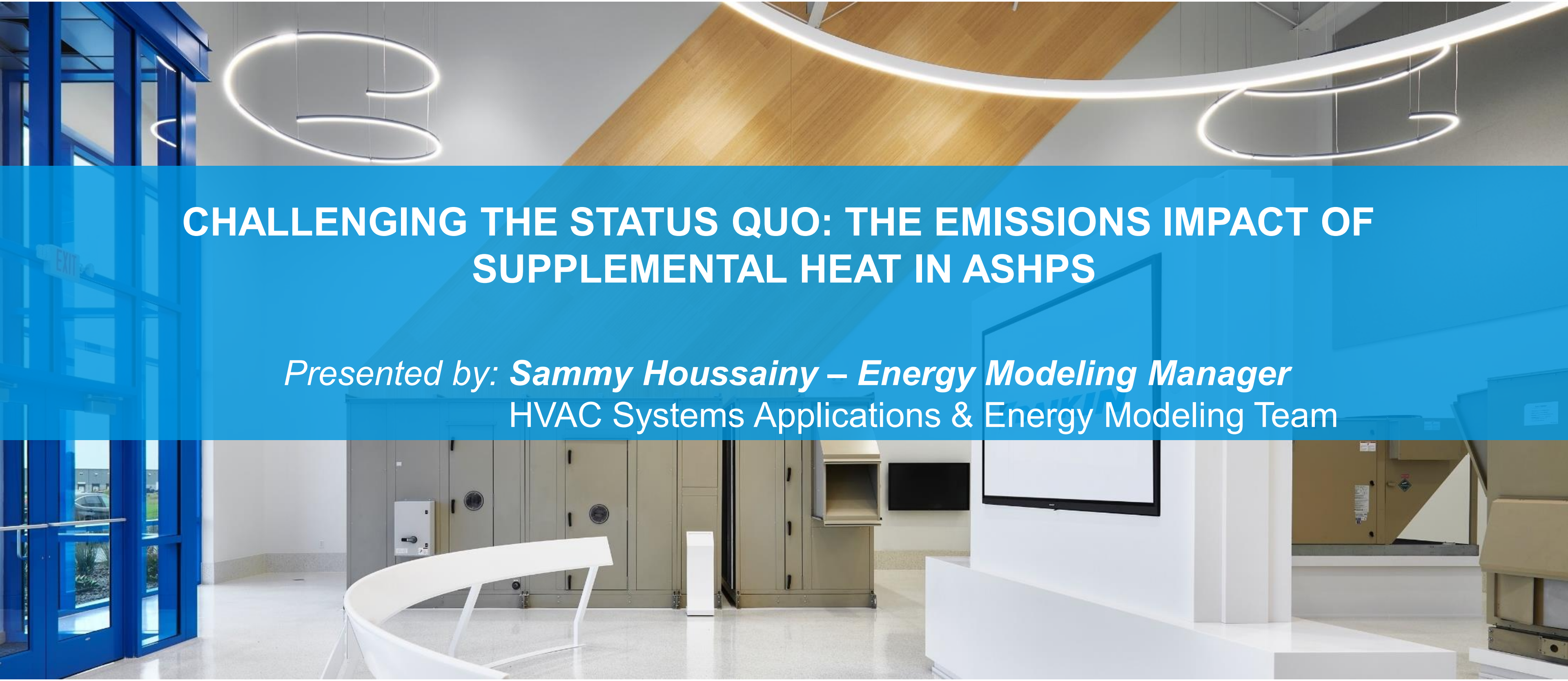

CHALLENGING THE STATUS QUO: THE EMISSIONS IMPACT OF SUPPLEMENTAL HEAT IN ASHPS

Presented by: ***Sammy Houssainy – Energy Modeling Manager***
HVAC Systems Applications & Energy Modeling Team

Introduction

Sammy Houssainy, PhD, PE

Energy Modeling Manager

HVAC Systems Applications and Energy Modeling Team

Sammy.Houssainy@DaikinApplied.com

- Joined Daikin in June 2024
- Previously
  - Project Manager at Department of Energy's National Renewable Energy Lab (NREL)

- Focus areas at Daikin include:
  - Energy modeling
  - EnergyAnalyzer Pro (EA Pro)
  - Decarbonization
  - Electrification

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- **Always consult your state & local codes**, which may take precedence over standards which vary in adoption, complete or partial, by state. Also note that a state may adopt a different year of the standard than the latest version.
- The local **Authority Having Jurisdiction (AHJ) has the final authority** in interpreting code requirements. When in doubt, contact the AHJ.

Question for You

Do you Recommend Dual Fuel Heat Pumps in your Decarbonization Projects?

Learning Objectives

Objectives and Motivation

- Describe the role of **dual fuel heat pumps** in reducing **greenhouse gas emissions** from **commercial buildings** across the U.S.
- Describe the **long-term decarbonization impacts** of **electric** vs. **gas supplemental** heating for **air source heat pumps**.
- Apply **region-specific insights** to inform **supplemental heating options** for air source heat pumps that minimize **emissions** while considering **cost** and electrical **infrastructure** constraints.

Dual fuel technologies are often overlooked in decarbonization and electrification discussions.

2025 ASHRAE Annual Conference Paper Publication

ASHRAE Conference Paper

Presented in June 2025 (Phoenix, AZ)

WEDNESDAY, JUNE 25TH, 2025 | 9:45-10:45AM MST

PHOENIX CONVENTION CENTER NORTH BUILDING, LEVEL 2, 225AB

Decarbonization Beyond Electrification: A Regional Emissions Analysis of Electric versus Gas Supplemental Heating for Heat Pumps

Sammy Houssainy, PhD, PE
Associate Member ASHRAE

Jeff Seewald, PE
Associate Member ASHRAE

Paul Ehrlich, PE
Member ASHRAE

ABSTRACT

Reducing greenhouse gas (GHG) emissions from building space heating is vital for decarbonizing the built environment. Air source heat pumps (ASHPs) offer a promising low-carbon alternative to gas heating, however their efficiency declines in colder climates, often requiring supplemental heating. While electric supplemental heat is assumed to be more sustainable than gas, this study provides the first comprehensive region-specific analysis across all U.S. grid regions and climate zones to assess long-term decarbonization outcomes. This study quantifies the emissions impact of electric versus gas supplemental heat for ASHPs through hourly whole-building energy modeling using the U.S. Department of Energy's EnergyPlus simulation engine. Models align with ASHRAE Standard 90.1 and represent common commercial building types across the U.S. Historical emissions factors from the Environmental Protection Agency's (EPA) eGRID dataset and forward-looking projections from the National Renewable Energy Laboratory's (NREL) Cambium dataset extend the analysis to 2050. Results show electric supplemental heat yields substantial emissions reductions (~20%) in states like New York and Minnesota but provides only marginal (<2%) or comparable reductions in numerous locations, even with anticipated grid decarbonization. These findings emphasize the need for precision in policy and design decisions as electrification continues to shape the future of sustainable buildings.

QR Code to Published ASHRAE Conference Paper:

Agenda

1 Introduction

- Background
- Hypothesis
- Assumptions
- Problem Statement & Study Goals

2 Approach

- GHG Emission Factors
- Building Energy Models
- Modeled Scenarios

3 Results

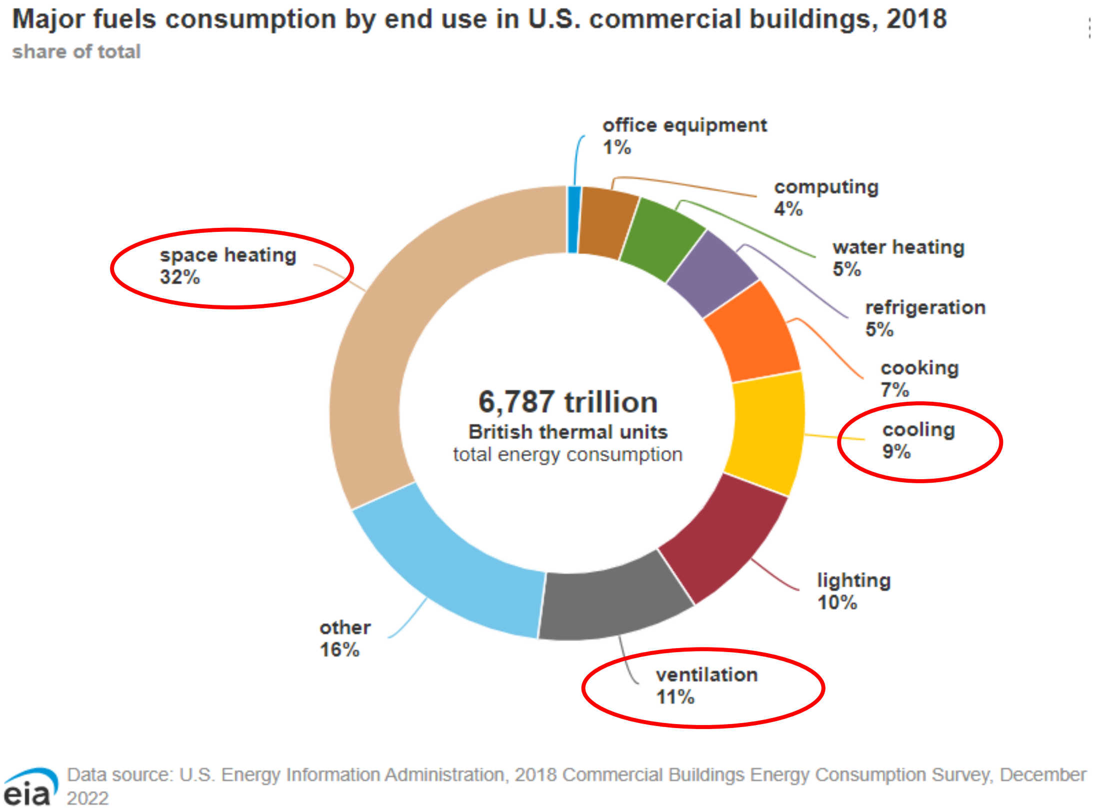
- Incremental, Nationwide, Dual-Fuel Heat Pump Emissions Savings from 2014-2050
- Added Savings from Supplemental Heat Electrification
- 15-year Assessment

4 Study Limitations, Conclusions, and Future Work

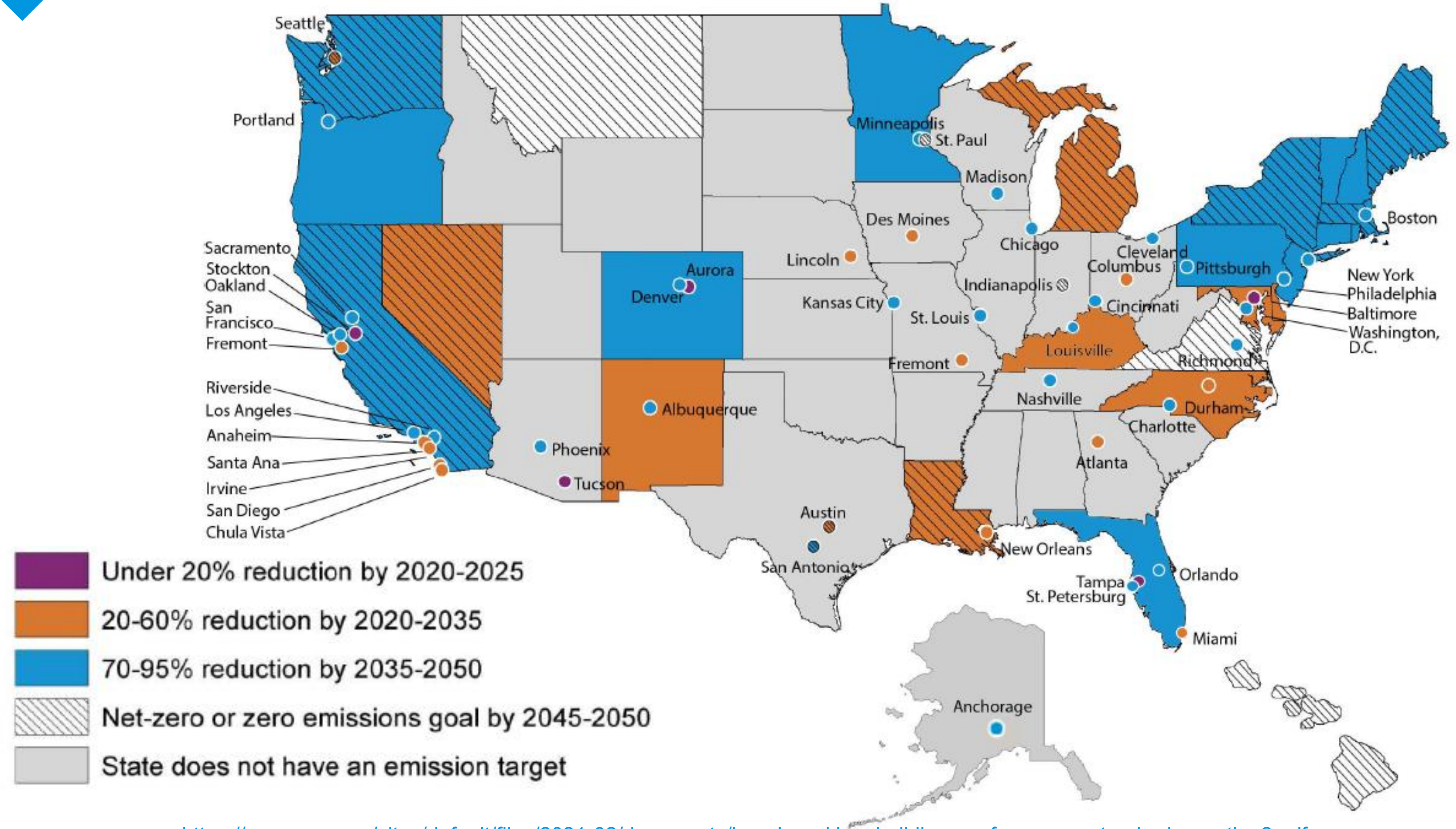
Background

Buildings and Space Heating

- In the U.S, buildings account for **~70% of electricity consumption, 40% of total primary energy use**
- Buildings are a major source of greenhouse gas (GHG) emissions, contributing **30% of U.S. operational emissions** and **37% of global CO_2 emissions**.
- Air Source Heat Pumps (**ASHPs**) are a promising **low-carbon heating** alternative, particularly when powered by renewable electricity.



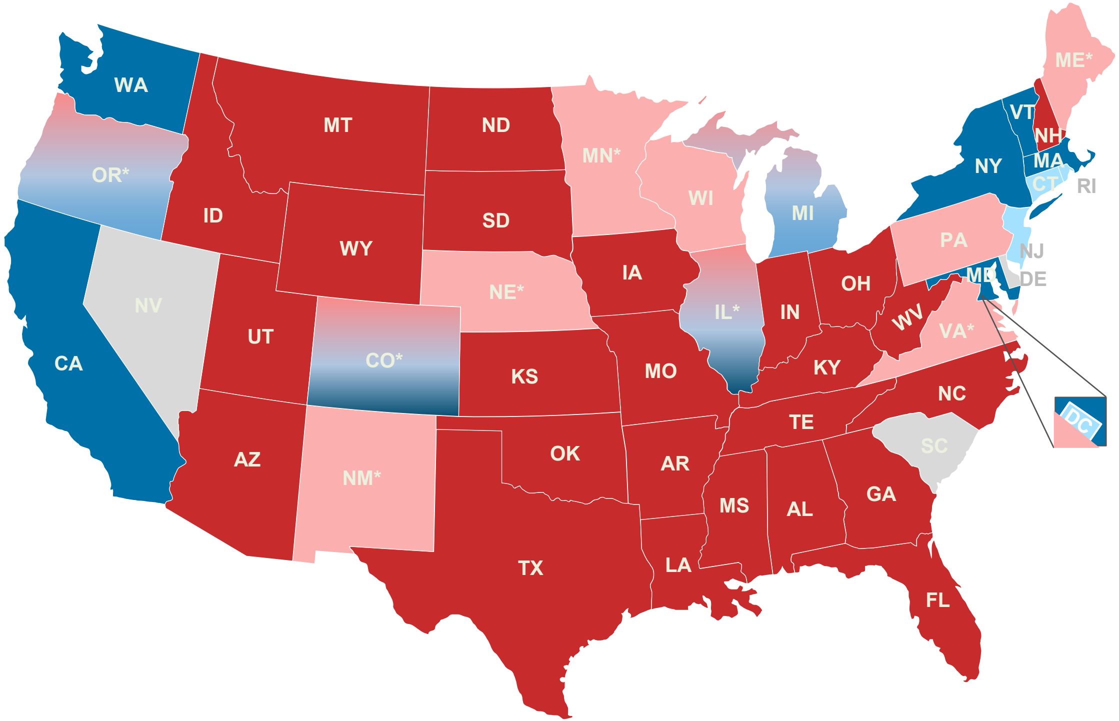
States and Cities with GHG Emissions Reduction Goals



https://www.epa.gov/sites/default/files/2021-02/documents/benchmarking_building_performance_standards_section2.pdf
https://www.c2es.org/document/greenhouse-gas-emissions-targets/

As of Aug. 2024

Gas Bans & Bans on Gas Bans



Local Gas Bans Passed

Local Gas Bans In Development

State Ban on Local Gas Bans Passed

State Ban on Local Gas Bans Proposed Or *Failed to advance

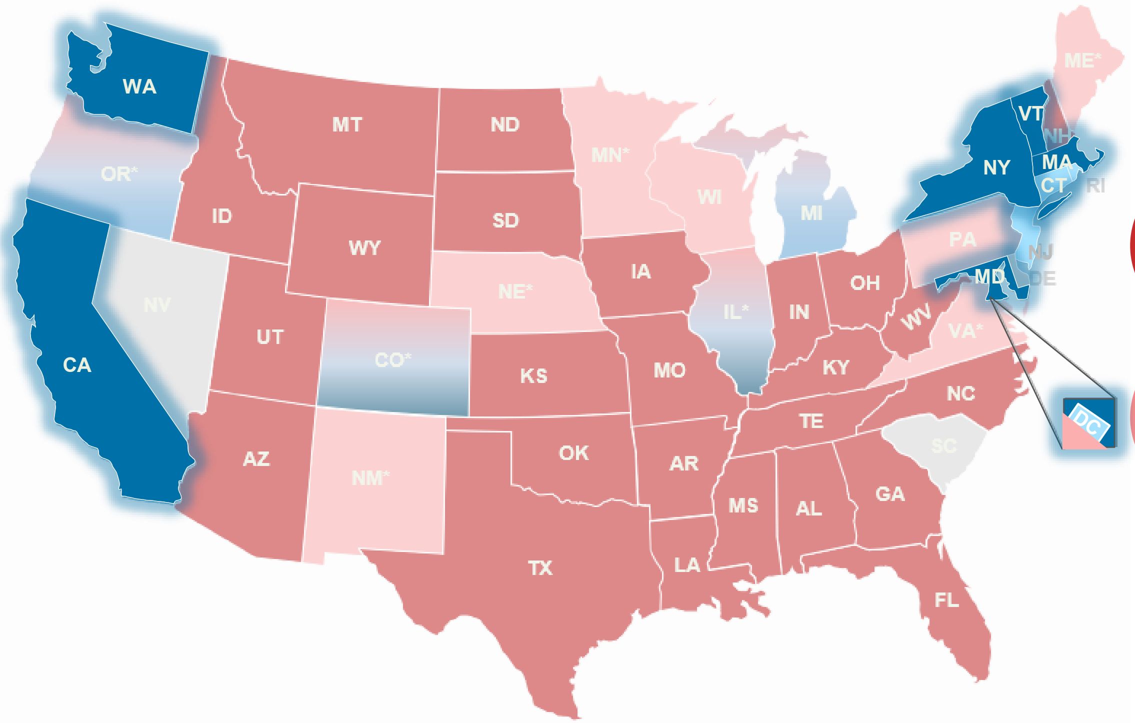
As of Oct. 2023

Source: S& P Global Commodity Insights
Map Credit: Joe Felizadio

https://www.businessinsider.com/cities-require-or-encourage-switch-green-buildings-natural-gas-electric-2023-2
https://www.spglobal.com/market-intelligence/en/news-insights/articles/2023/11/gas-ban-monitor-1st-mass-bans-advance-amid-broader-new-england-push-78205323

Gas Bans & Bans on Gas Bans

About 1 out of 5 Americans now live in places with some sort of legislation pushing toward electrification. That consists of about 100 major cities.



