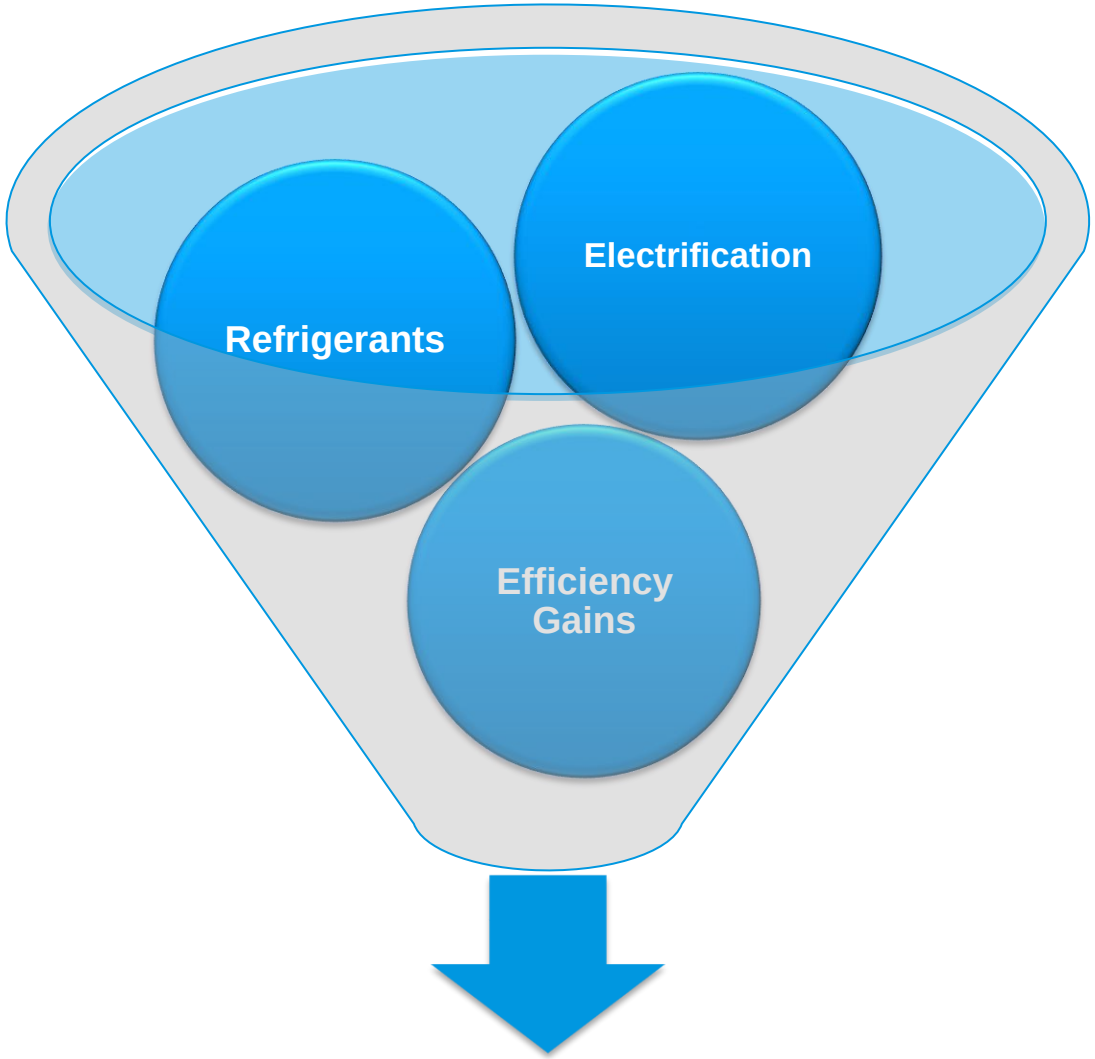

# DECARBONIZATION OF HVAC SYSTEMS

# Agenda

- **Electrification & Decarbonization in Applied HVAC Systems**
  - Cold Climate HPs
- **Legislation & Incentives**
- **How Refrigerants Tie In**
- **How Will This Impact HVAC System Designs**
- **Technology Enablers**

