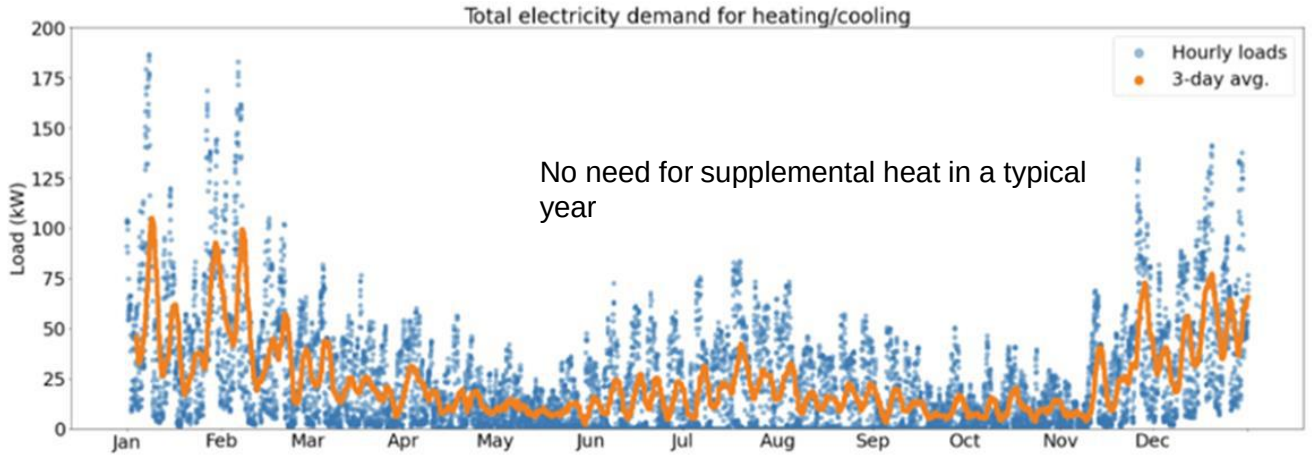


CCHP w/ Envelope Improvements

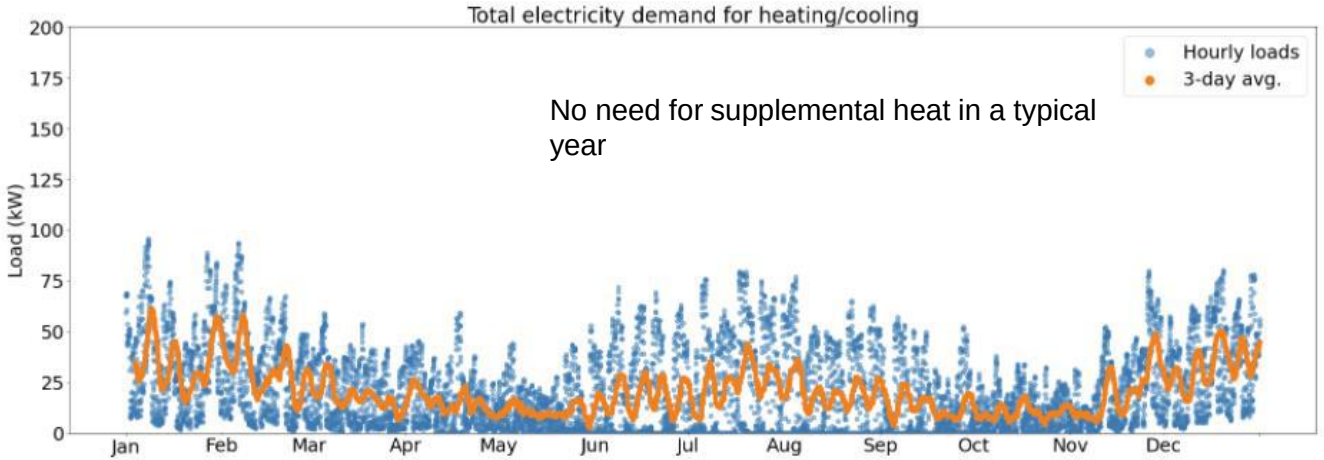


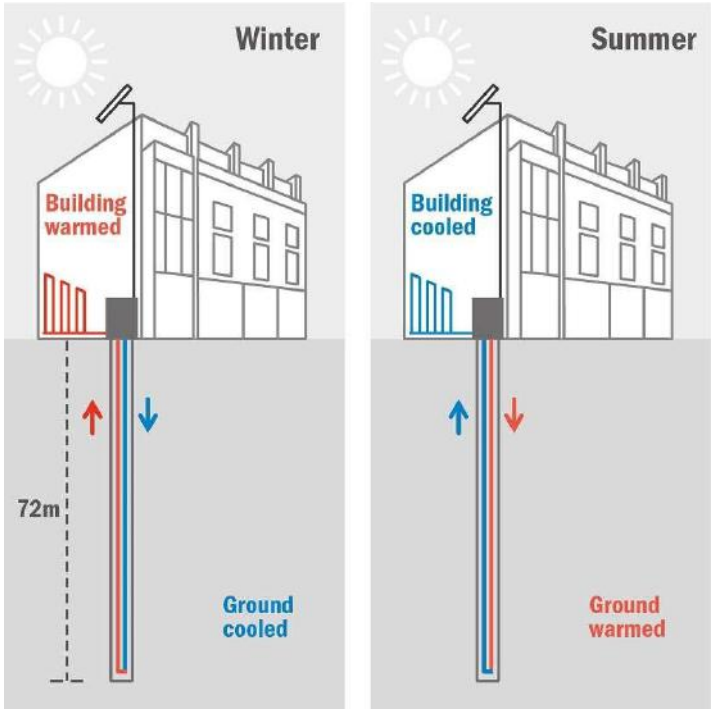
CCHP vs. GSHP: Sized for 100th Percentile Heating Load

Cold Climate HP (CCHP)



Ground Source HP (GSHP)



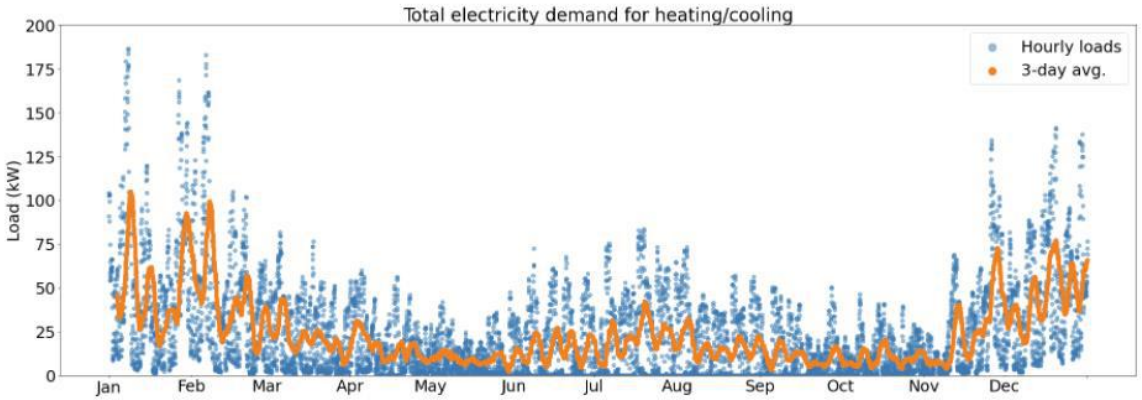


Significant space is needed for GSHP heat exchanger

Graphs by author. GSHP diagram source: https://www.iop.org/explore-physics/sustainable-building-design/ground-source-heat-pump
All results are preliminary and subject to revision

Example of CCHP profiles with/without electric supplemental heat

100th-percentile sized CCHP



90th-percentile sized CCHP w/ electric supplemental heat