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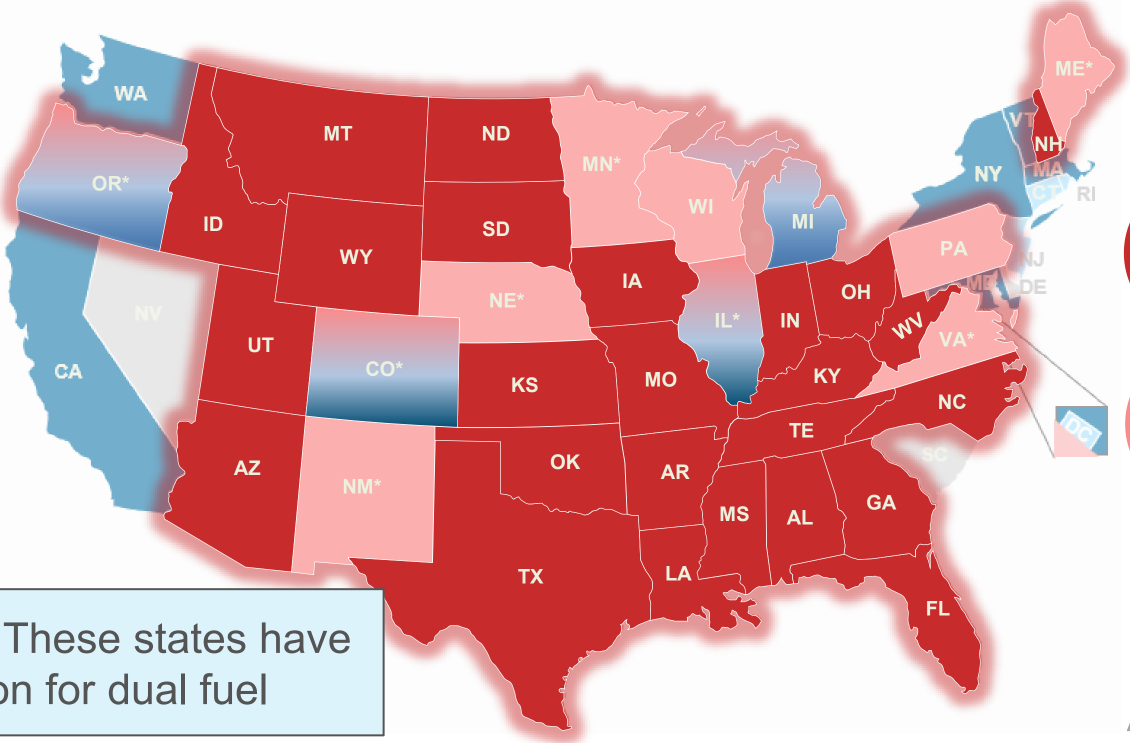
Gas Bans & Bans on Gas Bans

On the opposite end of the spectrum, about 25 states have passed legislation that local governments cannot ban the use of natural gas at the local level, accounting for over 1/3rd of natural gas usage.

Local Gas Bans Passed

Local Gas Bans In Development



State Ban on Local Gas Bans Passed

State Ban on Local Gas Bans Proposed Or *Failed to advance

Take-away: These states have the option for dual fuel

As of Oct. 2023

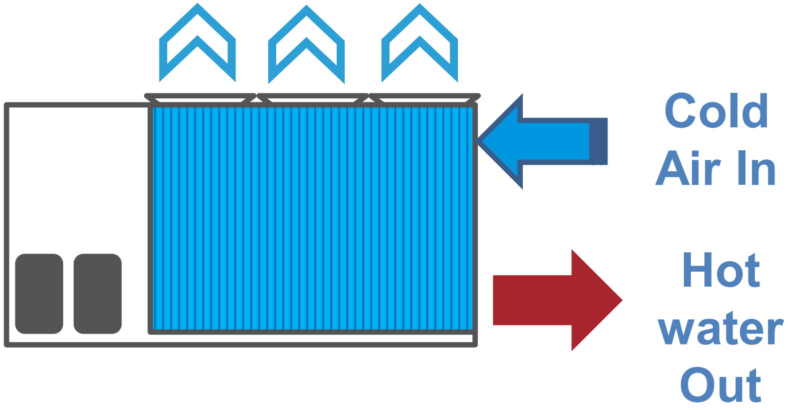
Source: S& P Global Commodity Insights
Map Credit: Joe Felizadio

https://www.businessinsider.com/cities-require-or-encourage-switch-green-buildings-natural-gas-electric-2023-2
https://www.spglobal.com/market-intelligence/en/news-insights/articles/2023/11/gas-ban-monitor-1st-mass-bans-advance-amid-broader-new-england-push-78205323

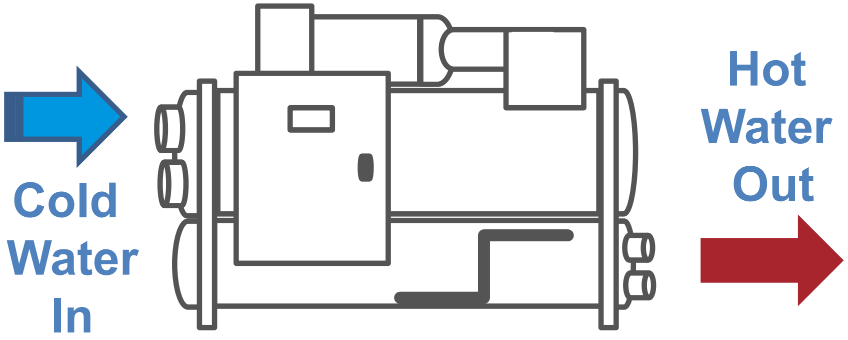
Heat Pump Primer

Types of Heat Pumps

Air to Water
Heat Pump

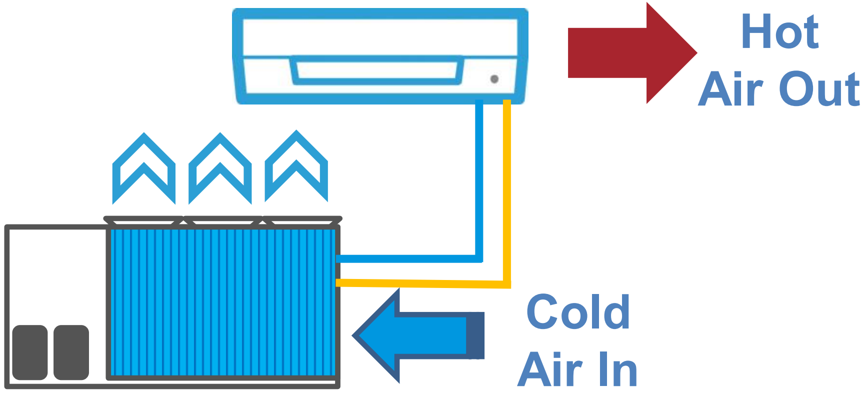


Water to Water
Heat Pump

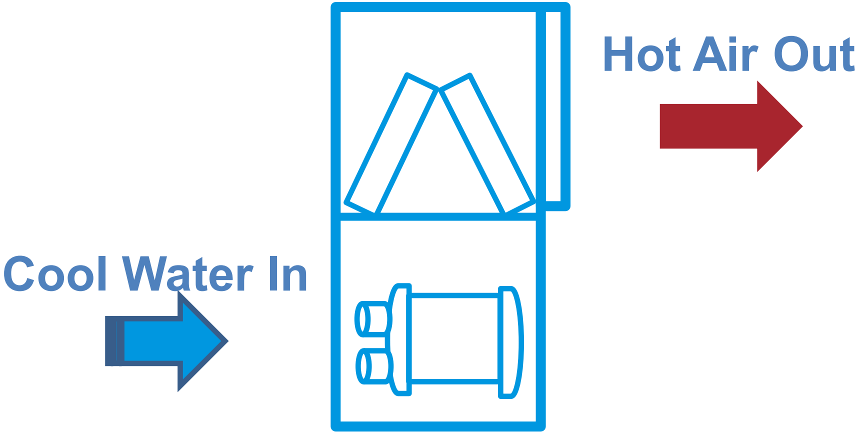


Heat Pumps Continued…

Air to Air Heat Pump



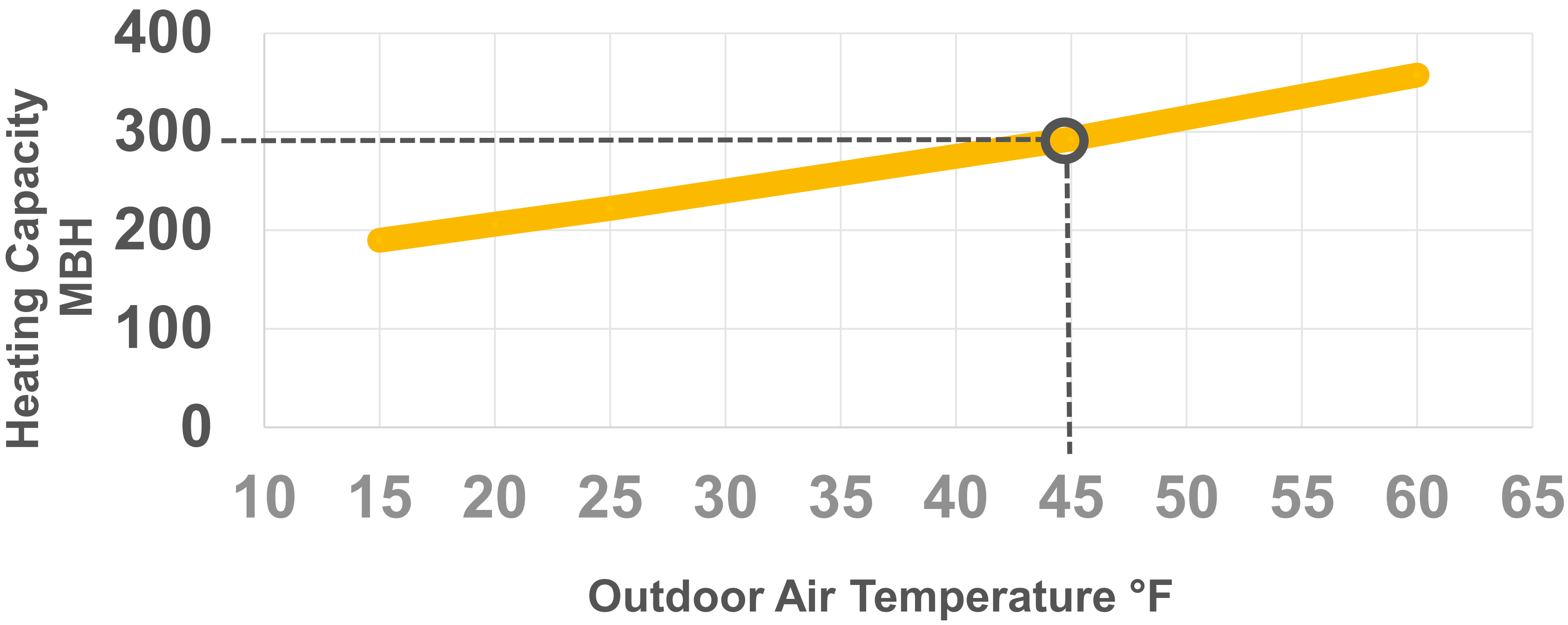
Water to Air Heat Pump



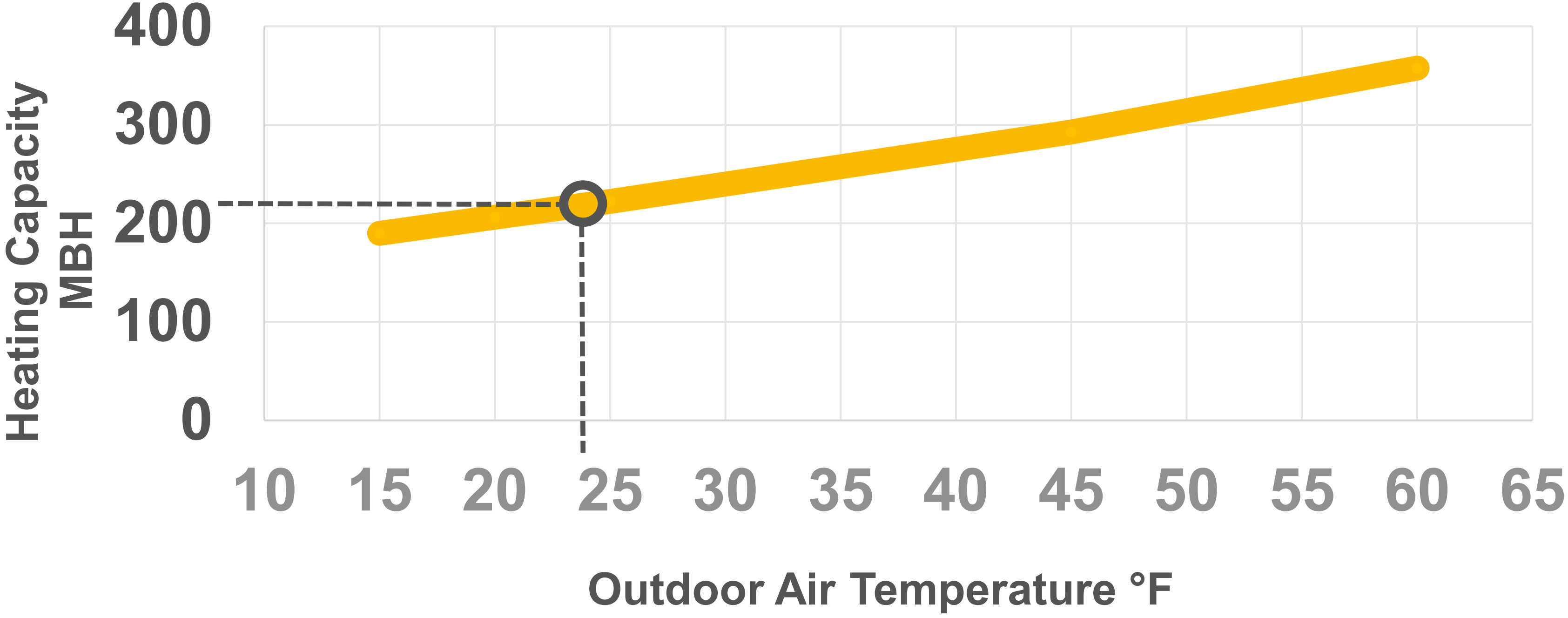
Air-to-air heat pumps are the dominant type of heat pump in North America

→ *Focus of this study*

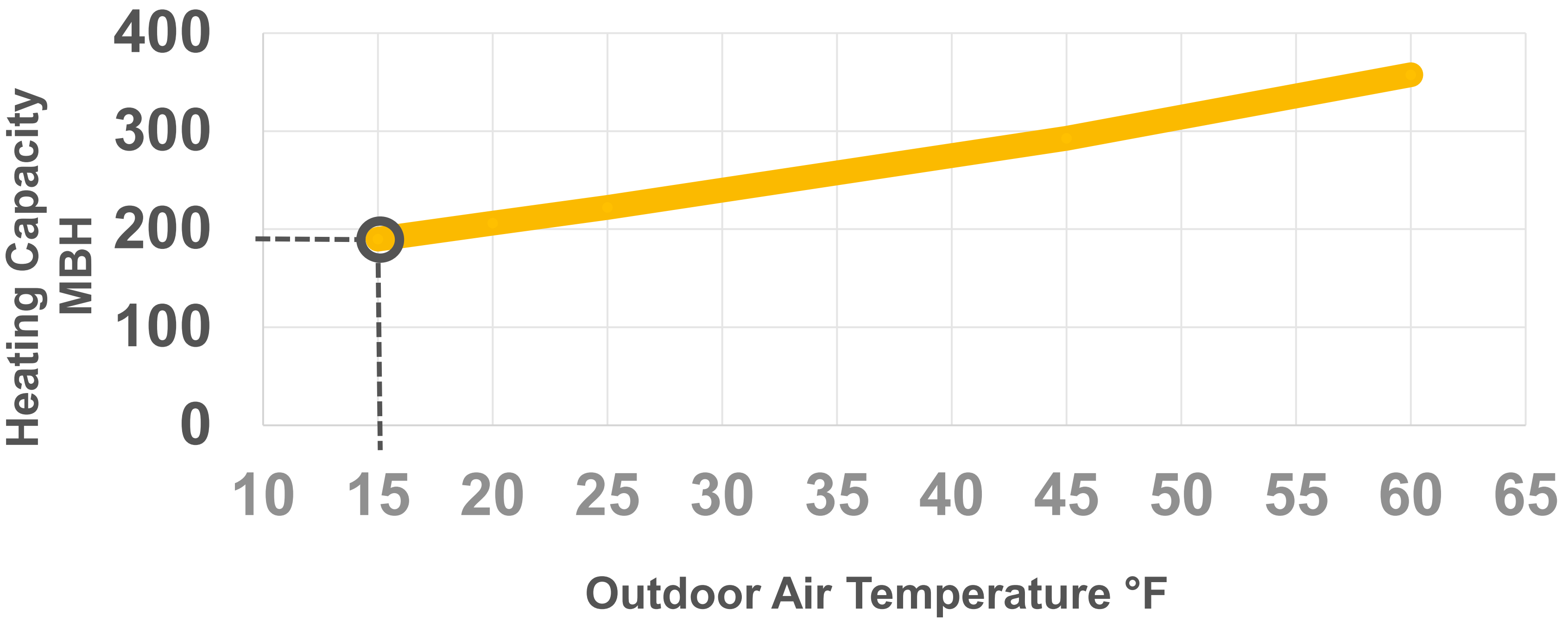
Heat Pump Capacity vs Ambient Temperature



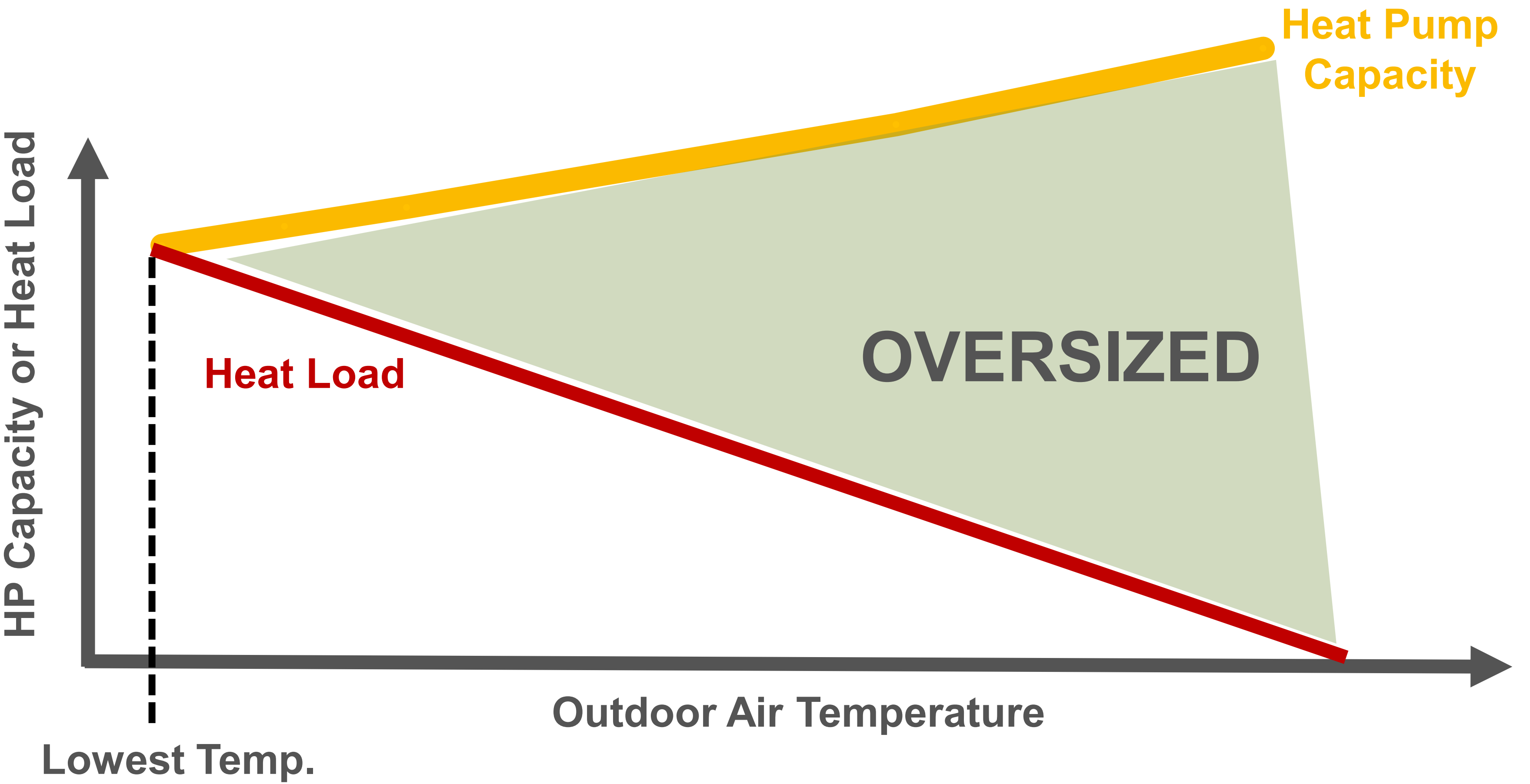
Heat Pump Capacity vs Ambient Temperature



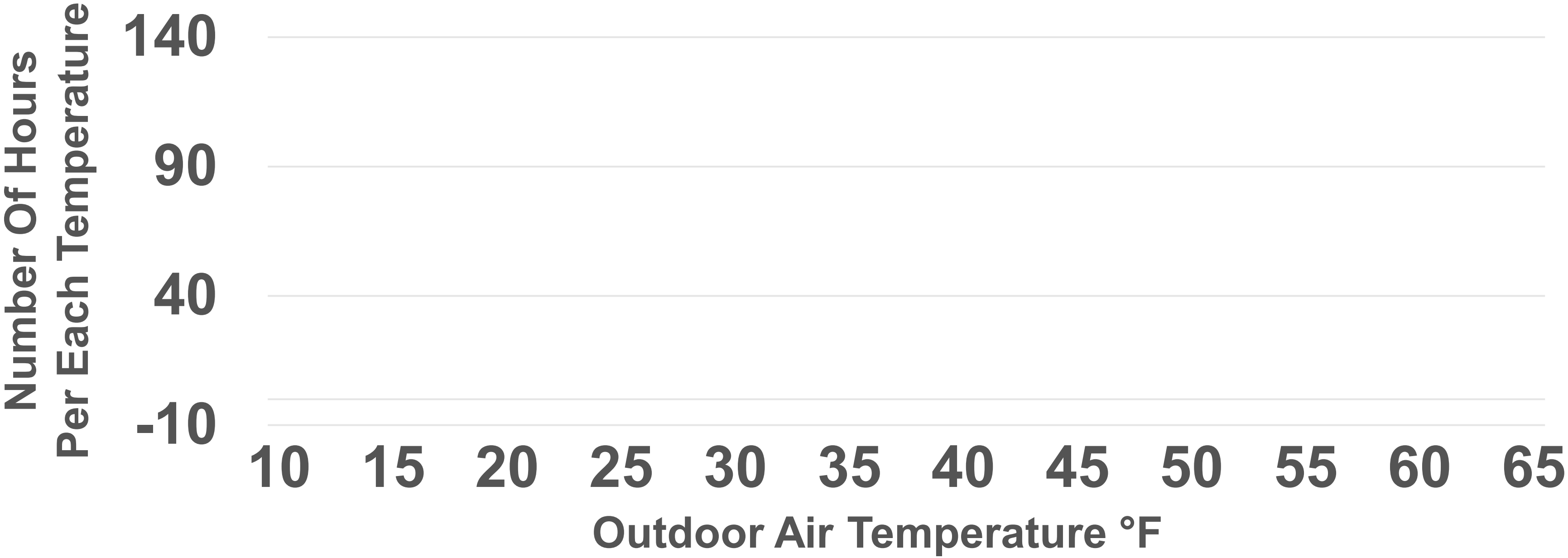
Heat Pump Capacity vs Ambient Temperature