# Decarbonization in HVAC




Decarbonization

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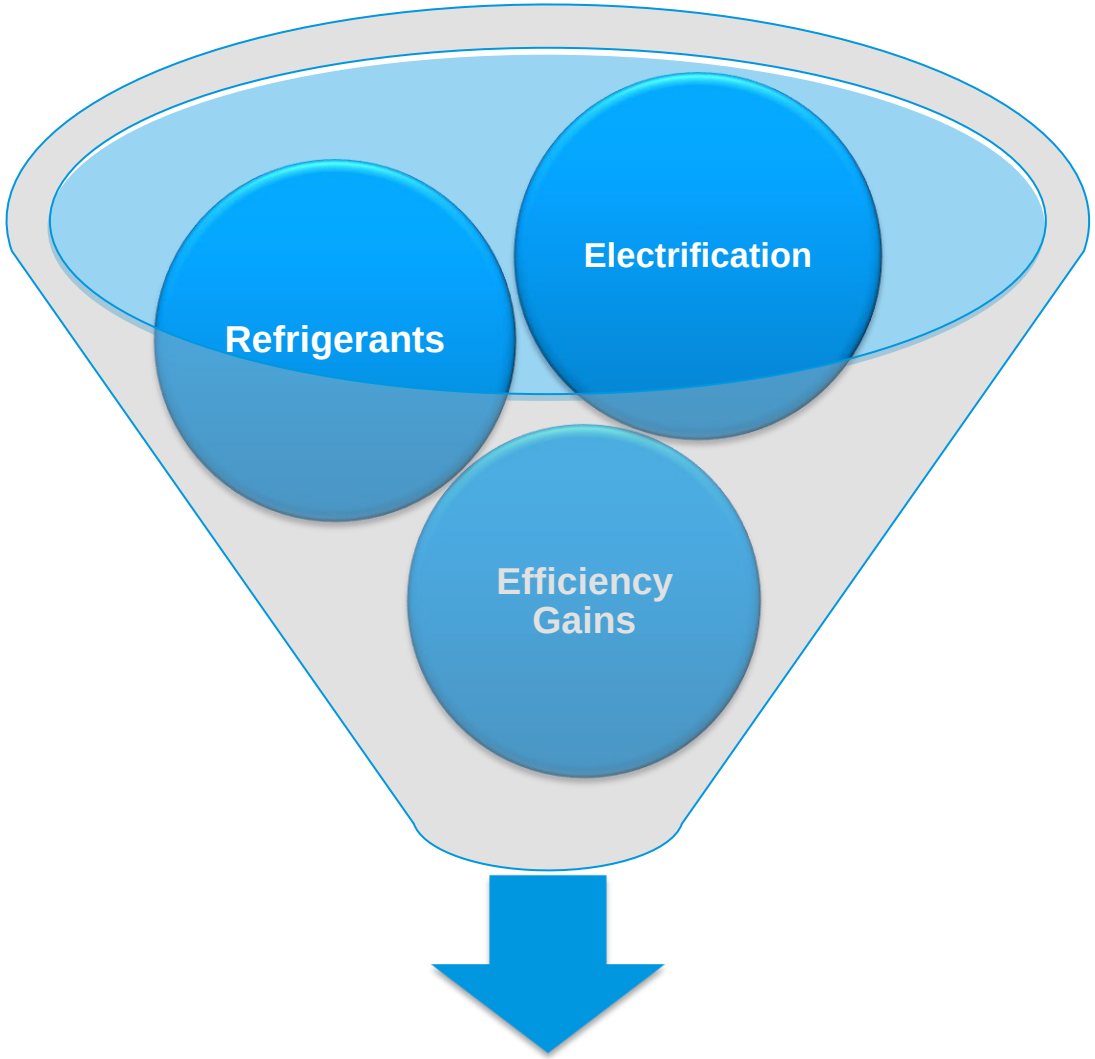
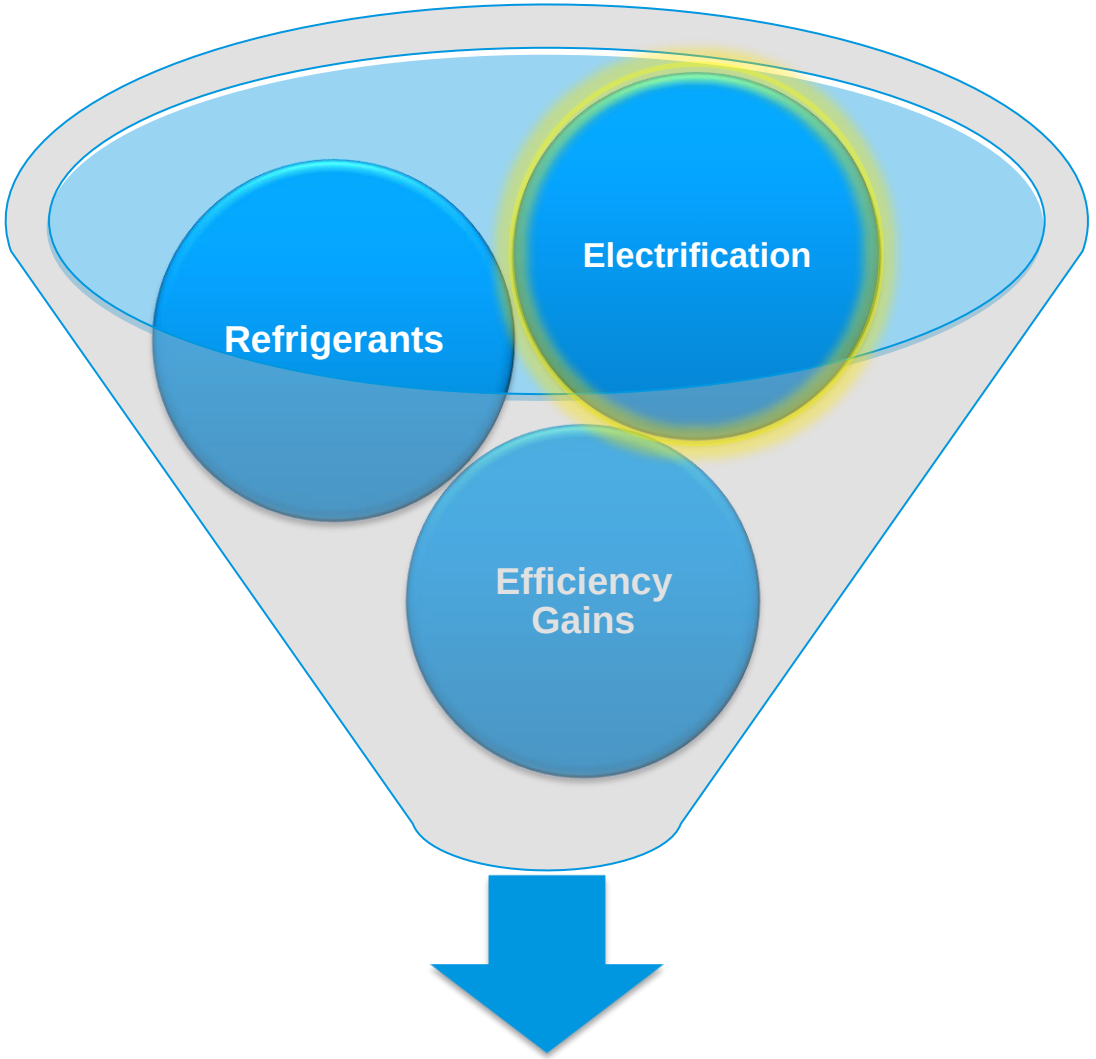