Selecting Based on Worst Case

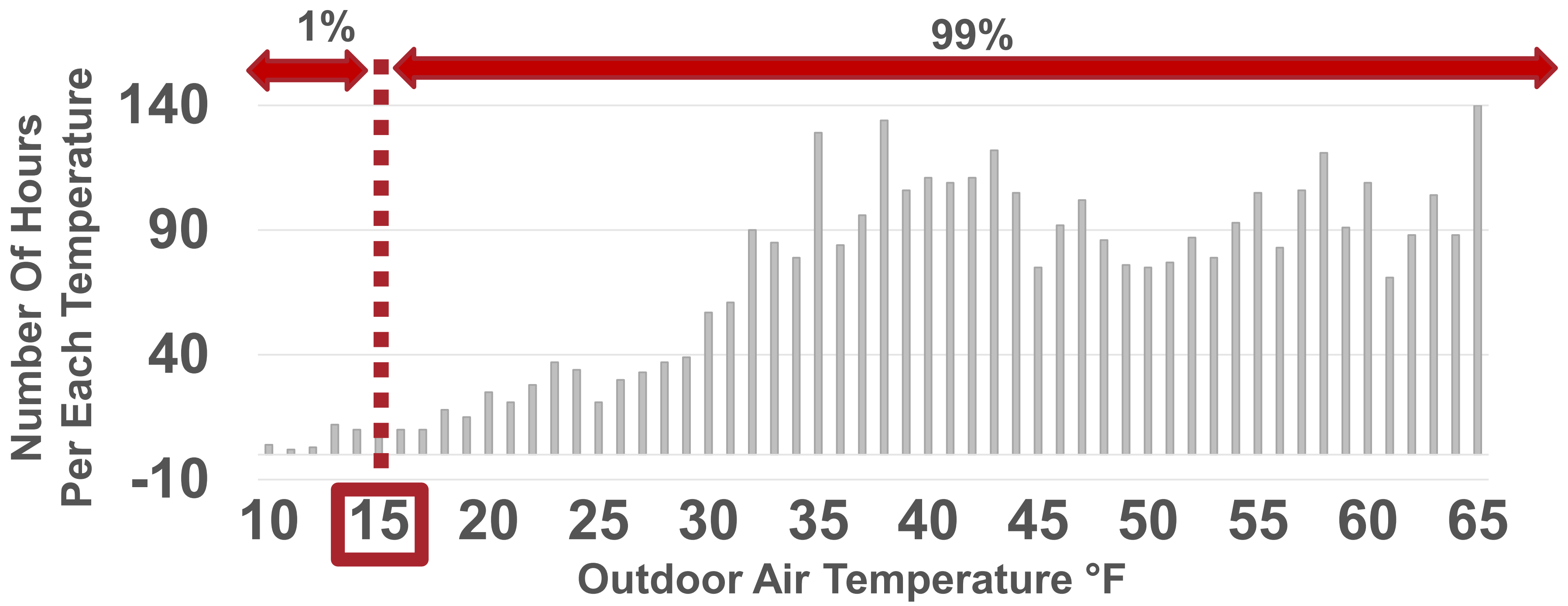


Design Conditions

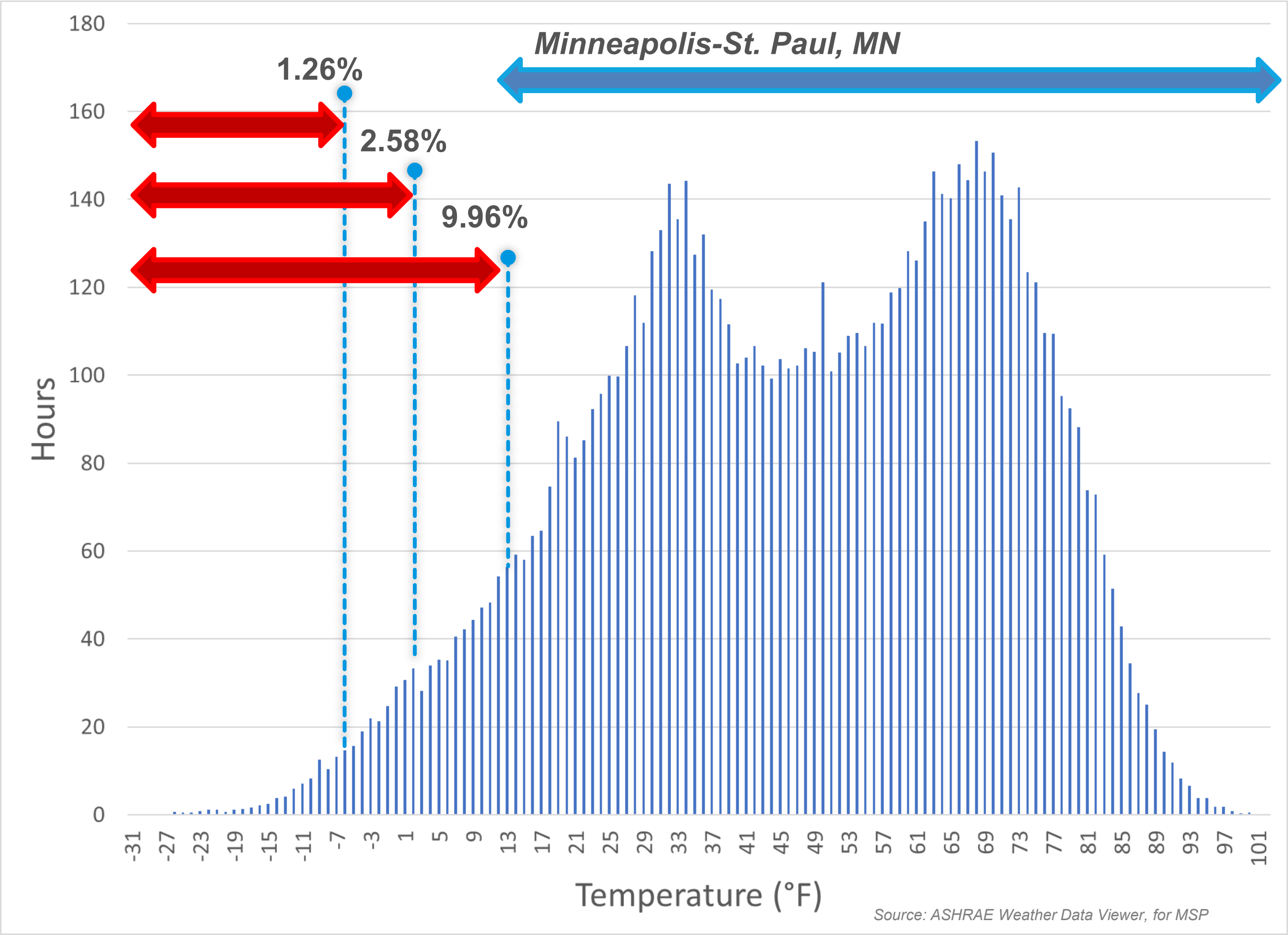


Design Conditions

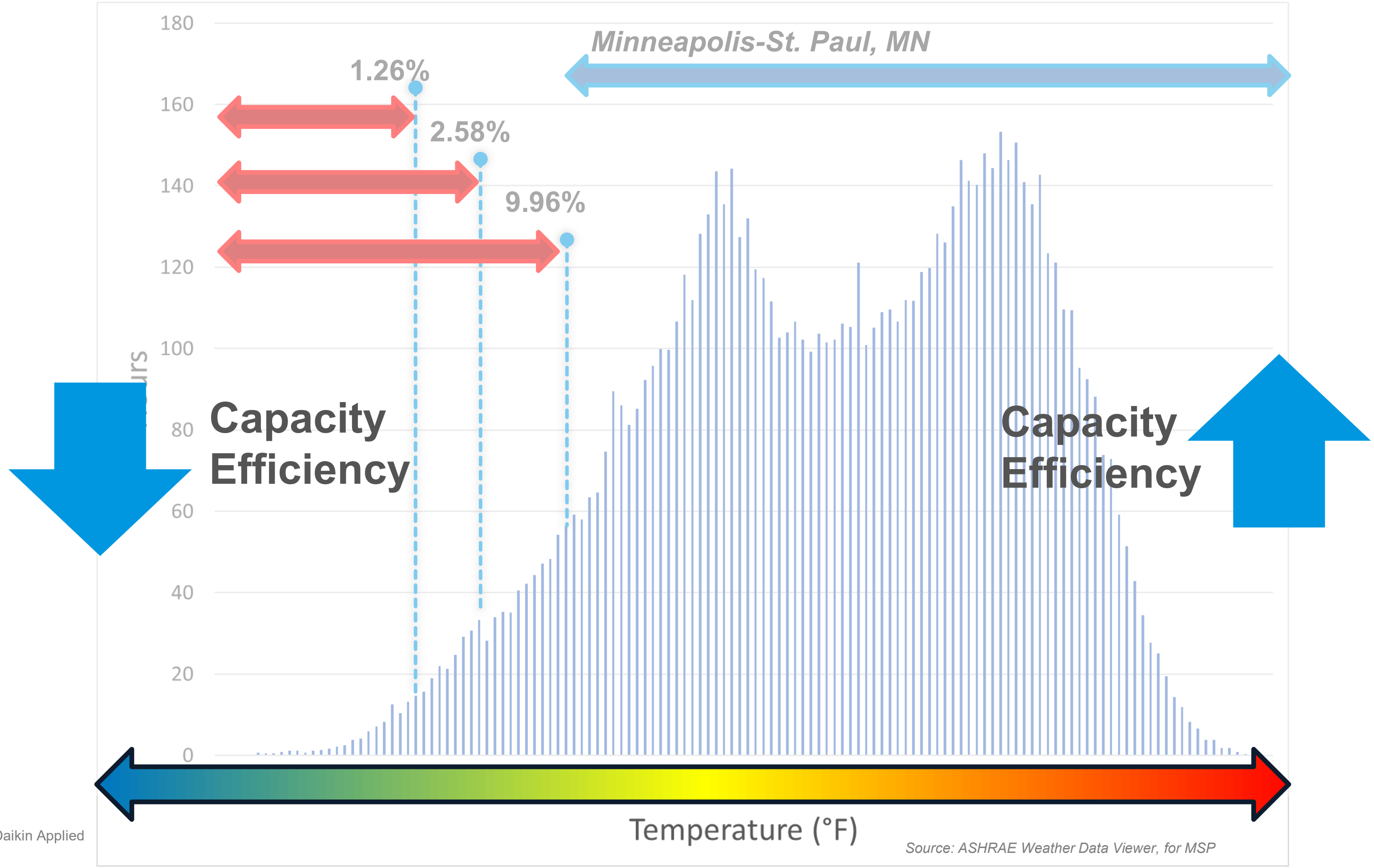
"Don't let the perfect be the enemy of the good"



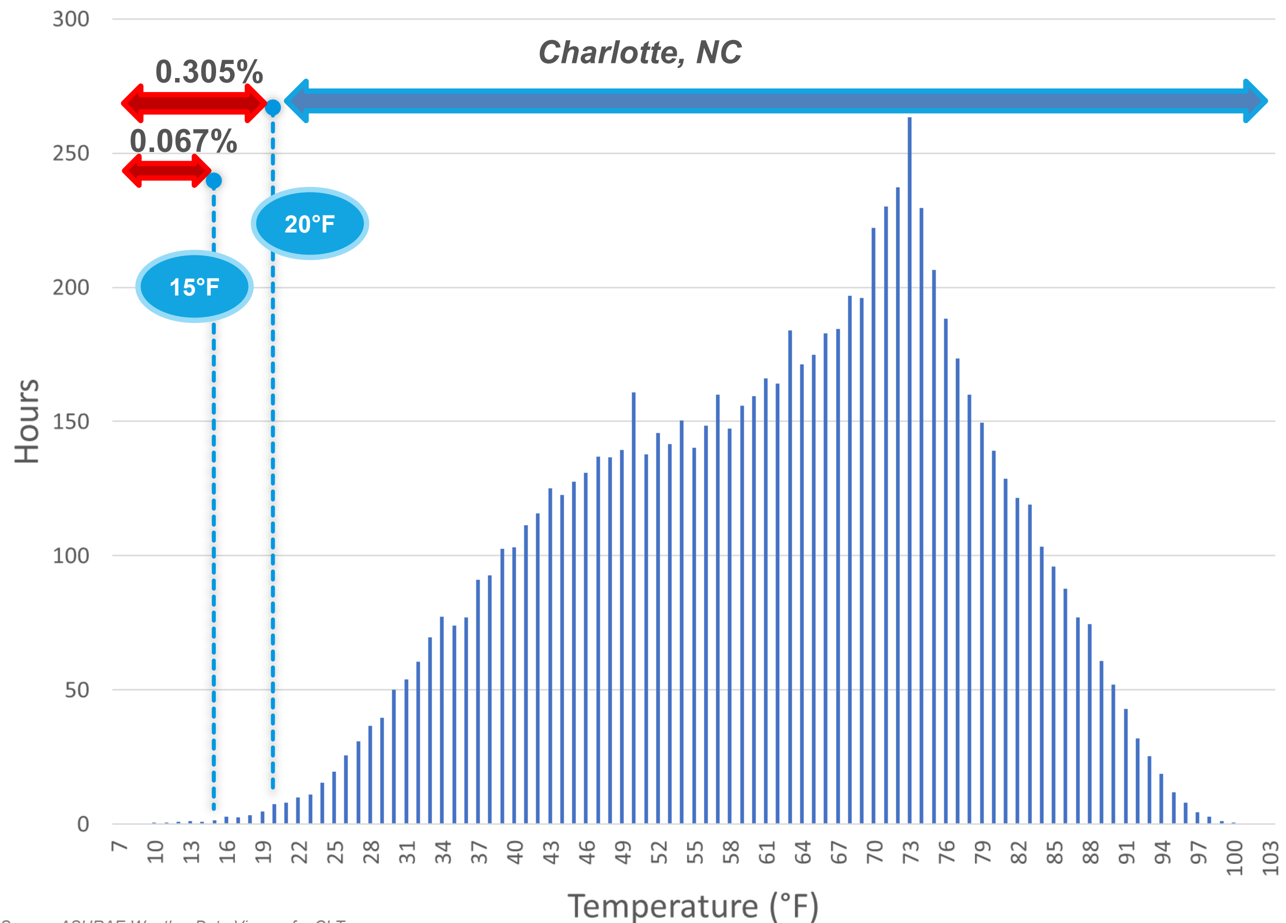
Climate and Heat Pump Performance



Climate and Heat Pump Performance

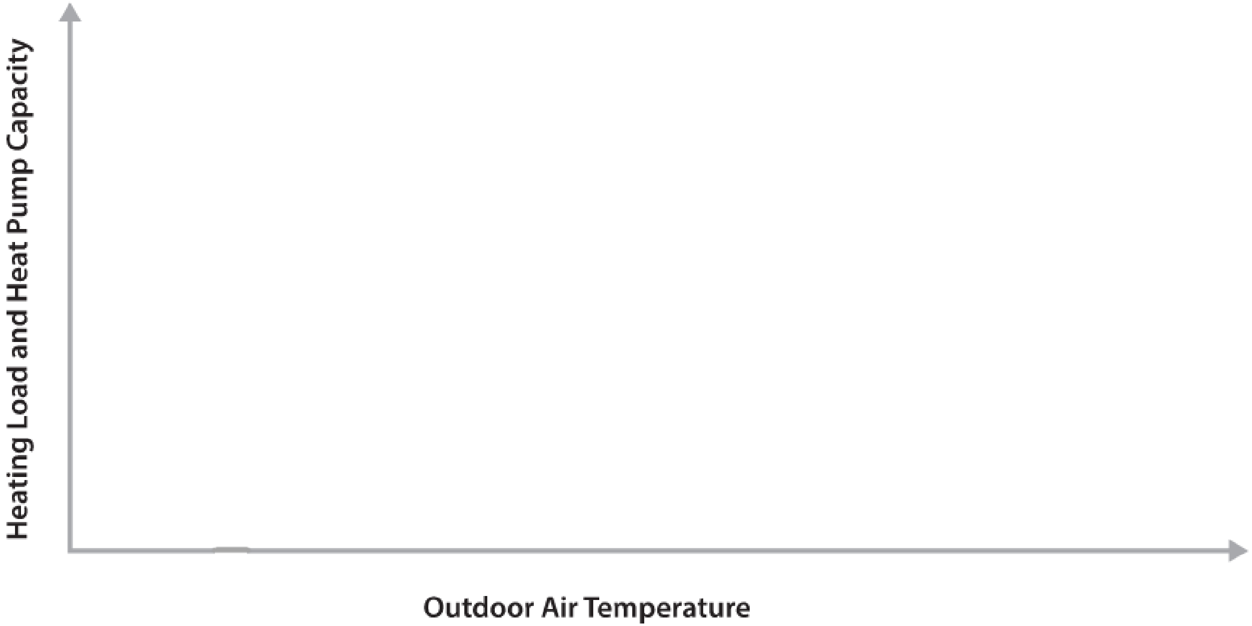


Climate and Heat Pump Performance



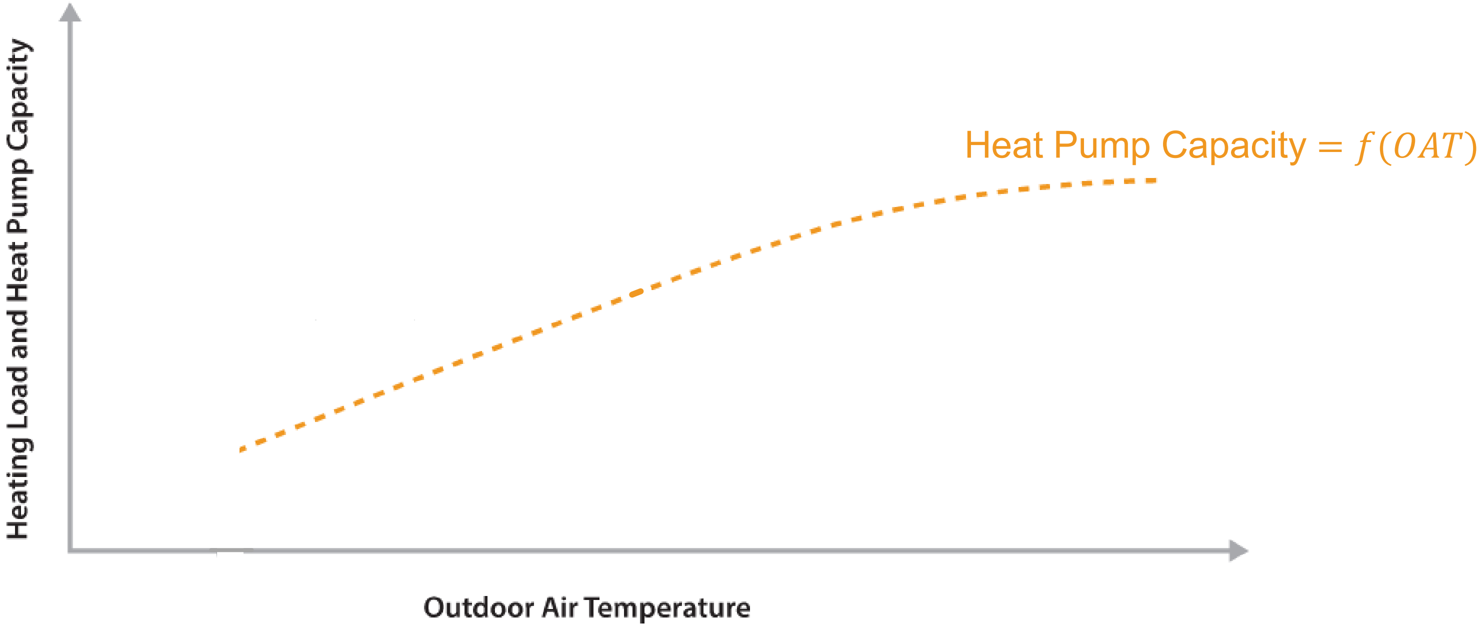
Source: ASHRAE Weather Data Viewer, for CLT

Load and Heat Pump Capacity vs. Outdoor Air Temperature



Source: Decarbonizing Building Thermal Systems: A How-To Guide for Applying Heat Pumps and Beyond, NREL