# Decarbonization in HVAC

## Electrification

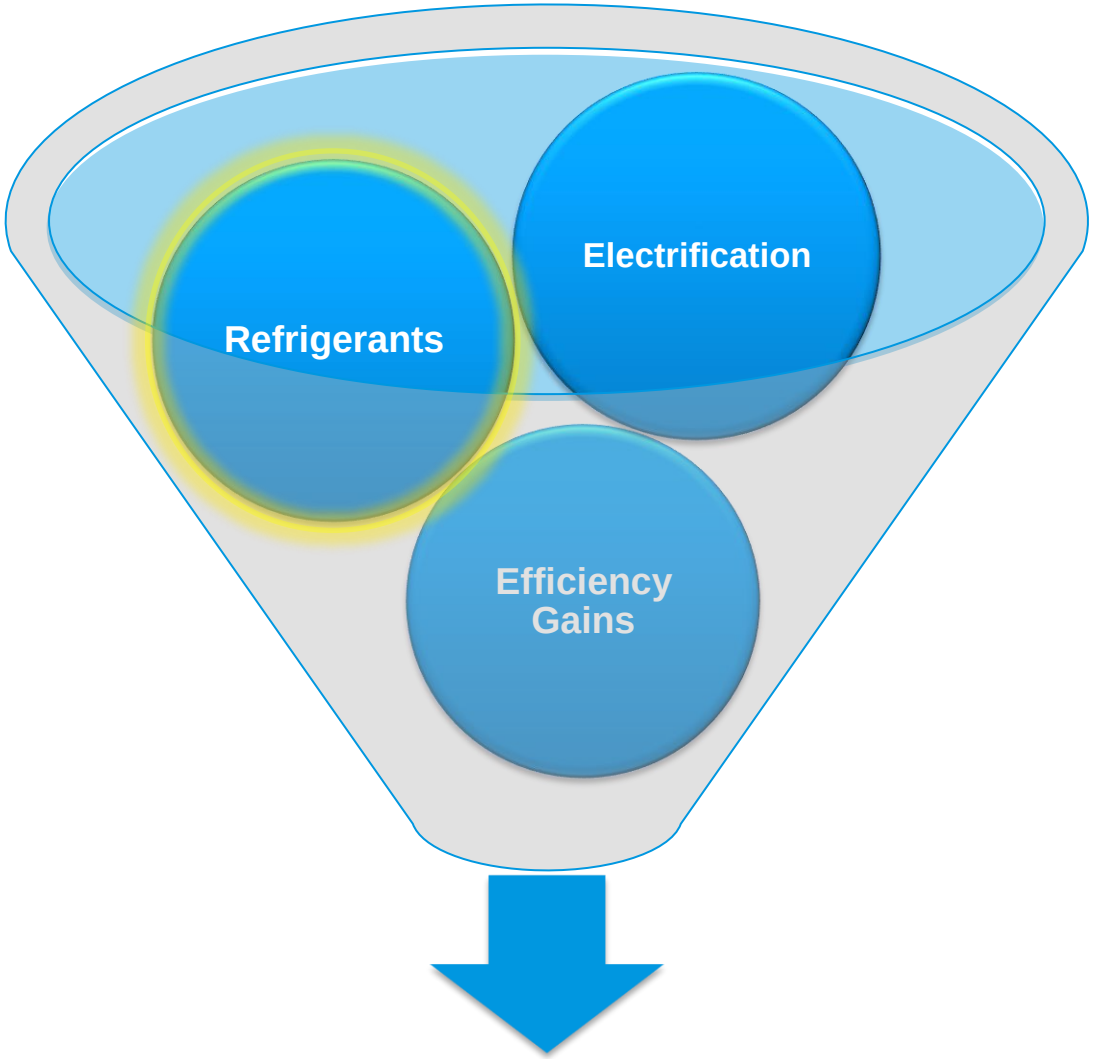
- Convert fossil fuel equipment/processes to electric
- Dependent on clean power grid