Load and Heat Pump Capacity vs. Outdoor Air Temperature



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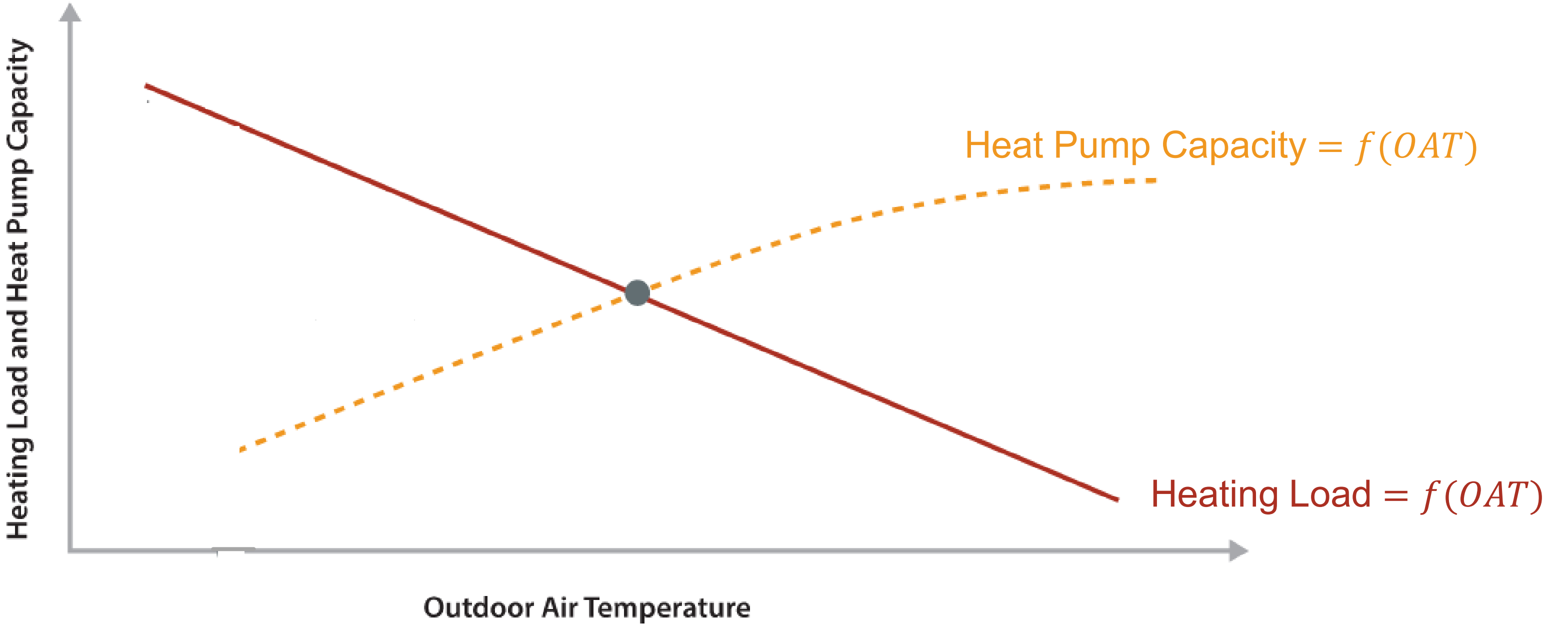

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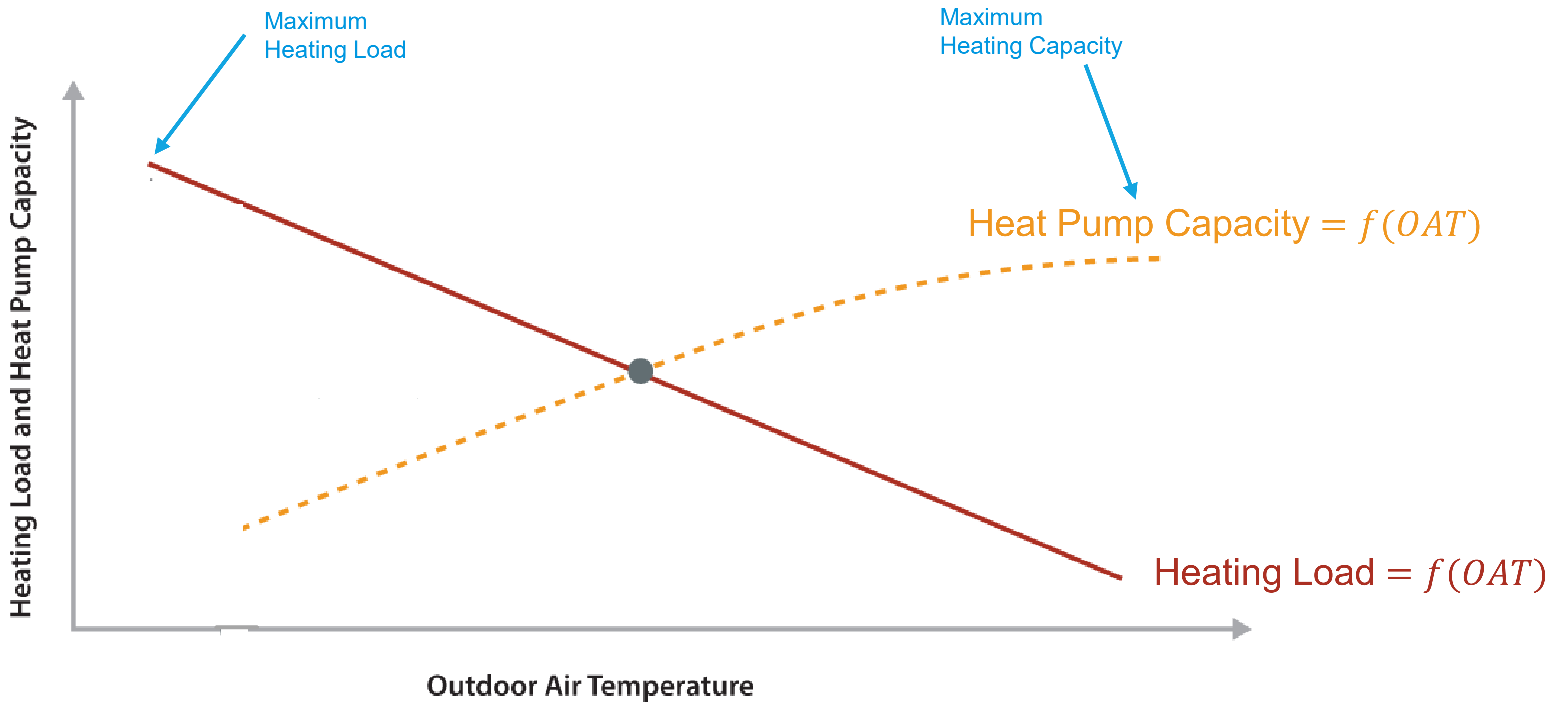

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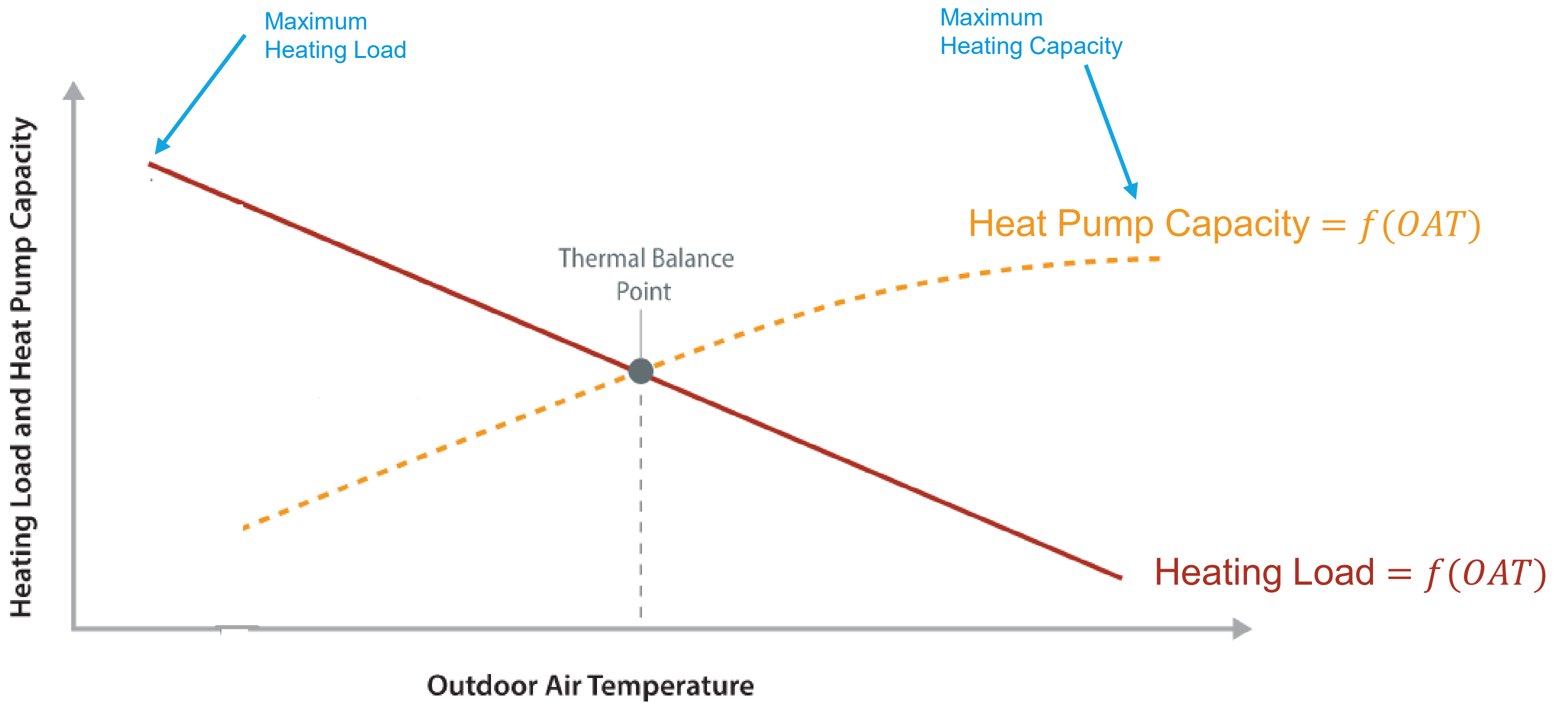

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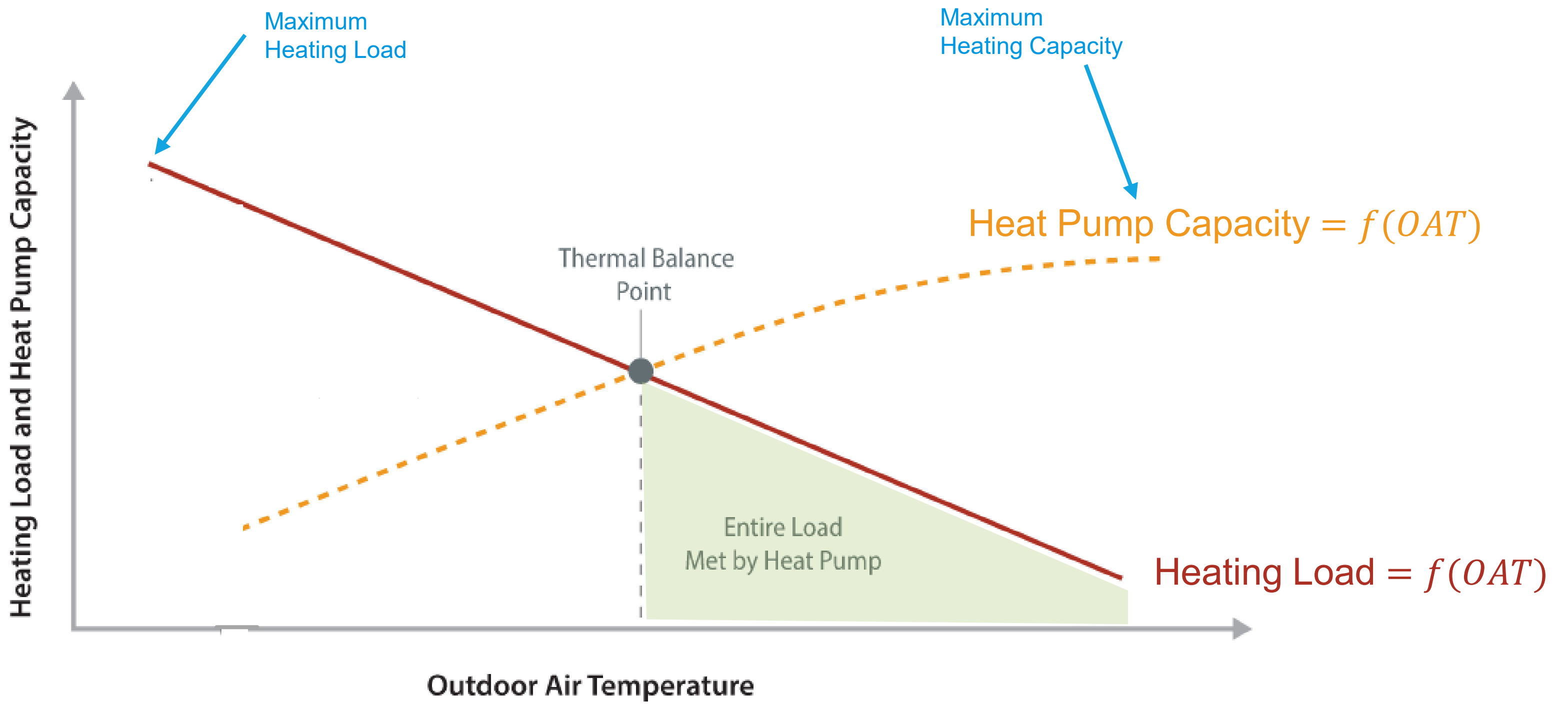

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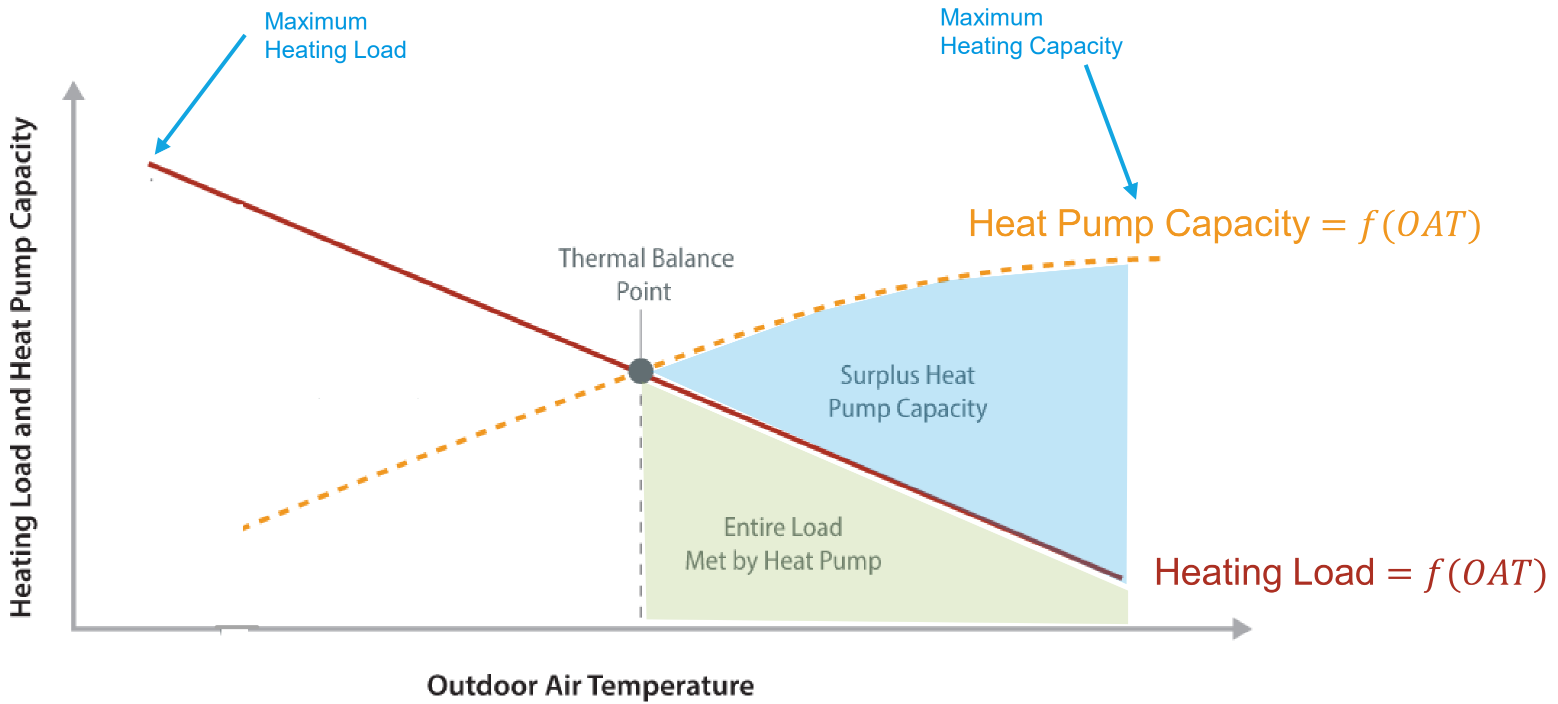

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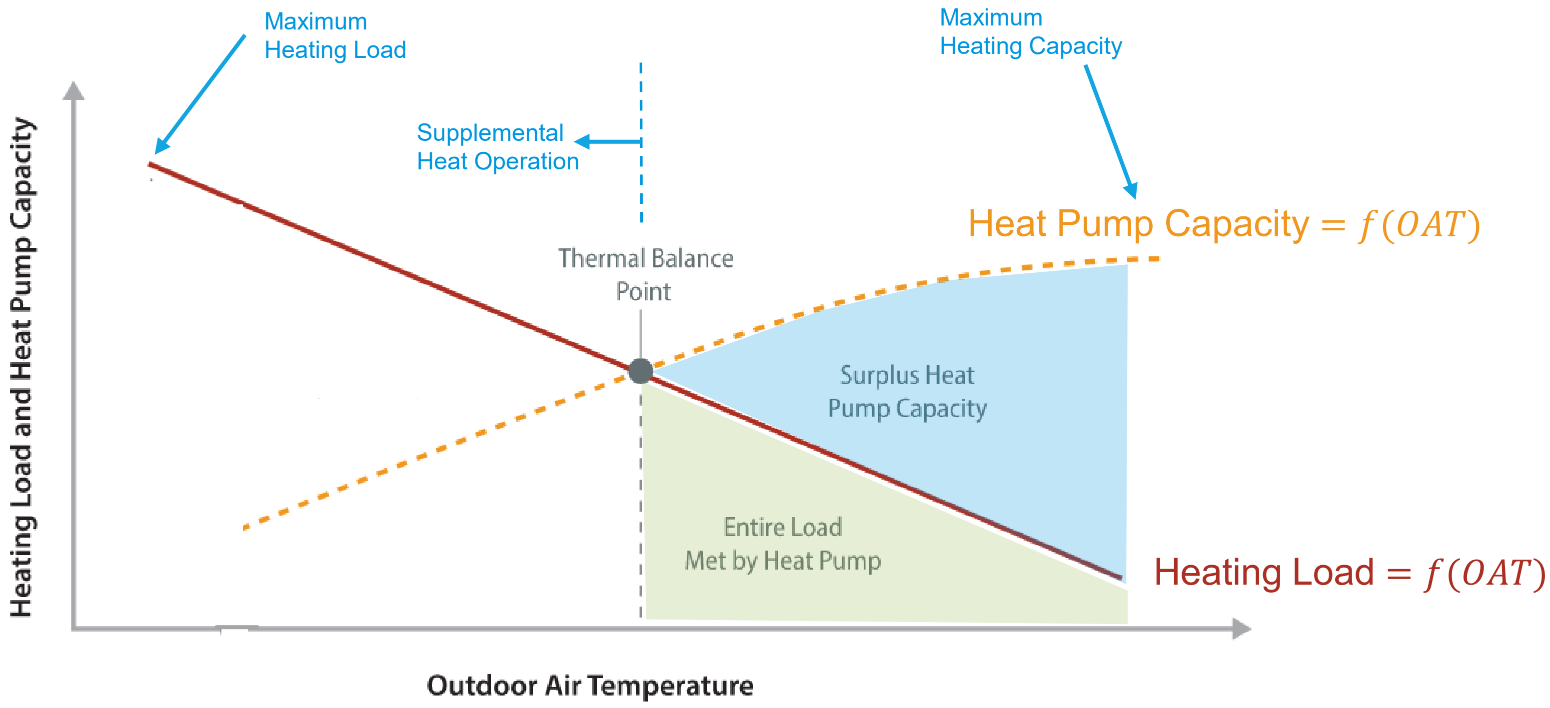

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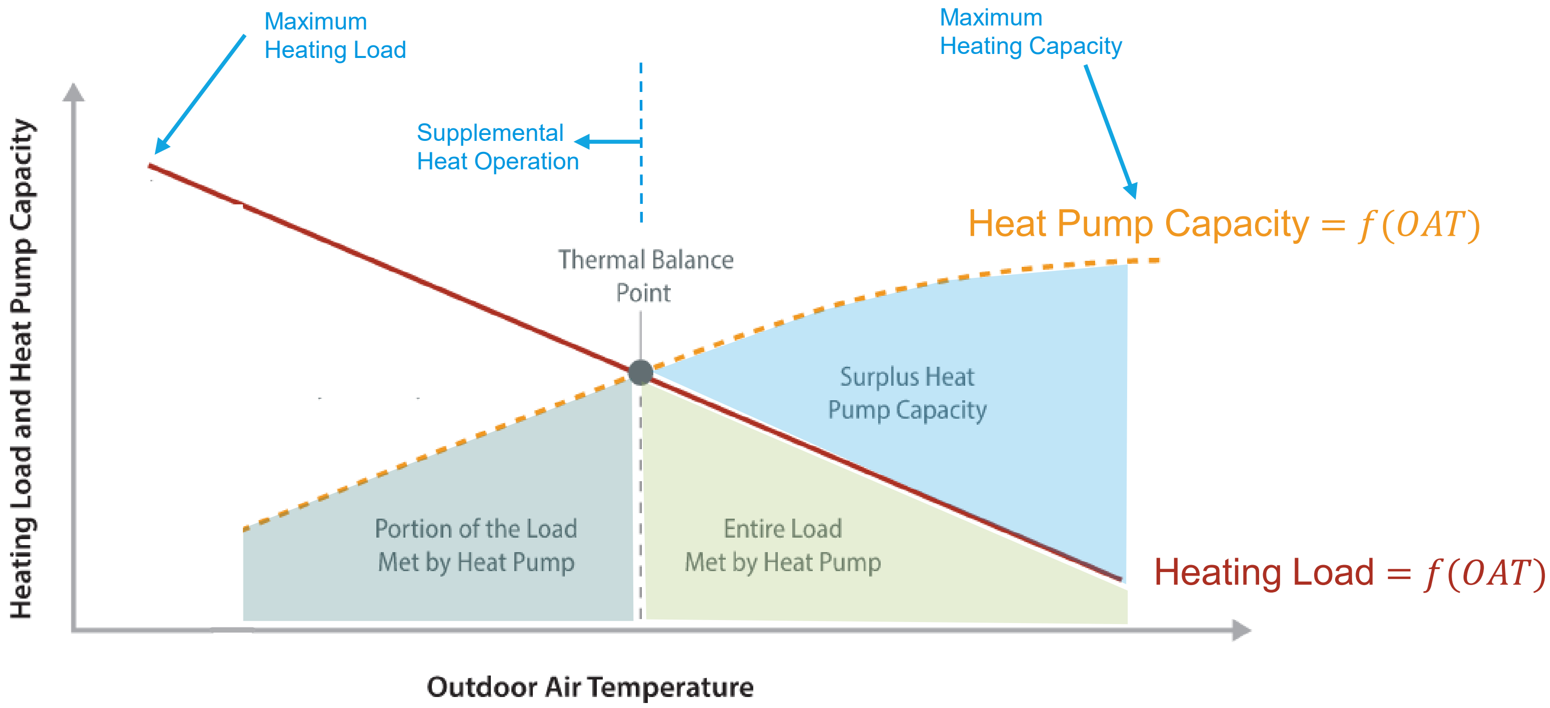

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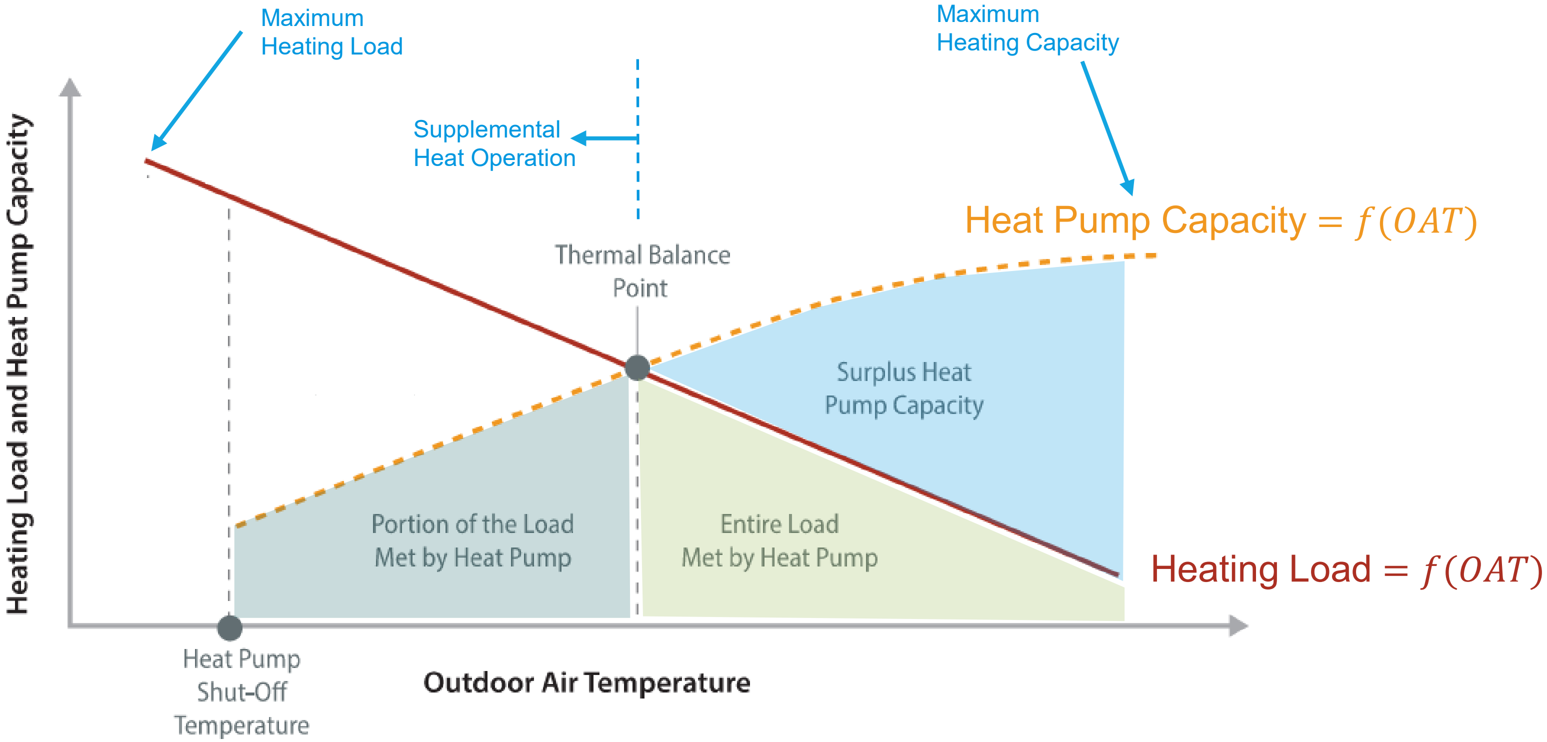

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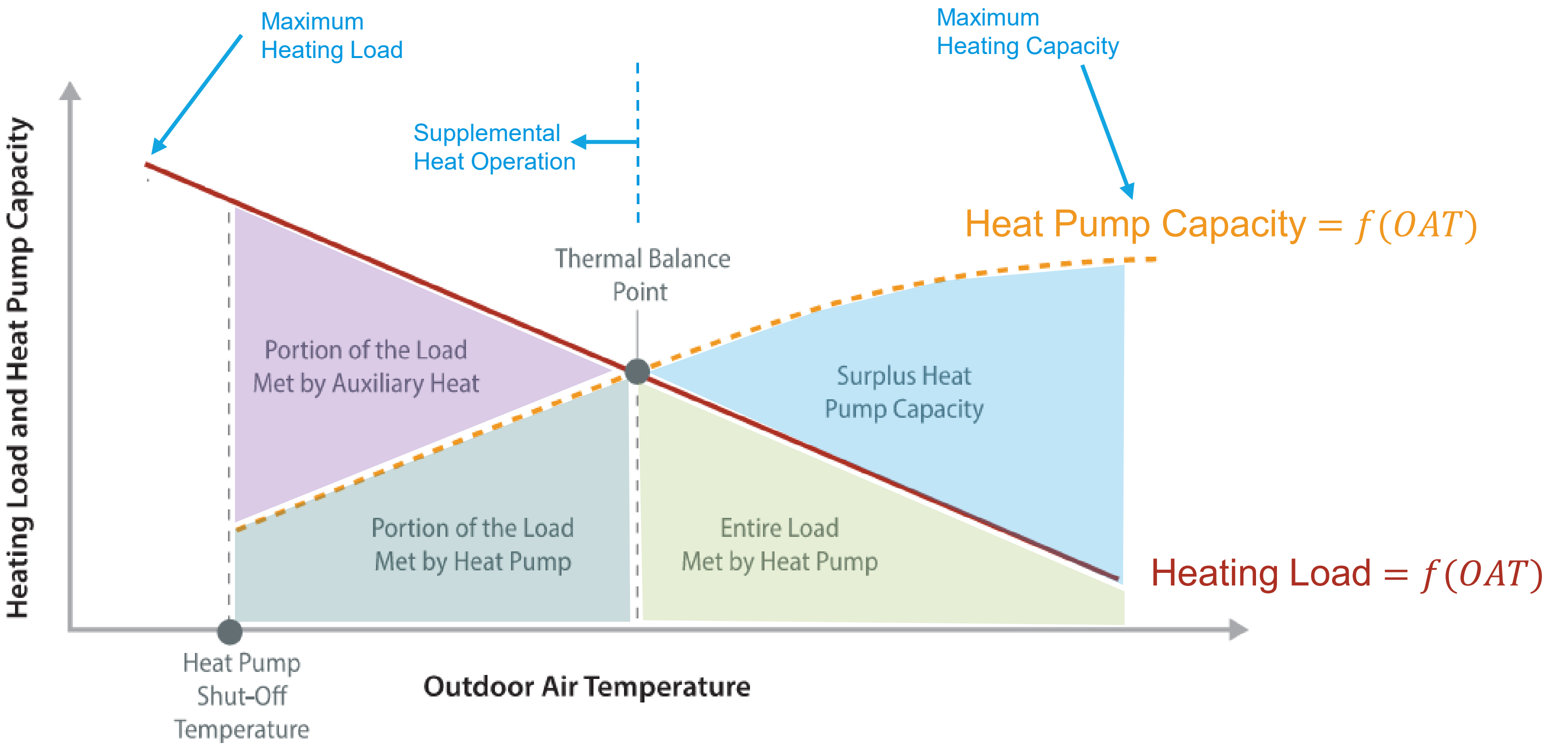

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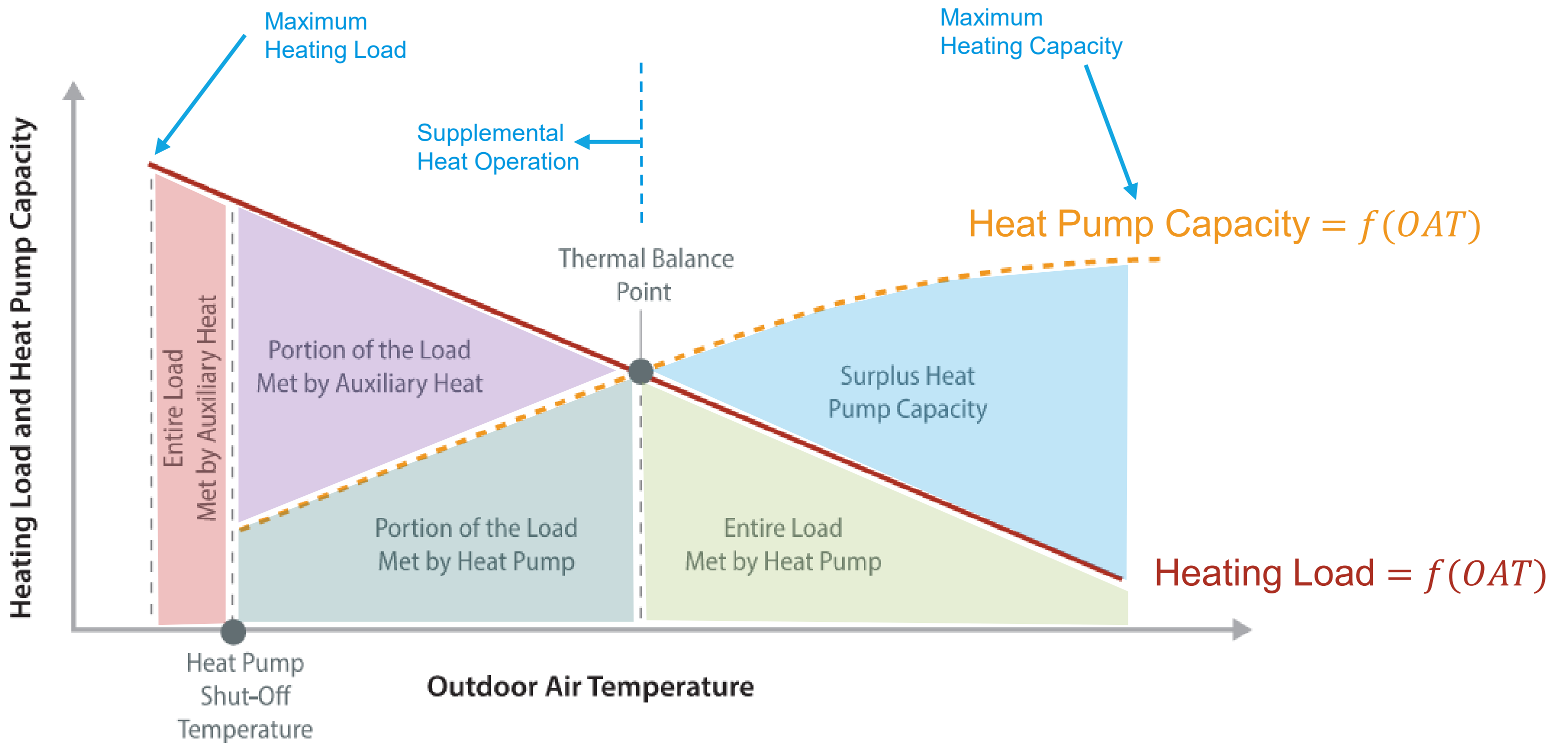

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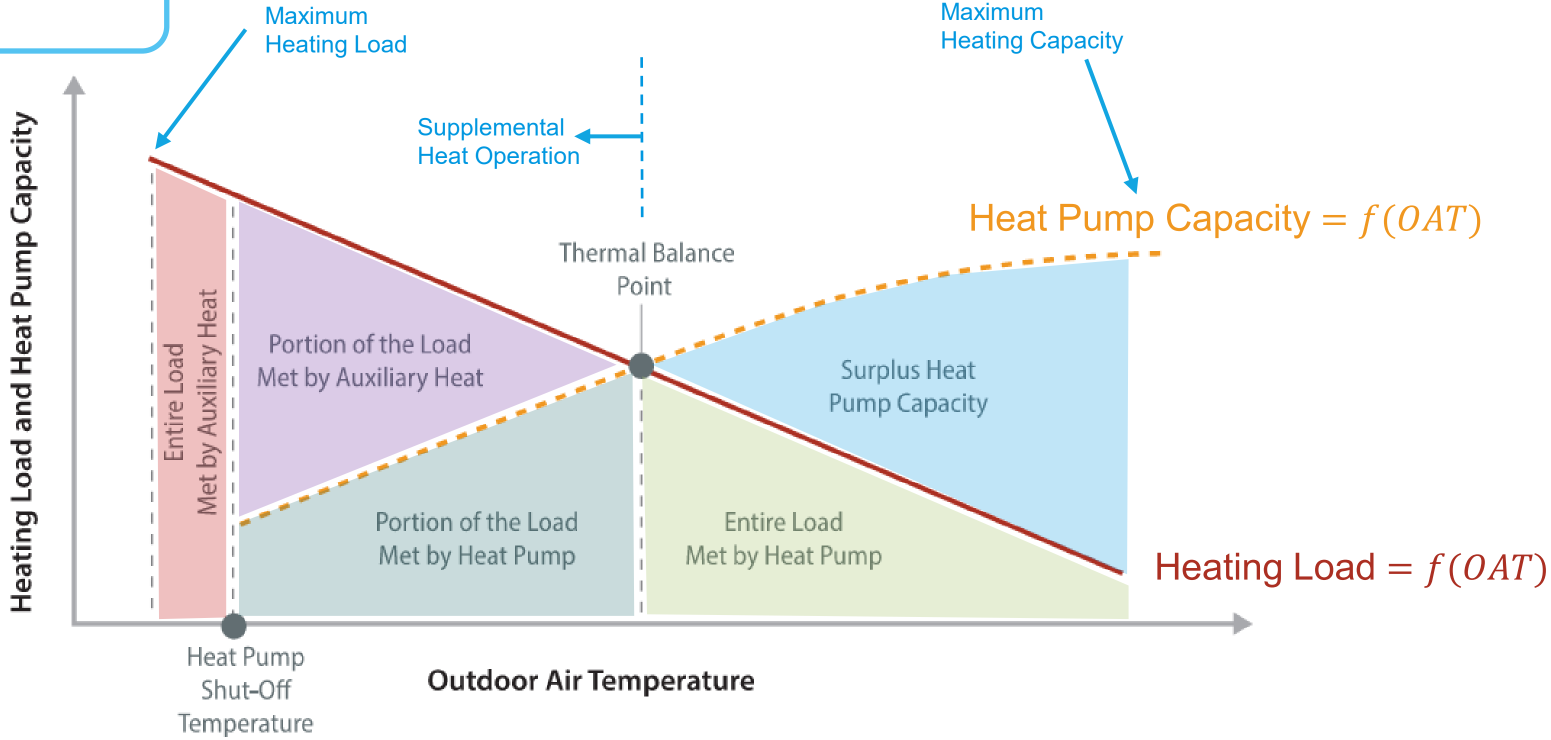
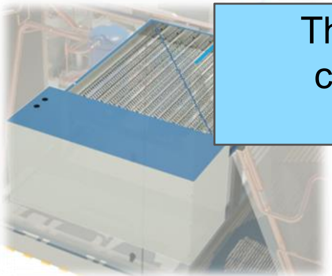
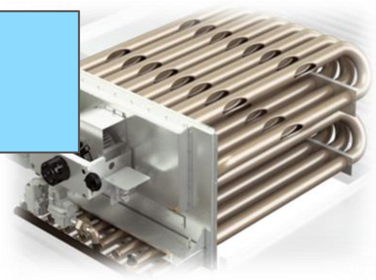
Load and Heat Pump Capacity vs. Outdoor Air Temperature

What Type of Supplemental Heat Option Should you Choose?



Source: Decarbonizing Building Thermal Systems: A How-To Guide for Applying Heat Pumps and Beyond, NREL

Dual Fuel vs. All Electric Heat Pump System

	All Electric	Dual Fuel
Primary Heating Source	Heat Pump (Electric)	Heat Pump (Electric)
Supplemental Heating Source (Operates for small fraction of hours over a year, during peak or extreme conditions)	Electricity (Electric Resistance) 	Gas Combustion 
Supplemental Heating Efficiency	~100%	~80%

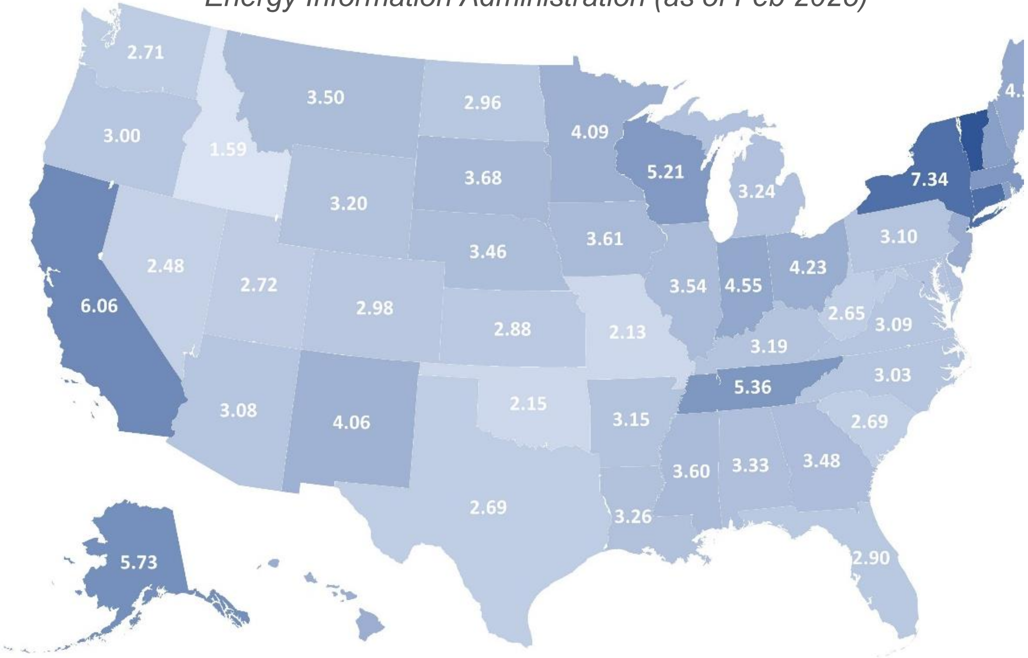
This table does not consider Scope 2 emissions!

Benefits of Dual Fuel over All Electric Heat Pumps

1. **Smaller Electrical Service Requirements** *(lower first cost)*
2. **Lower Operating Costs**
3. **Lower Peak Electric Demand Charges**
4. **Enables Demand Response**
5. **System Flexibility for Future Changes**

Ratio of Electricity over Gas Utility Prices by State

Energy Information Administration (as of Feb 2025)



Electricity is currently more expensive than gas throughout the U.S!