# Decarbonization in HVAC

## Refrigerants

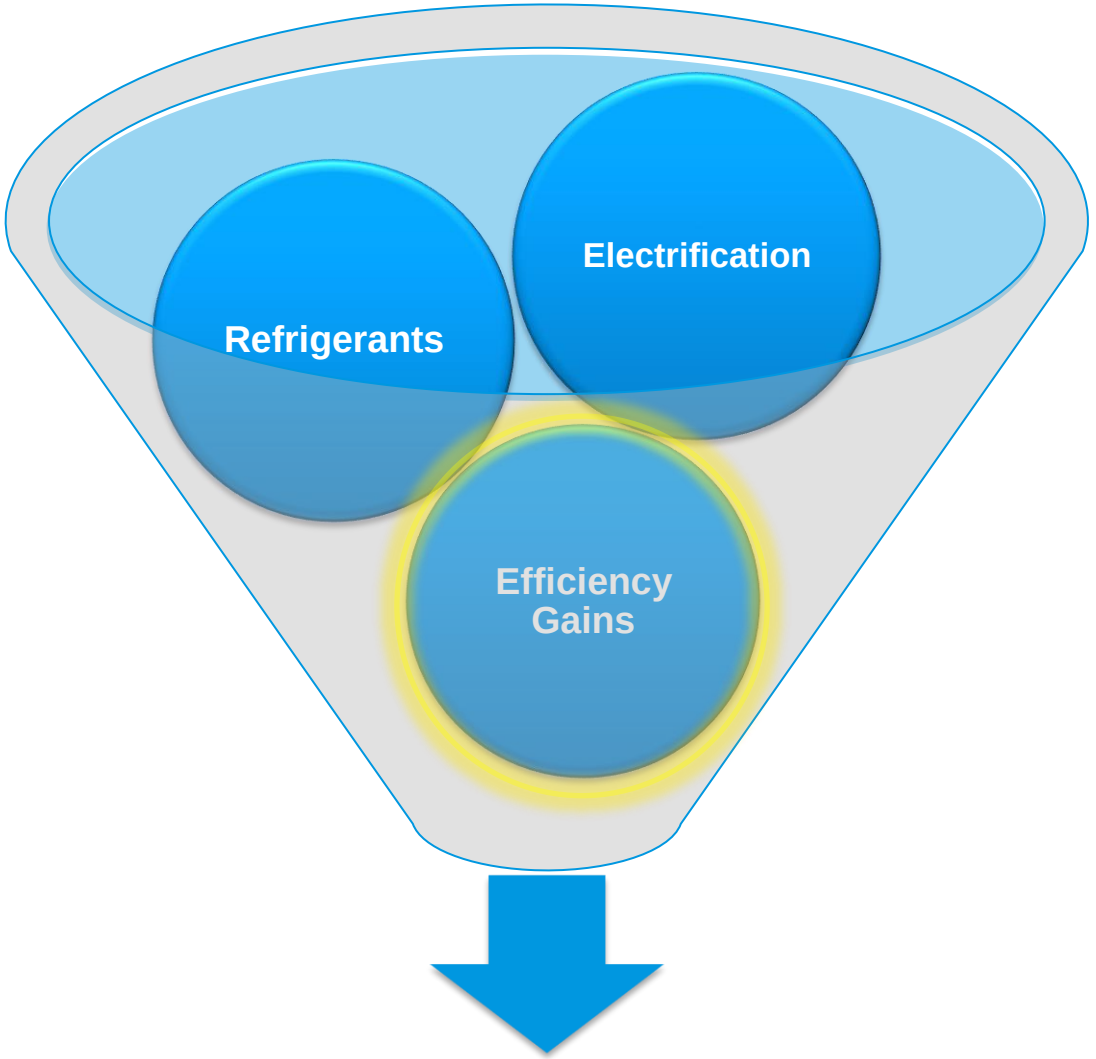
- Can have much higher global warming potential per pound than $CO_2$
- Direct effect: greenhouse effect of the gas
- Indirect effect: change in efficiency changes power usage over equipment lifecycle
- Life Cycle Climate Performance (LCCP): combines direct and indirect effect into one metric



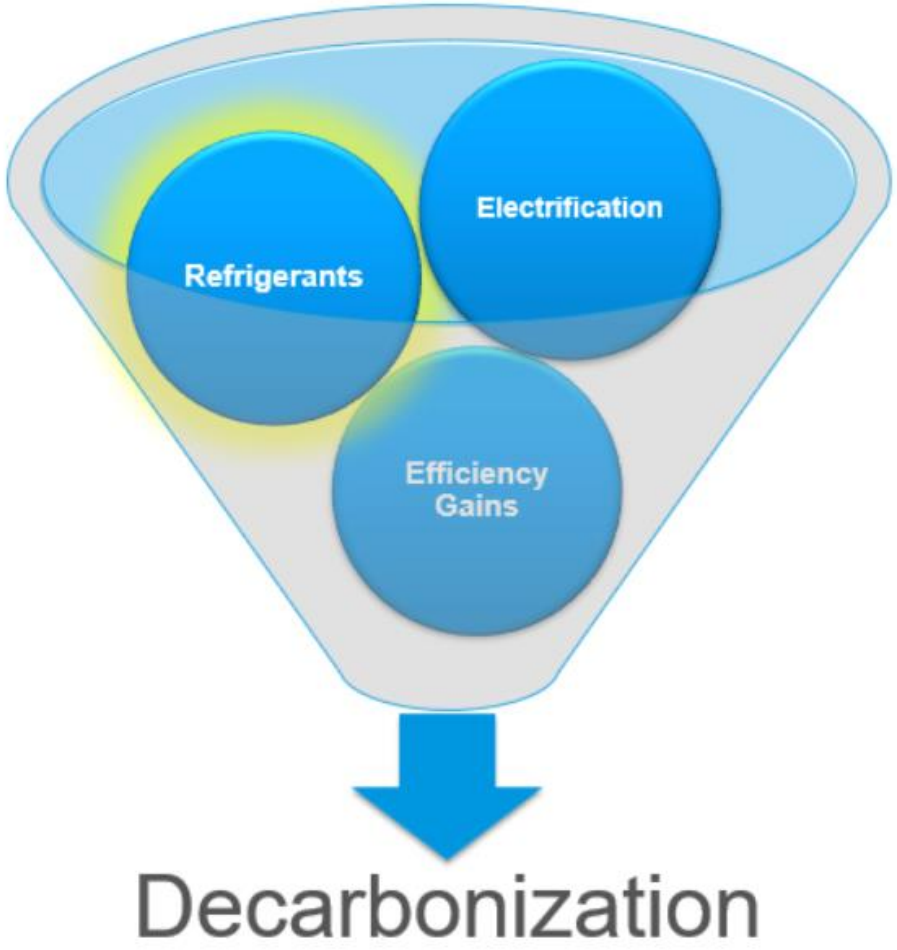
# Decarbonization in HVAC

## Efficiency improvements

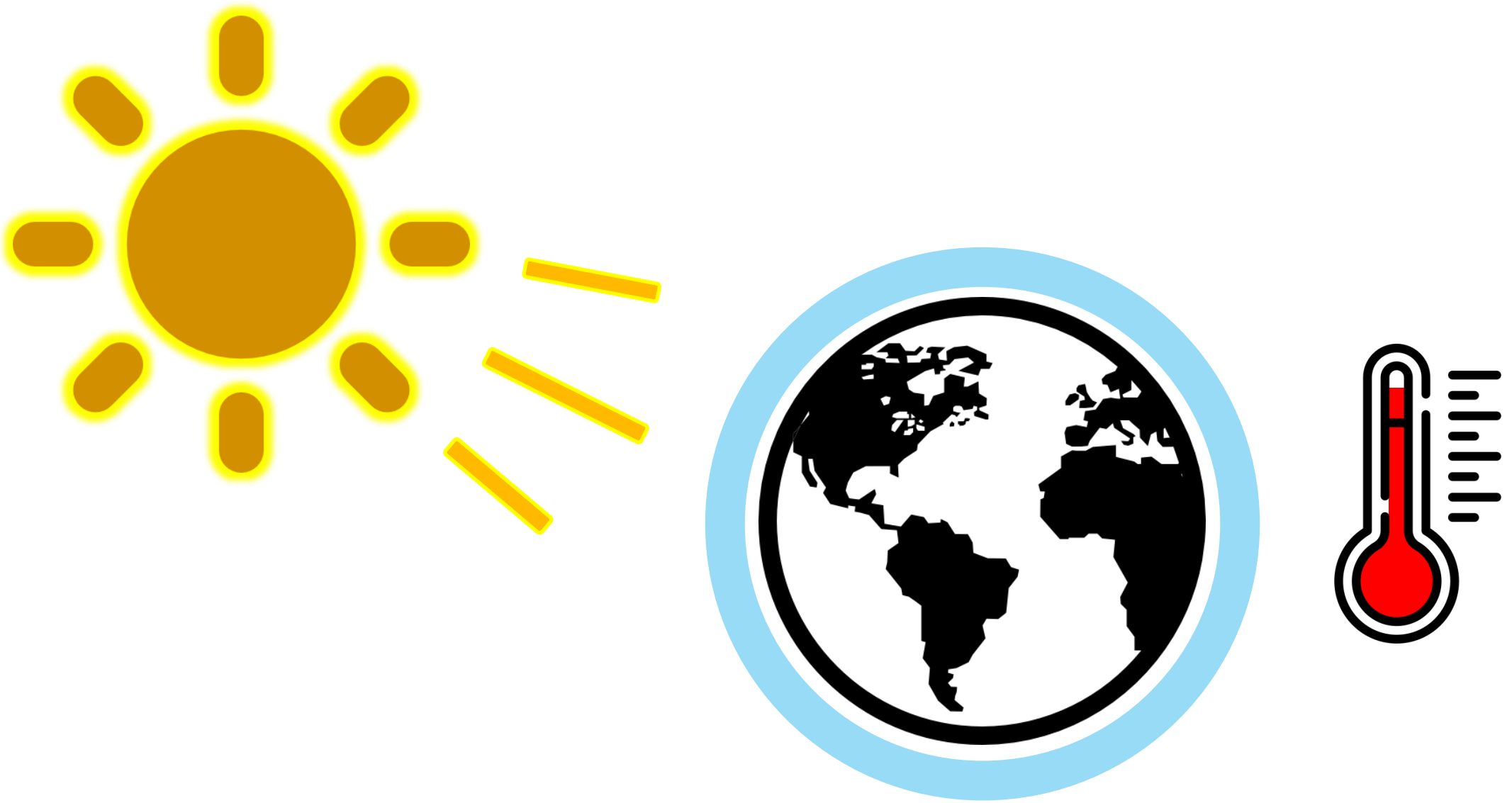
- Greatest impact with dirty grid
- Reduced (but not zero) impact as grid converts to renewable
  (e.g. embedded carbon in power gen equipment)