Study Goals

Problem Statement

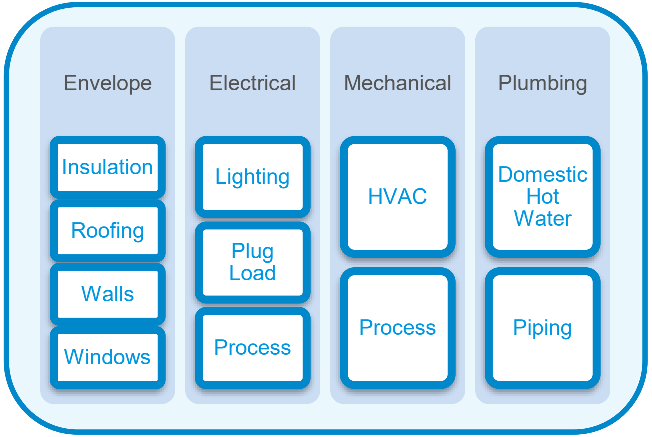
What are the **GHG impacts of dual fuel ASHPs** and what are the **long-term, region-specific,** incremental emissions savings of **electrifying supplemental heat**?

Hypothesis

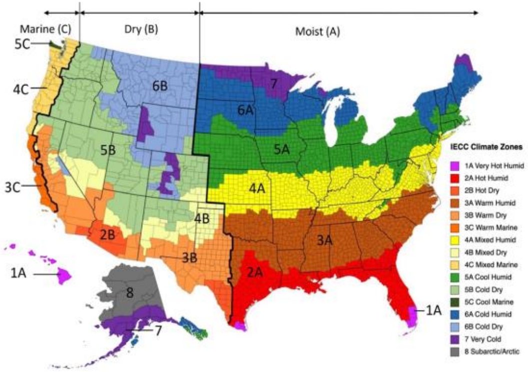
When applying air-source heat pumps, **electric supplemental heat does not yield appreciable emissions reductions** relative to using natural gas supplemental heat.

Why? Supplemental heat emissions depend on the following:

Building

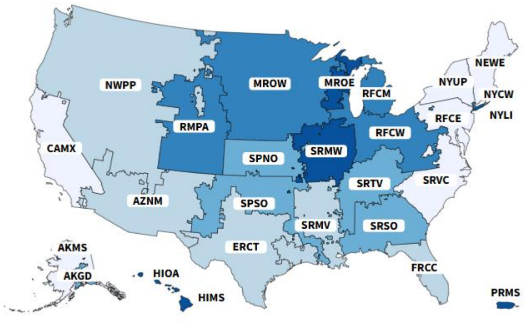


Climate



Source: US Department of Energy

Grid Emissions



Source: US EPA eGRID

Study Goals

Evaluate Emissions Impact

Conduct a Nationwide Assessment

Incorporate Historical & Forward-Looking Grid Projections (up to 2050)

Address Gaps in Prior Studies

Provide insights for Policy & System Design Decisions

Agenda

1 **Introduction**
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- GHG Emission Factors
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- Modeled Scenarios

3 **Results**
- Incremental, Nationwide, Dual-Fuel Heat Pump Emissions Savings from 2014-2050
- Added Savings from Supplemental Heat Electrification
- 15-year Assessment

4 **Study Limitations, Conclusions, and Future Work**

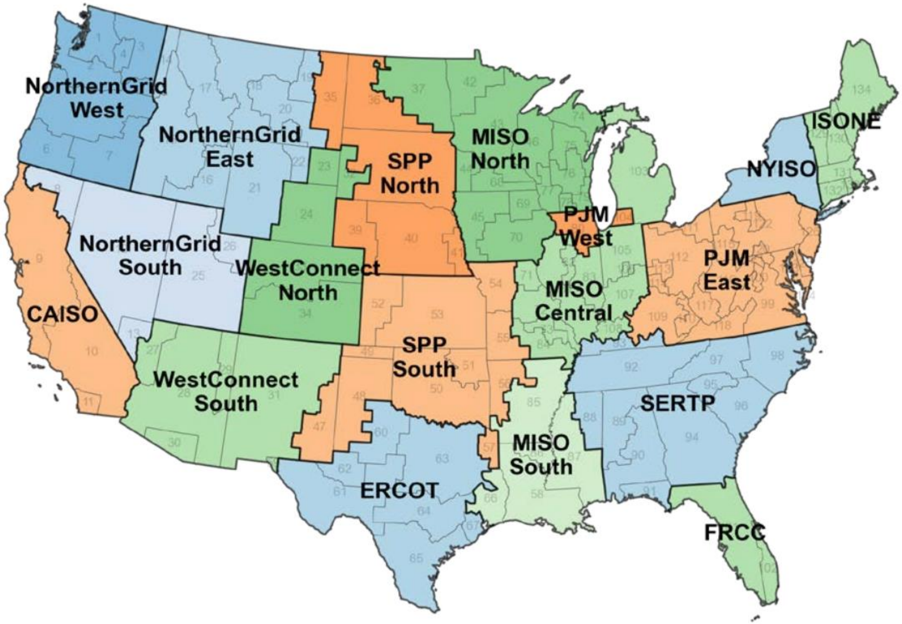
Electric GHG Emission Factors

- **Historical Emissions Factors (2014-2022)**
  - Derived from ***EPA's eGRID*** dataset
  - Based on actual operational reports from U.S. power plants

- **Projected Emissions Factors (2025-2050)**
  - Based on ***NREL's Cambium*** dataset
  - *Mid-case scenario:* Assumes central estimates for technology costs, fuel prices, and demand growth
  - Excludes nascent technologies
  - Assumes 2023 electric sector policies

- Data covers all 18 U.S. grid regions, aligned with electric grid system operators

- Gas emissions factor applied uniformly: 117 lb/MBtu (181 kg/MWh) across all years & regions (EIA)



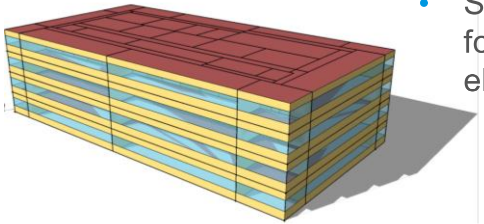
U.S electrical grid regions defined in NREL's Cambium dataset for simulated and projected electricity emission factors (through 2050) and historical emissions factors from EPA's eGRID data (NREL 2023).

Source:. *Cambium Data Sets: Forward-looking Projections. Golden, CO: National Renewable Energy Laboratory, 2023.*

Building Energy Models

Simulation Approach

- Developed hourly whole-building energy models using DOE's EnergyPlus v23.1
- Focuses on four common commercial building types:
  - Office (125k ft² / 11.6k m², 4 stories)
  - Multifamily (35k ft² / 3.3k m², 5 stories)
  - Hospital (240k ft² / 22.2k m², 5 stories)
  - School (210k ft² / 19.5k m², 3 stories)



Key Modeling Parameters

- ASHRAE Standard 90.1 (2004) compliant models, reflecting HVAC replacement scenarios for existing buildings
- Simulations incorporate TMY3 hourly weather files for representative cities, covering all 18 U.S. electric grid regions

Modeled Representative Cities for Each Electric Grid Region Across the U.S.

Grid Region	Modeled State, City	Grid Region	Modeled State, City
NorthernGrid West	Washington, Seattle	SPP South	Kansas, Kansas City
CAISO	California, Los Angeles	ERCOT	Texas, Temple
NorthernGrid East	Montana, Helena	PJM West	Illinois, Chicago
NorthernGrid South	Nevada, Las Vegas	MISO Central	Indiana, Indianapolis
SPP North	South Dakota, Pierre	MISO South	Mississippi, Jackson
WestConnect North	Colorado, Denver	ISONE	Maine, Augusta
WestConnect South	New Mexico, Santa Fe	NYISO	New York, Queens
MISO North	Minnesota, International Falls	PJM East	Pennsylvania, Philadelphia
SERTP	North Carolina, Raleigh	FRCC	Florida, Tampa

Modeled Scenarios

Scenario 1: Gas-Fueled Heating Baseline

- **System type:** Packaged single-zone VAV rooftop air conditioner (PSZ-AC)
- **Cooling:** Direct expansion (DX)
- **Heating:** Gas combustion
- **Used as the baseline for emissions comparisons**

Scenario 2: Dual Fuel (ASHP + Gas Supplemental Heat)

- **System type:** Packaged single-zone VAV rooftop, air-to-air heat pump (PSZ-HP)
- **Cooling**: DX
- **Heating:** Electric heat pump with gas supplemental heating

Scenario 3: All Electric (ASHP + Electric Supplemental Heat)

- **System type:** Packaged single-zone VAV rooftop, air-to-air heat pump (PSZ-HP)
- **Cooling:** DX
- **Heating:** Electric heat pump with electric resistance supplemental heating

System Specifications & Modeling Parameter:

- **Heat pump sizing**: Based on design cooling load for scenarios 2 & 3
- **DX cooling performance**: Identical across all three scenarios. Variable speed supply fans & compressors modeled for all systems
- **Efficiency assumptions:**
  - **Heat pump COP**: 3.5 at 47°F (8.33°C), 2.335 at 17°F (-8.33°C)
  - **Gas combustion efficiency**: 80%
  - **Electric supplemental heating efficiency:** 100%
- **Heat pump compressor shutoff temperature:** -10°F (-23.33°C)
- Defrost cycles not considered in analysis

216 simulations (18 regions × 4 building types × 3 scenarios)

Primary Results of Interest

Emission Savings Comparison

1. ASHP with gas supplemental heat (dual fuel) vs. all-gas space heating:

$$\%\ \textit{Emissions Savings}_{\textit{Dual Fuel}} = \frac{\textit{Annual Emissions}_{\textit{All Gas}} - \textit{Annual Emissions}_{\textit{Dual Fuel}}}{\textit{Annual Emissions}_{\textit{All Gas}}} \times 100$$

2. Additional savings from electrifying the supplemental heat:

$$\%\ \textit{Incremental Emissions Savings}_{\textit{All Electric}} = \frac{\textit{Annual Emissions}_{\textit{Dual Fuel}} - \textit{Annual Emissions}_{\textit{All Electric}}}{\textit{Annual Emissions}_{\textit{All Gas}}} \times 100$$

Emissions Calculation Methodology

- Annual emissions = Σ hourly whole-building gas emissions + Σ hourly whole-building electricity emissions

Electricity Emissions Factors:

- Derived using EPA's eGRID annual emission factors (pre-2025)
- NREL Cambium hourly emission factors for future years
- Multiplied by modeled hourly whole-building electricity consumption

Gas Emissions:

- Based on EPA's gas emission factor (constant value)
- Multiplied by modeled annual whole-building gas consumption

Agenda

1 **Introduction**
- Background
- Hypothesis
- Assumptions
- Problem Statement & Study Goals

2 **Approach**
- GHG Emission Factors
- Building Energy Models
- Modeled Scenarios

3 **Results**
- Incremental, Nationwide, Dual-Fuel Heat Pump Emissions Savings from 2014-2050
- Added Savings from Supplemental Heat Electrification
- 15-year Assessment

4 **Study Limitations, Conclusions, and Future Work**

Emissions Impact of Replacing Gas-Fueled Space Heating with Dual Fuel ASHP

Historical Savings (2014-2022):

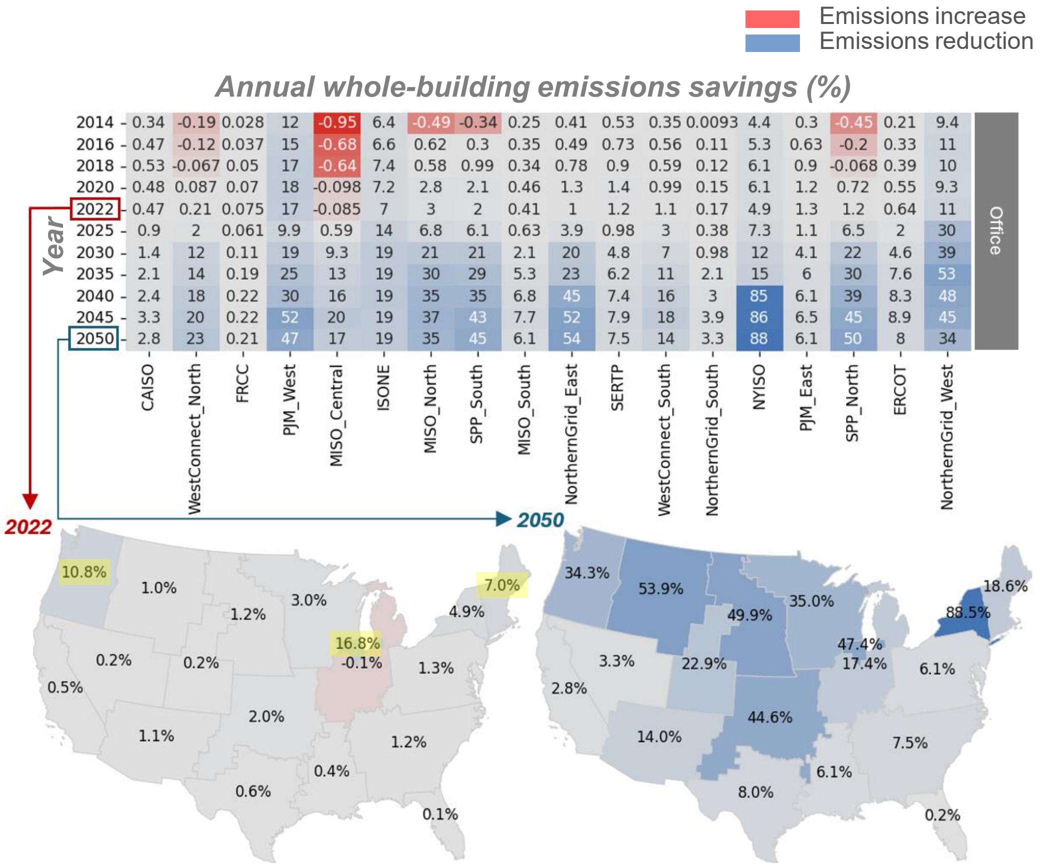
- Significant savings (≥10%) in PJM West, Northern Grid West, and ISONE.
- Key drivers of regional savings:
  - **PJM West:** ~33% nuclear energy share.
  - **Northern Grid West:** ~50% hydropower share.
  - **ISONE:** ~40% energy from wind, solar, and hydro.

Future Projections (2025-2050)

- Heat pumps expected to significantly increase emissions savings as grids shift to cleaner energy.

Influence of Policy & Grid Evolution

- **NYISO:** New York's zero-emissions electricity target (2040) and net-zero goal (2050).
- **MISO North, SPP North, SPP South:** Significant wind power contributions



Emissions Impact of Replacing Gas-Fueled Space Heating with Dual Fuel ASHP

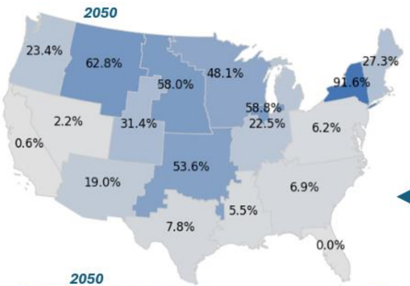
Consistent Trends Across Building Types

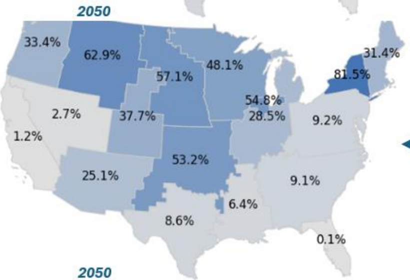
Impact varies by building due to differences in:

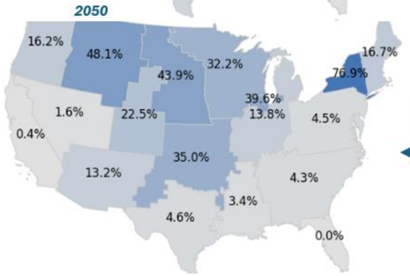
- Magnitude of heating loads
- Heating load profiles
- Ventilation rates

NYISO: Most Impacted Region through 2050

- Emissions savings reach 77%-92% with dual-fuel ASHPs





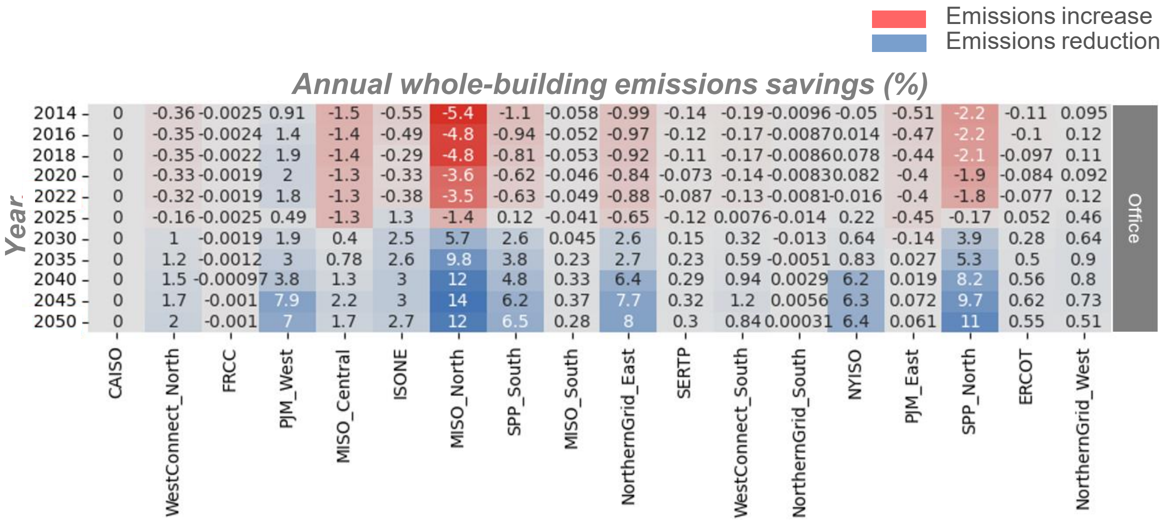


Emissions increase
Emissions reduction

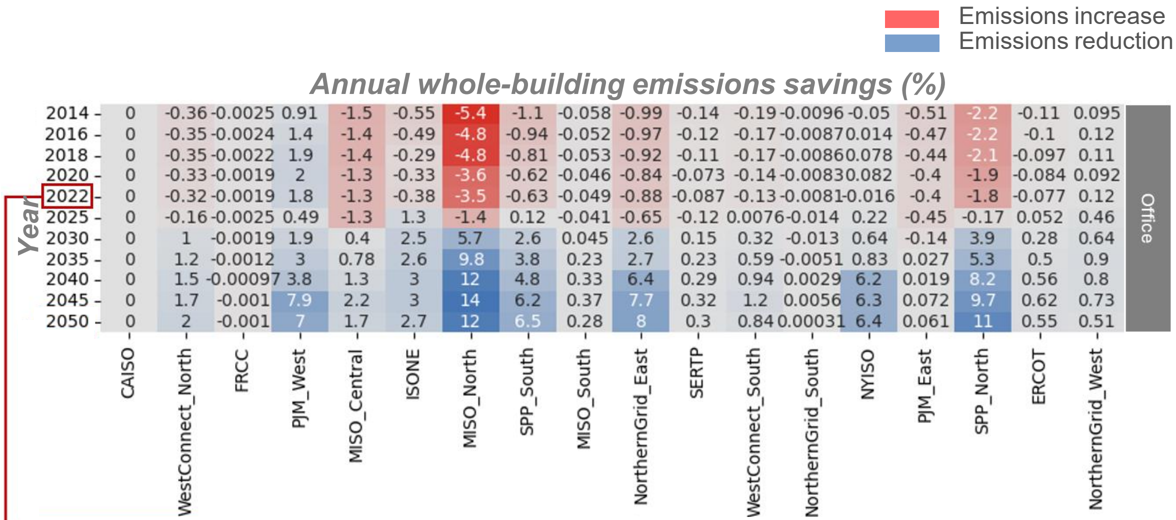
Annual whole-building emissions savings (%)