# REFRIGERANTS



# Global Warming Potential



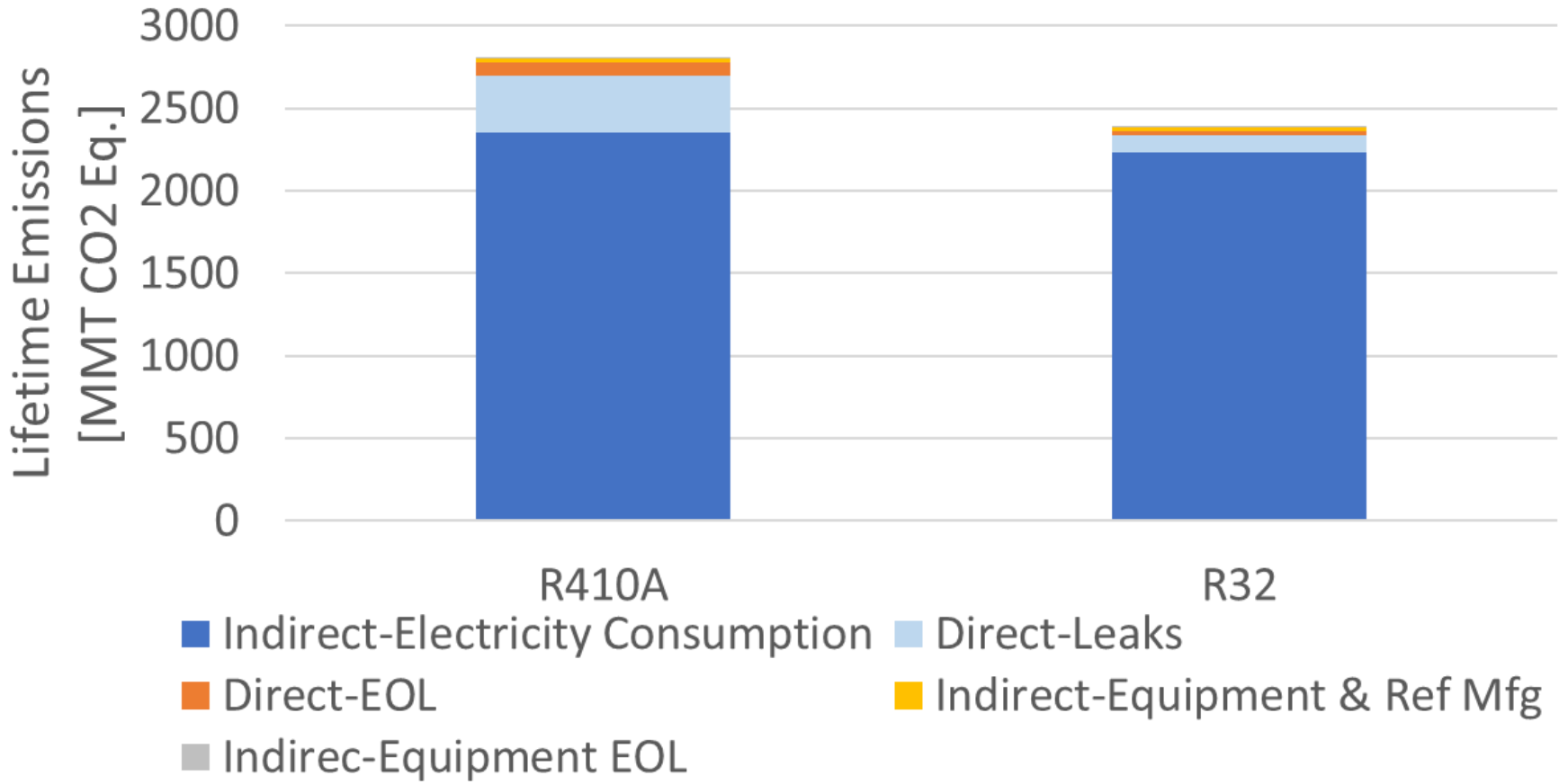
# GWP is Not the Full Measure of Emissions

**Direct Effect from Refrigerant** + **Indirect Effect from Energy Use** = **Life Cycle Climate Performance (LCCP)**

- Majority of climate impact from HVAC is electrical power generation over equipment lifetime
- A lower GWP refrigerant with lower efficiency could actually create more global warming!

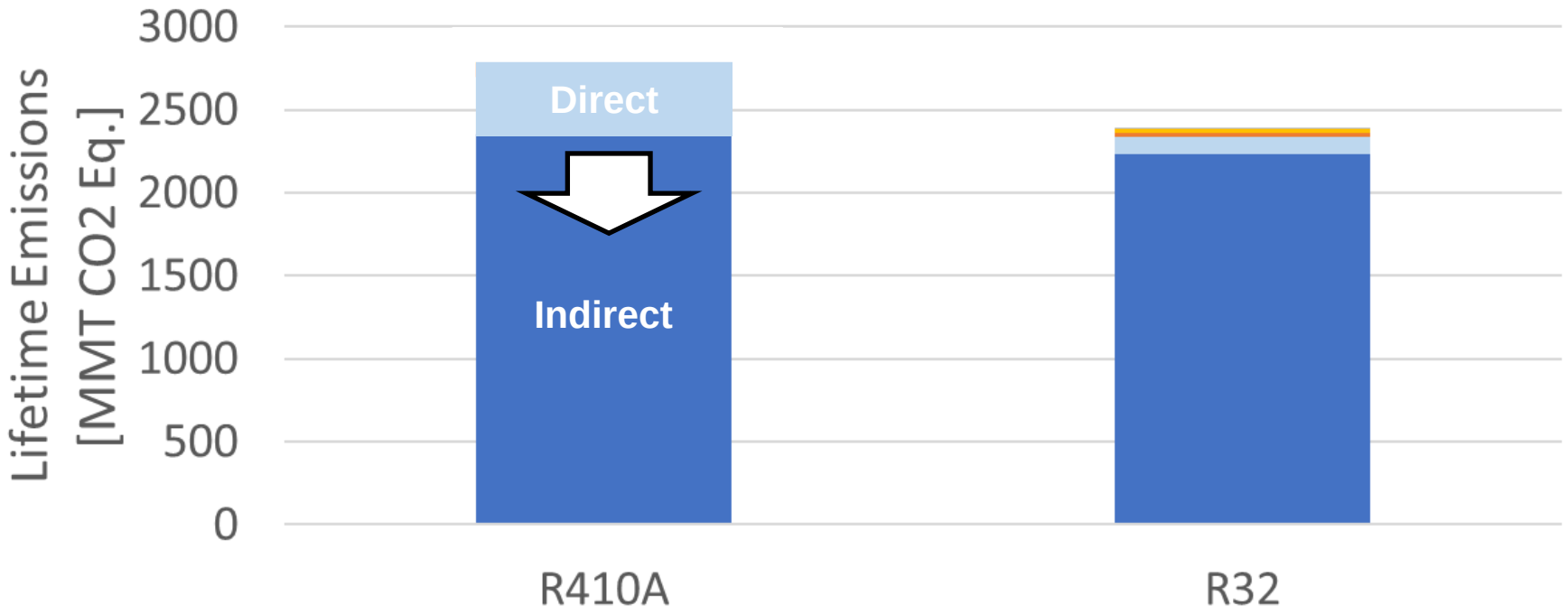
Source: Zhang M., et al. 2011. “Life Cycle Climate Performance Model for Residential Heat Pump Systems.” AHRTI Report 09003-01