Building	Year	CAISO	WestConnect_North	FRCC	PJM_West	MISO_Central	ISONE	MISO_North	SPP_South	MISO_South	NorthernGrid_East	SERTP	WestConnect_South	NorthernGrid_South	NYISO	PJM_East	SPP_North	ERCOT	NorthernGrid_West
Multifamily	2014	0.096	-1.1	0.00094	17	-1.7	11	2.4	-0.79	0.13	-0.21	0.15	0.055	-0.16	4.9	-0.39	-0.79	-0.085	5.6
Multifamily	2016	0.13	-0.96	0.0072	21	-1.3	11	4.3	0.2	0.26	-0.098	0.38	0.44	-0.071	5.9	0.057	-0.38	0.065	6.4
Multifamily	2018	0.15	-0.86	0.017	24	-1.2	12	4.2	1.3	0.24	0.36	0.59	0.5	-0.06	7	0.42	-0.17	0.14	6
Multifamily	2020	0.13	-0.59	0.03	26	-0.38	12	7.9	2.9	0.39	1.1	1.2	1.2	-0.032	7	0.88	1.1	0.34	5.5
Multifamily	2022	0.13	-0.38	0.034	24	-0.36	12	8.3	2.8	0.33	0.71	0.97	1.5	-0.013	5.4	0.9	1.8	0.45	6.5
Multifamily	2025	0.17	2.1	0.0083	15	0.82	21	15	9.3	0.41	5	0.5	4.1	-0.2	8.3	0.56	11	2	21
Multifamily	2030	0.31	18	0.025	26	14	27	33	28	2	28	4.8	10	0.23	14	4.3	30	5	29
Multifamily	2035	0.47	21	0.042	33	18	28	43	37	5.1	31	6.1	16	1.2	17	6.4	39	7.9	42
Multifamily	2040	0.52	26	0.047	39	21	29	48	44	6.5	54	7.2	22	2	89	6.2	48	8.5	36
Multifamily	2045	0.72	28	0.046	63	26	29	50	53	7.4	61	7.6	26	2.8	90	6.6	54	9	33
Multifamily	2050	0.61	31	0.044	59	22	27	48	54	5.5	63	6.9	19	2.2	92	6.2	58	7.8	23
School	2014	0.13	0.26	0.0037	21	1.2	16	8	1.6	0.25	3.5	0.69	1.1	-0.069	6.4	1.1	3.8	0.31	9
School	2016	0.19	0.41	0.0088	25	1.7	16	10	2.8	0.36	3.6	0.94	1.6	0.015	7.4	1.6	4.3	0.44	10
School	2018	0.21	0.53	0.016	28	1.8	17	10	4.1	0.35	4.3	1.2	1.6	0.025	8.5	2	4.6	0.5	9.7
School	2020	0.19	0.86	0.028	29	2.8	17	14	6.1	0.48	5.3	1.8	2.5	0.051	8.6	2.5	6.1	0.68	8.9
School	2022	0.18	1.1	0.03	27	2.8	17	15	6	0.42	4.8	1.6	2.8	0.069	6.9	2.6	7	0.78	10
School	2025	0.37	4.7	0.021	18	4.2	26	21	12	0.59	11	1.2	6.4	0.21	9.8	2.3	16	2.2	30
School	2030	0.6	23	0.045	29	18	32	37	32	2.1	36	5.8	14	0.68	16	6.4	35	4.9	38
School	2035	0.9	26	0.088	36	23	32	45	40	5.5	39	7.5	21	1.6	18	9.1	43	8.1	52
School	2040	1	32	0.11	41	27	32	48	46	7.1	57	8.9	27	2.4	80	9.2	51	8.8	47
School	2045	1.4	34	0.1	58	32	32	49	52	8.1	62	9.5	32	3.3	80	9.7	54	9.6	44
School	2050	1.2	38	0.095	55	28	31	48	53	6.4	63	9.1	25	2.7	82	9.2	57	8.6	33
Hospital	2014	0.077	0.45	0.02	11	0.4	7.3	2.7	0.69	0.35	1.7	0.5	0.95	0.058	3.5	0.85	1.3	0.28	4
Hospital	2016	0.1	0.52	0.024	13	0.6	7.5	3.7	1.2	0.43	1.8	0.64	1.2	0.11	4.1	1.1	1.5	0.36	4.5
Hospital	2018	0.11	0.59	0.029	15	0.63	8.1	3.6	1.7	0.42	2	0.76	1.2	0.12	4.7	1.3	1.7	0.41	4.3
Hospital	2020	0.1	0.75	0.036	16	1	8	5.5	2.6	0.52	2.5	1.1	1.7	0.14	4.7	1.5	2.3	0.52	3.9
Hospital	2022	0.099	0.89	0.038	15	1	7.9	5.7	2.5	0.48	2.2	0.97	1.8	0.15	3.8	1.5	2.7	0.58	4.6
Hospital	2025	0.13	2.6	0.026	9.4	1.7	13	9.2	5.9	0.55	5.3	0.74	3.6	0.14	5.3	1.4	7.2	1.4	15
Hospital	2030	0.21	13	0.037	16	8.6	17	20	17	1.5	20	3.2	7.4	0.44	8.7	3.4	19	3.2	20
Hospital	2035	0.31	15	0.047	21	11	17	28	23	3.4	22	3.9	11	1.1	10	4.7	27	4.8	30
Hospital	2040	0.34	18	0.05	25	13	18	32	28	4	41	4.5	15	1.5	74	4.6	35	5.1	26
Hospital	2045	0.46	20	0.05	43	16	17	34	34	4.4	47	4.7	18	2	74	4.8	40	5.2	23
Hospital	2050	0.39	22	0.049	40	14	17	32	35	3.4	48	4.3	13	1.6	77	4.5	44	4.6	16

Emissions Impact of Replacing Dual Fuel ASHP with All Electric ASHP

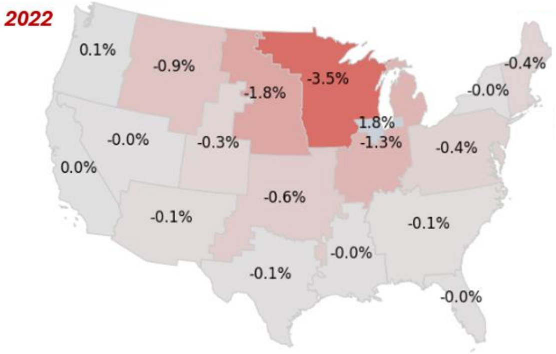


Emissions Impact of Replacing Dual Fuel ASHP with All Electric ASHP



Annual Emissions Savings from Transitioning to All-electric Heating

- Negative impact in 2022!



Emissions Impact of Replacing Dual Fuel ASHP with All Electric ASHP

Emissions increase
Emissions reduction

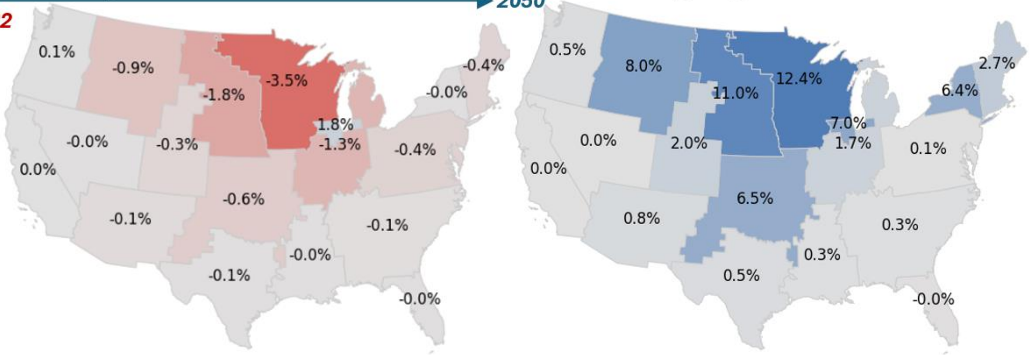
Annual Emissions Savings from Transitioning to All-electric Heating

- Negative impact in 2022!
- In 12 of 18 regions, savings are **less than 2.7% through 2050**
- Most impacted regions: MISO North, SPP North, Northern Grid East, PJM West *(Upper Midwest)*

Annual whole-building emissions savings (%) — Office

Year	CAISO	WestConnect_North	FRCC	PJM_West	MISO_Central	ISONE	MISO_North	SPP_South	MISO_South
2014	0	-0.36	-0.0025	0.91	-1.5	-0.55	-5.4	-1.1	-0.058
2016	0	-0.35	-0.0024	1.4	-1.4	-0.49	-4.8	-0.94	-0.052
2018	0	-0.35	-0.0022	1.9	-1.4	-0.29	-4.8	-0.81	-0.053
2020	0	-0.33	-0.0019	2	-1.3	-0.33	-3.6	-0.62	-0.046
2022	0	-0.32	-0.0019	1.8	-1.3	-0.38	-3.5	-0.63	-0.049
2025	0	-0.16	-0.0025	0.49	-1.3	1.3	-1.4	0.12	-0.041
2030	0	1	-0.0019	1.9	0.4	2.5	5.7	2.6	0.045
2035	0	1.2	-0.0012	3	0.78	2.6	9.8	3.8	0.23
2040	0	1.5	-0.00097	3.8	1.3	3	12	4.8	0.33
2045	0	1.7	-0.001	7.9	2.2	3	14	6.2	0.37
2050	0	2	-0.001	7	1.7	2.7	12	6.5	0.28

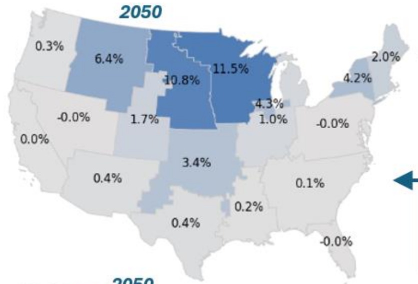
Year	NorthernGrid_East	SERTP	WestConnect_South	NorthernGrid_South	NYISO	PJM_East	SPP_North	ERCOT	NorthernGrid_West
2014	-0.99	-0.14	-0.19	-0.0096	-0.05	-0.51	-2.2	-0.11	0.095
2016	-0.97	-0.12	-0.17	-0.0087	0.014	-0.47	-2.2	-0.1	0.12
2018	-0.92	-0.11	-0.17	-0.0086	0.078	-0.44	-2.1	-0.097	0.11
2020	-0.84	-0.073	-0.14	-0.0083	0.082	-0.4	-1.9	-0.084	0.092
2022	-0.88	-0.087	-0.13	-0.0081	-0.016	-0.4	-1.8	-0.077	0.12
2025	-0.65	-0.12	0.0076	-0.014	0.22	-0.45	-0.17	0.052	0.46
2030	2.6	0.15	0.32	-0.013	0.64	-0.14	3.9	0.28	0.64
2035	2.7	0.23	0.59	-0.0051	0.83	0.027	5.3	0.5	0.9
2040	6.4	0.29	0.94	0.0029	6.2	0.019	8.2	0.56	0.8
2045	7.7	0.32	1.2	0.0056	6.3	0.072	9.7	0.62	0.73
2050	8	0.3	0.84	0.00031	6.4	0.061	11	0.55	0.51

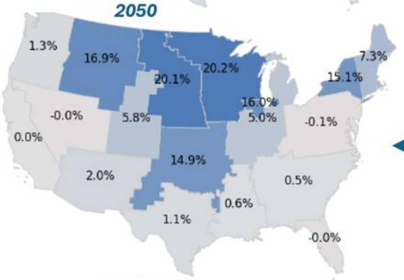


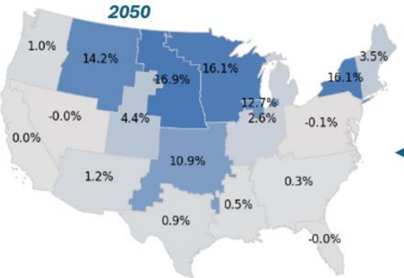
Emissions Impact of Replacing Dual Fuel ASHP with All Electric ASHP

Electrification Trends Across Building Types

- Similar impact observed across multiple building categories
- Upper mid-west is most positively impacted by full transition to electrification
- Other U.S. electrical grid regions show marginal (<1%) difference in emissions savings through 2050
- **Take-away:** all electric is beneficial in a few regions and only after 25 years







Emissions increase
Emissions reduction

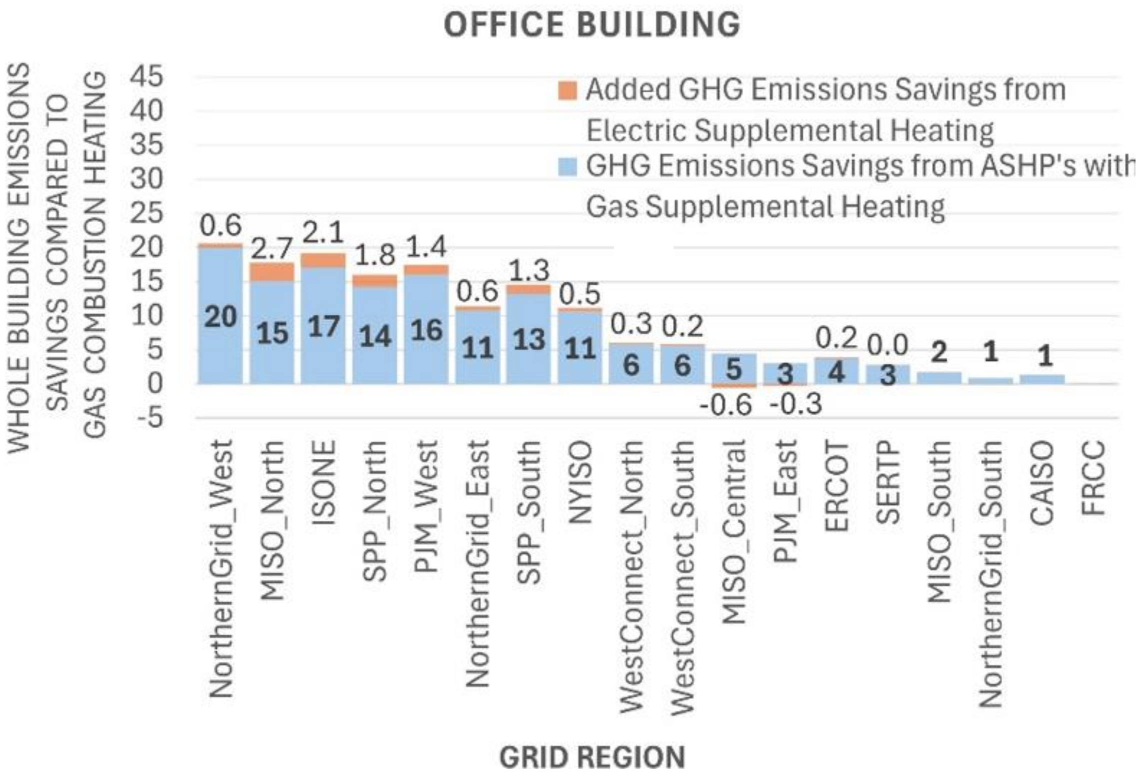
Annual whole-building emissions savings (%)

Building	Year	CAISO	WestConnect_North	FRCC	PJM_West	MISO_Central	ISONE	MISO_North	SPP_South	MISO_South	NorthernGrid_East	SERTP	WestConnect_South	NorthernGrid_South	NYISO	PJM_East	SPP_North	ERCOT	NorthernGrid_West
Multifamily	2014	0	-0.41	-0.0017	0.67	-0.98	-0.48	-6.7	-0.74	-0.066	-1	-0.11	-0.21	-0.0065	-0.04	-0.35	-3.2	-0.12	0.046
Multifamily	2016	0	-0.4	-0.0016	1	-0.94	-0.43	-5.9	-0.65	-0.06	-1	-0.1	-0.19	-0.0059	0.011	-0.32	-3	-0.11	0.057
Multifamily	2018	0	-0.4	-0.0015	1.3	-0.94	-0.26	-6	-0.57	-0.061	-0.96	-0.092	-0.19	-0.0058	0.062	-0.3	-3	-0.1	0.052
Multifamily	2020	0	-0.38	-0.0013	1.4	-0.87	-0.29	-4.4	-0.43	-0.053	-0.87	-0.062	-0.16	-0.0057	0.064	-0.28	-2.6	-0.09	0.045
Multifamily	2022	0	-0.36	-0.0013	1.3	-0.86	-0.33	-4.2	-0.43	-0.056	-0.92	-0.074	-0.15	-0.0055	-0.013	-0.28	-2.4	-0.083	0.059
Multifamily	2025	0	-0.26	-0.0019	0.42	-0.82	1	-1.2	0.14	-0.058	-0.77	-0.11	-0.085	-0.012	0.16	-0.31	-0.11	0.05	0.26
Multifamily	2030	0	0.93	-0.002	1.3	0.37	1.9	6.3	1.5	0.02	2.5	0.1	0.14	-0.014	0.49	-0.1	4.5	0.27	0.37
Multifamily	2035	0	1.1	-0.0023	2	0.51	1.9	9.2	2.1	0.19	2.3	0.14	0.36	-0.01	0.61	-0.011	5.9	0.45	0.55
Multifamily	2040	0	1.4	-0.0025	2.5	0.79	2.4	12	2.6	0.26	5.2	0.17	0.61	-0.0063	4	-0.047	8.7	0.48	0.47
Multifamily	2045	0	1.5	-0.0026	4.7	1.2	2.3	12	3.3	0.27	6.2	0.17	0.79	-0.0048	4.1	-0.024	9.9	0.51	0.42
Multifamily	2050	0	1.7	-0.0026	4.3	0.95	2	11	3.4	0.18	6.4	0.14	0.44	-0.0059	4.2	-0.027	11	0.43	0.28
School	2014	0	-1.4	-0.0041	3	-5.8	-1.8	-16	-4.1	-0.13	-4.2	-0.34	-0.68	-0.011	-0.17	-1.8	-7.6	-0.25	0.24
School	2016	0	-1.4	-0.0039	4.6	-5.6	-1.6	-14	-3.6	-0.12	-4.2	-0.3	-0.62	-0.0098	0.048	-1.7	-7.4	-0.23	0.29
School	2018	0	-1.4	-0.0036	5.8	-5.6	-0.94	-14	-3.1	-0.12	-3.9	-0.27	-0.62	-0.0097	0.27	-1.6	-7.2	-0.22	0.27
School	2020	0	-1.3	-0.0032	6.2	-5.1	-1.1	-9.9	-2.3	-0.1	-3.5	-0.18	-0.5	-0.0094	0.28	-1.4	-6.3	-0.19	0.23
School	2022	0	-1.3	-0.0031	5.7	-5.1	-1.2	-9.5	-2.4	-0.11	-3.7	-0.22	-0.47	-0.0092	-0.056	-1.4	-5.8	-0.18	0.3
School	2025	0	-0.93	-0.004	1.4	-5	3.5	-3.8	0.22	-0.11	-2.6	-0.34	-0.17	-0.016	0.71	-1.7	-0.038	0.042	1.2
School	2030	0	3.1	-0.003	4.9	1.4	6.6	11	6.9	0.083	7.8	0.24	0.72	-0.016	2.1	-0.69	9.7	0.52	1.7
School	2035	0	3.6	-0.0021	7.5	2.4	6.7	17	9.6	0.46	7.5	0.4	1.5	-0.007	2.6	-0.24	12	0.98	2.3
School	2040	0	4.7	-0.0017	9.6	4	8.2	20	12	0.69	15	0.55	2.4	0.00097	15	-0.28	16	1.1	2
School	2045	0	5.1	-0.0016	17	6.3	8.2	22	14	0.78	17	0.6	3	0.0039	15	-0.095	18	1.3	1.9
School	2050	0	5.8	-0.0014	16	5	7.3	20	15	0.58	17	0.53	2	-0.0018	15	-0.1	20	1.1	1.3
Hospital	2014	0	-0.96	-0.0029	1.6	-2.2	-0.7	-6.9	-1.8	-0.19	-1.9	-0.32	-0.57	-0.025	-0.098	-0.87	-3.2	-0.27	0.16
Hospital	2016	0	-0.95	-0.0027	2.6	-2.2	-0.62	-6.1	-1.6	-0.17	-1.9	-0.28	-0.52	-0.022	0.028	-0.81	-3.1	-0.24	0.2
Hospital	2018	0	-0.93	-0.0025	3.4	-2.2	-0.37	-6.2	-1.4	-0.18	-1.8	-0.25	-0.51	-0.022	0.15	-0.75	-3	-0.23	0.18
Hospital	2020	0	-0.89	-0.0022	3.6	-2	-0.41	-4.6	-1	-0.15	-1.6	-0.17	-0.42	-0.021	0.16	-0.69	-2.7	-0.2	0.15
Hospital	2022	0	-0.85	-0.0021	3.3	-2	-0.48	-4.5	-1	-0.16	-1.7	-0.2	-0.39	-0.021	-0.032	-0.69	-2.5	-0.18	0.2
Hospital	2025	0	-0.57	-0.0031	1.1	-1.8	1.7	-1.2	0.62	-0.17	-1.3	-0.31	-0.21	-0.043	0.4	-0.78	0.36	0.092	0.92
Hospital	2030	0	2.3	-0.0032	3.6	1.1	3.2	8.2	4.4	0.052	5.2	0.28	0.43	-0.048	1.2	-0.24	6.1	0.6	1.4
Hospital	2035	0	2.6	-0.0038	5.3	1.5	3.3	13	6.4	0.52	4.8	0.37	1	-0.033	1.6	-0.021	8.7	0.97	2.1
Hospital	2040	0	3.5	-0.004	6.9	2.2	4	16	8.2	0.69	11	0.43	1.7	-0.016	15	-0.12	13	1	1.7
Hospital	2045	0	3.9	-0.004	14	3.3	4	18	11	0.72	14	0.44	2.2	-0.0051	16	-0.067	15	1.1	1.5
Hospital	2050	0	4.4	-0.004	13	2.6	3.5	16	11	0.46	14	0.33	1.2	-0.013	16	-0.075	17	0.89	1

15-year Assessment (2025-2040)

Regional Differences in Emissions Savings

- Dual fuel is beneficial everywhere
- Electrifying supplemental heat provides marginal differences in savings in most regions (<1%)
- Negative savings in MISO central – Indiana, PJM East – Pennsylvania)
- MISO North sees greatest emissions savings from electrifying supplemental heating
- NYISO is not the biggest beneficiary ahead of 2040/2050 goals



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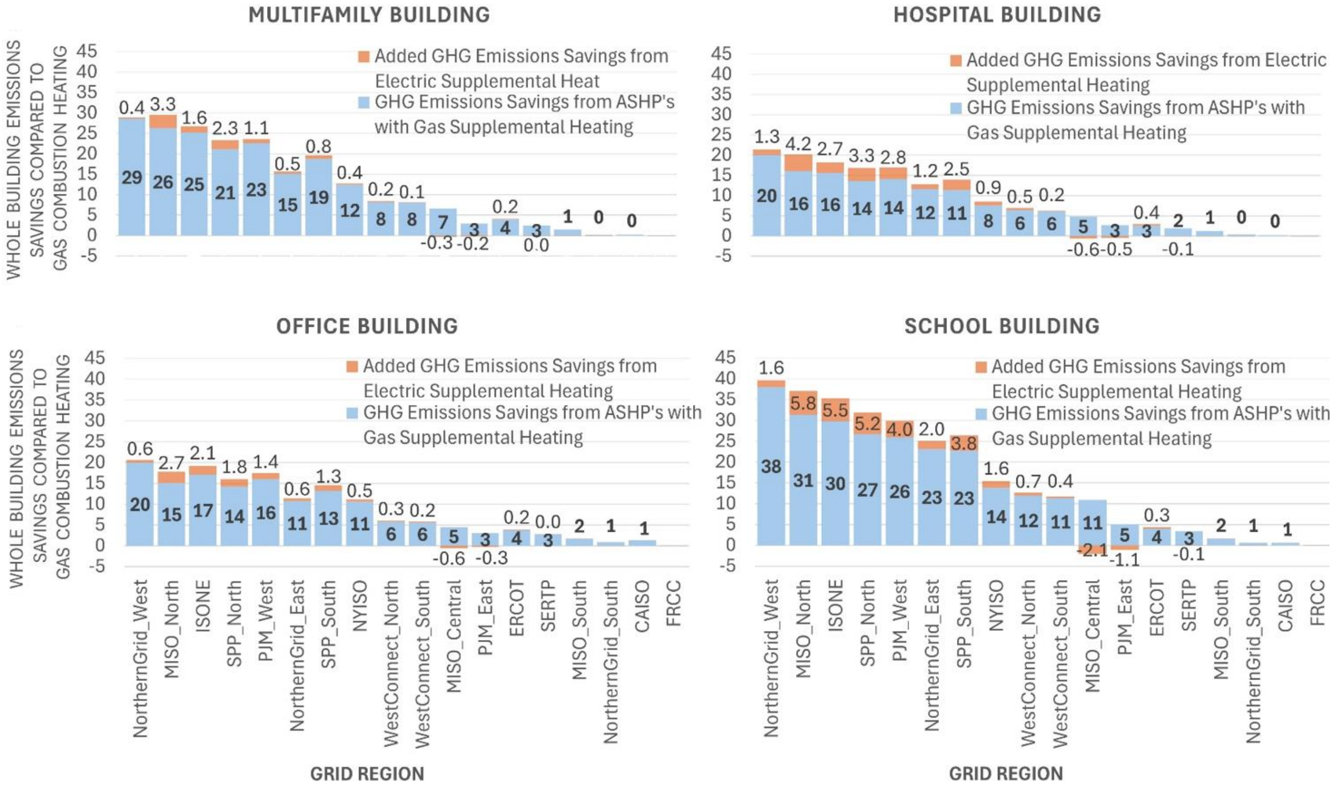


Schools See the Most Benefit

Example of Operational Cost Implications - Office

Building Type: Medium Office

Building Area: 50,000 ft^2

Scenario-1 Location: *Kansas City, KS*

- **Electricity Utility Price:** $0.1059/kWh
- **Gas Utility Price:** $10.77/MMBtu *($0.03675/kWh)*
- *$E/$G=2.88*

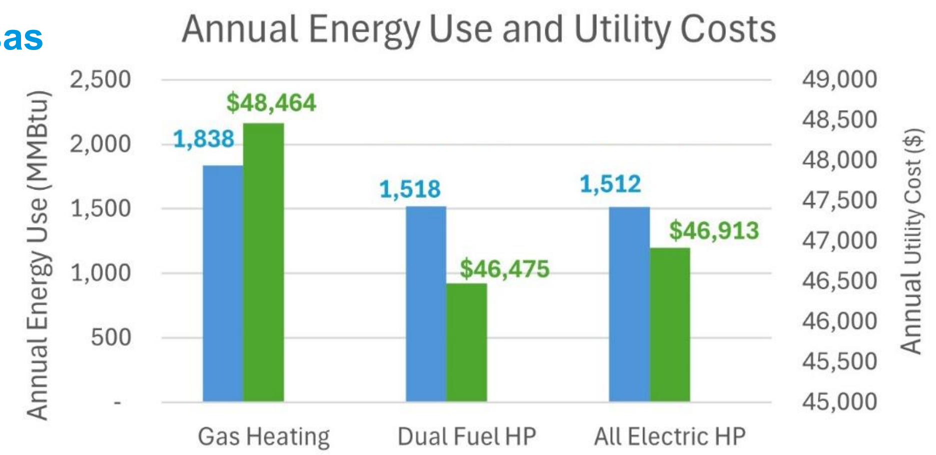
Scenario-2 Location: *New York, NY*

- **Electricity Utility Price:** $0.2067/kWh
- **Gas Utility Price:** $8.25/MMBtu *($0.02814/kWh)*
- *$E/$G=7.34*

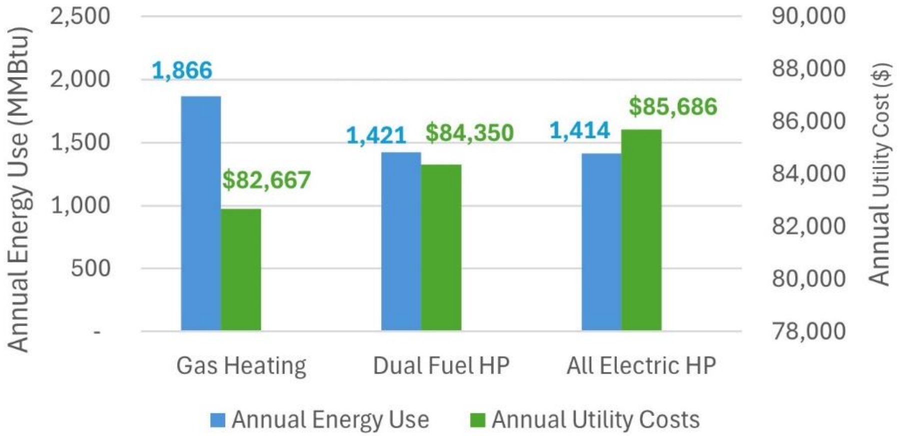
While dual fuel isn't always cheaper than all gas, it is typically more economical than fully electric

This is specifically for operational costs, does not include incentives/first costs. Etc.

Kansas



New York

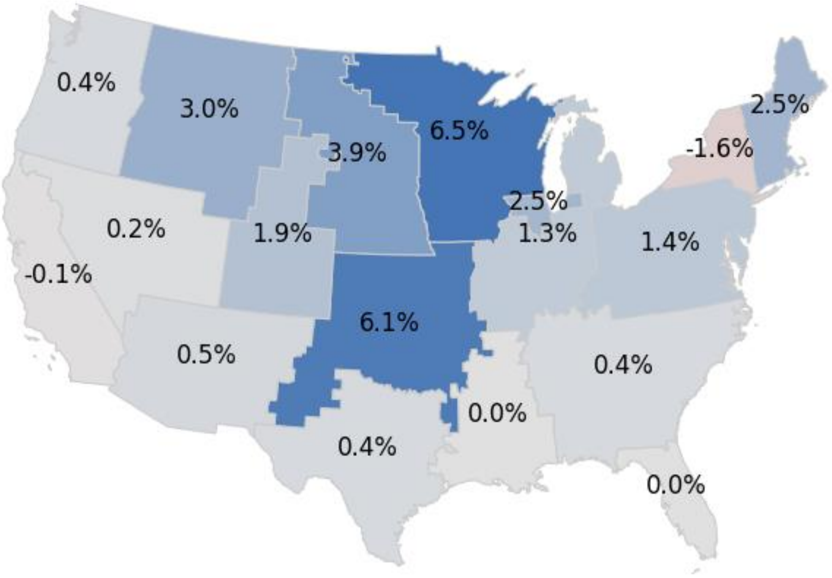


Example of Operational Cost Implications - School

% Whole-Building Operational Cost Savings

Example of Operational Cost Implications - School

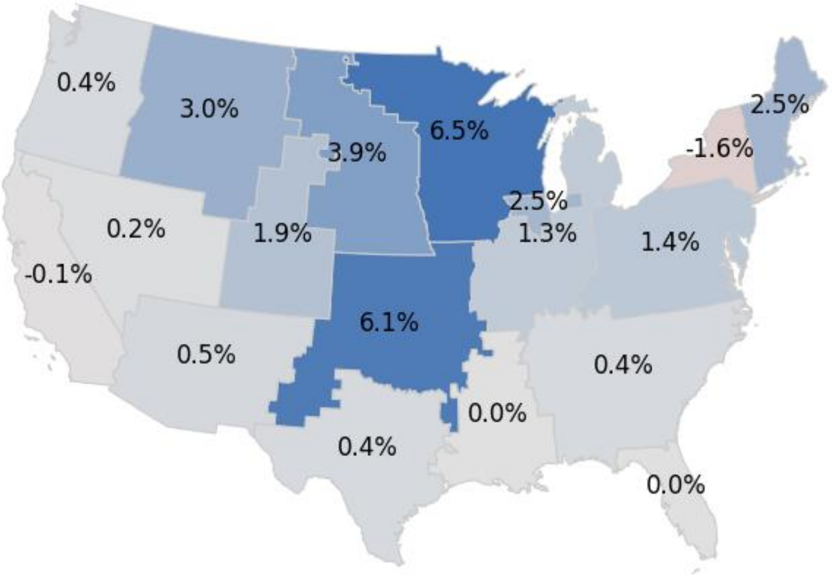
% Whole-Building Operational Cost Savings



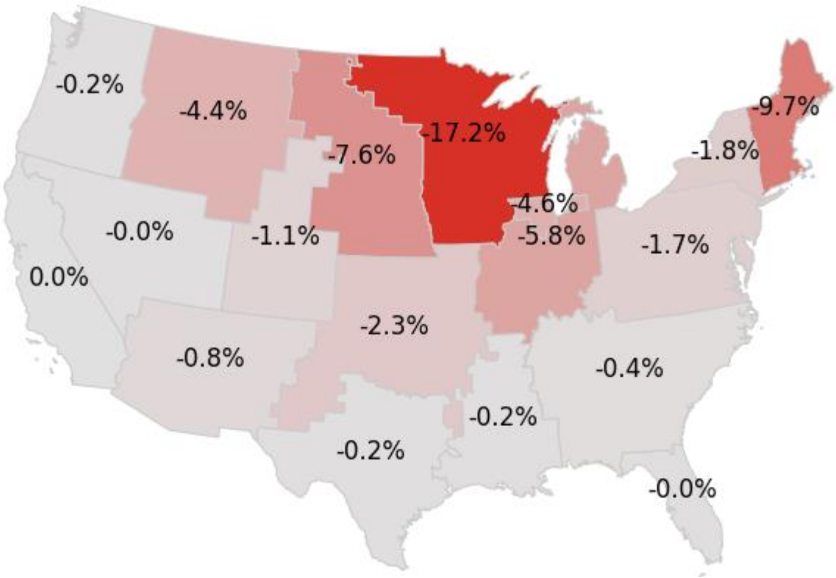
All Gas to Dual Fuel

Example of Operational Cost Implications - School

% Whole-Building Operational Cost Savings



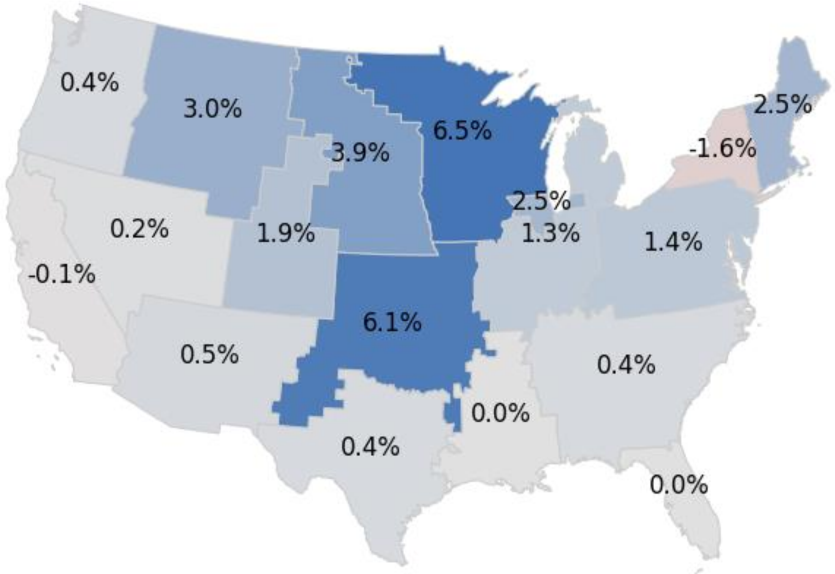
All Gas to Dual Fuel



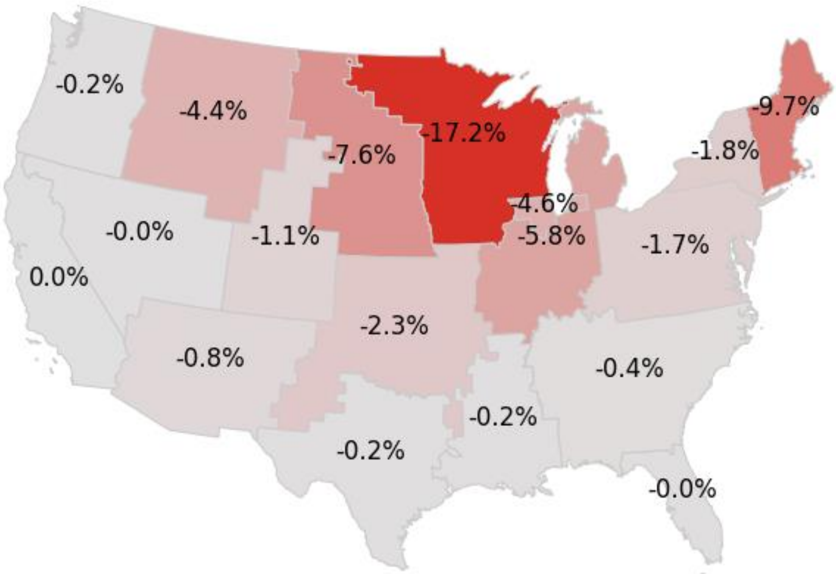
Dual Fuel to All Electric

Example of Operational Cost Implications - School

% Whole-Building Operational Cost Savings



All Gas to Dual Fuel



Dual Fuel to All Electric

- Electrifying supplemental heat costs more, operationally, throughout the U.S
- Dual fuel offers positive savings across the U.S, except in NY and CA
- Results are not general to all building types (***attend 2026 ASHRAE Winter Conference to learn more***)

Case Study - *EAGLE STREET "ZERO CARBON" INDUSTRIAL FACILITY*

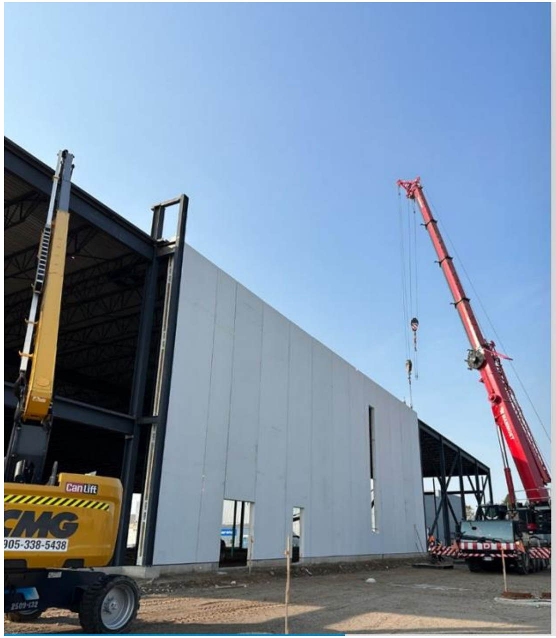
Who: Eagle Street Industrial Limited Partnership

Building Type: 158k ft^2 Premium warehouse facility

Location: Ontario, Canada (cold climate)

Goal: Max Efficiency and min carbon footprint

Solution: Dual fuel rooftops with SVT, and low-GWP refrigerant (R-32)



Results:

- **27% reduction in total electricity use** and **82% annual GHG emissions reduction** compared to conventional industrial buildings
- **95% of the year**, the building operates using **fully electric heating and cooling**
- **Supplemental gas heating is required for only the coldest 5% of the year** (extreme weather conditions)

QR Code to Published Case Study:

Agenda

1. **Introduction**
   - Background
   - Hypothesis
   - Assumptions
   - Problem Statement & Study Goals
2. **Approach**
   - GHG Emission Factors
   - Building Energy Models
   - Modeled Scenarios
3. **Results**
   - Incremental, Nationwide, Dual-Fuel Heat Pump Emissions Savings from 2014-2050
   - Added Savings from Supplemental Heat Electrification
   - 15-year Assessment
4. **Study Limitations, Conclusions, and Future Work**

Study Limitations and Future Work

- **Data limitations:** Cambium's hourly emissions data and EPA's historical annual emissions factors
- **Technology scope:** Focuses on heat pumps with shut-off temperatures of -10°F (-23.33°C), does not account for defrost cycles
- **Future grid assumptions:** Based on Cambium's mid-case future grid scenario
- **Potential areas for further investigation:**
  - Cost analysis between supplemental heat options →
  - Expanded grid scenario evaluations using Cambium dataset
  - Inclusion of more building types and vintages
  - Defrost cycle considerations and impact

2026 ASHRAE WINTER CONFERENCE

2026 ASHRAE Winter Conference

- **Accepted Conference Paper & Presentation Abstract**
- **Title:** "*Cost Optimal Decarbonization: A Regional Analysis of Electric versus Gas Supplemental Heating for Heat Pumps*"
- **January 31 - February 4, 2026**, in **Las Vegas, NV**

Conclusions & Key Findings

ASHPs with **gas supplemental heating can significantly reduce** whole-building **emissions today and into the future** as U.S. grids transition to cleaner energy, with potential reductions of up to 38%.

Electrifying supplemental heating yields minimal or even negative whole-building emissions savings in most U.S electric grid regions, with impacts ranging from –2.1% to +5.8%.

- ✓ Regions most impacted by electric supplemental heating through 2050: MISO North and SPP North (upper Midwest)

All electric solutions do not always yield greater emissions savings → Critical importance of long-term and region-specific assessments to achieve desired results

Where Can I Go for Information?

Center of Excellence for
Building Decarbonization

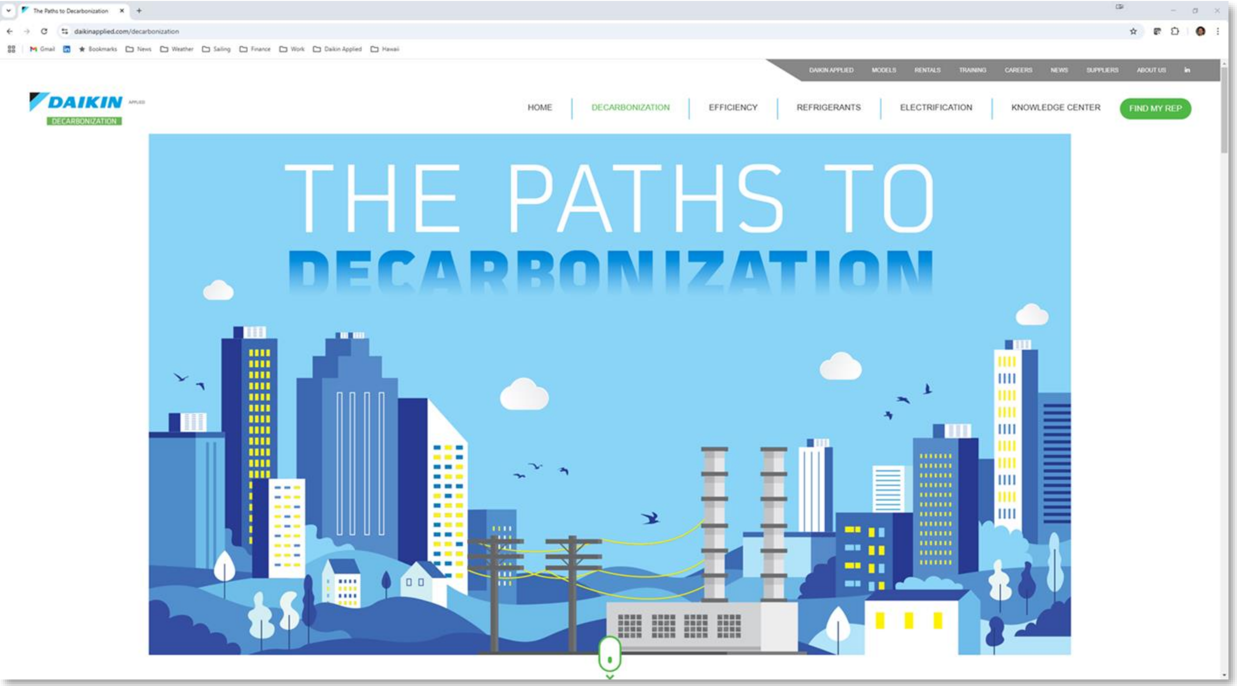
Selected Resources

- https://www.ashrae.org/about/cebd-center-of-excellence-for-building-decarbonization
- https://www.ashrae.org/about/cebd-building-decarb-101
- US Department of Energy: *Decarbonizing the U.S. Economy by 2050: A National Blueprint for the Buildings Sector*
- Decarbonization Guides
    - Decarbonizing Building Thermal Systems: A How-To Guide for Applying Heat Pumps and Beyond
- Pathways to Commercial Liftoff: Geothermal Heating and Cooling

Where Can I Go for Information?

Selected Resources

- Dedicated web site
- On demand webinars:
  - The Path to Decarbonization for Applied HVAC Systems
  - Decarbonization in HVAC
    - Part 1: Update & Review
    - Part 2: Thermal Systems Guidance
    - Part 3: RTU Heat Pumps
  - Refrigerants
  - Preparing Buildings for A2L Refrigerants



https://www.daikinapplied.com/decarbonization

THANK YOU FOR YOUR TIME AND ATTENTION

For more information, contact:

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Sammy.Houssainy@DaikinApplied.com

QR Code to ASHRAE Conference Paper