# $CO_2$ eq. Emissions Mostly from Electricity Consumption




Projected lifetime Residential AC & HP $CO_2$ Eq. Emissions in USA

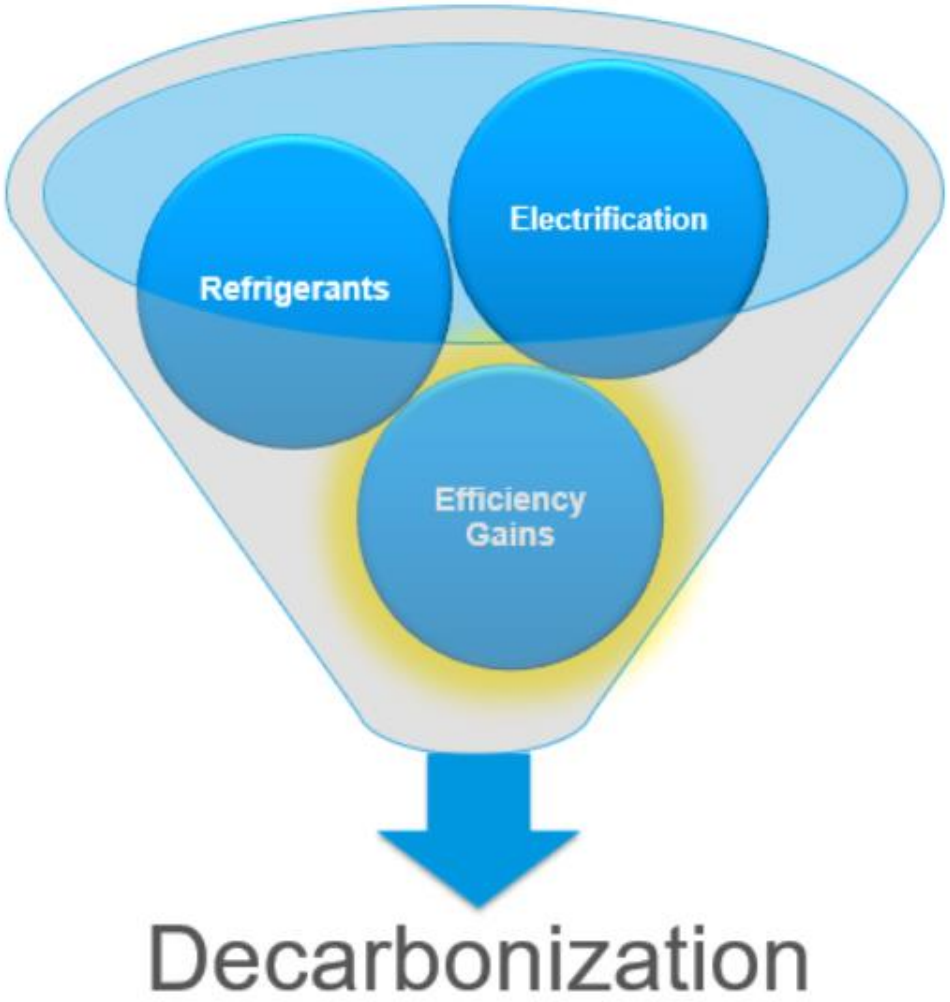
# $CO_2$ eq. Emissions Mostly from Electricity Consumption



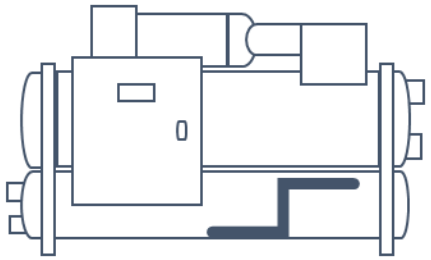

**As Grid becomes more renewable, direct emissions will become a larger percentage of the total, but today are a very small impact compared to equipment efficiency / power use**

***(animation not to scale)***

# EQUIPMENT & SYSTEM EFFICIENCY



# Addressing Efficiency Needs

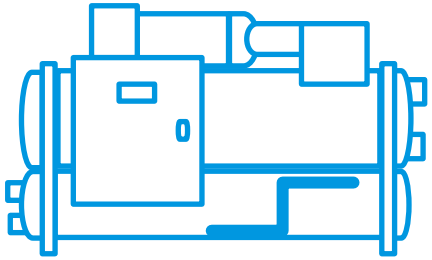


Efficiency-Enabling Technologies

Codes, Standards & Regulations

System & Design Changes

# Addressing Efficiency Needs



**Efficiency-Enabling Technologies**

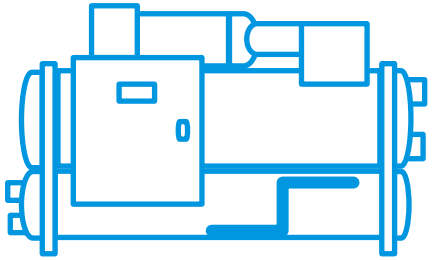
**Codes, Standards & Regulations**

**Include:**

- ASHRAE 90.1 & IECC
- DOE requirements
- CA Title 24
- Local codes
- ASHRAE 228 – net zero energy buildings
- ASHRAE 240 – quantify building GHG emissions

**System & Design Changes**

# Addressing Efficiency Needs



**Efficiency-Enabling Technologies**

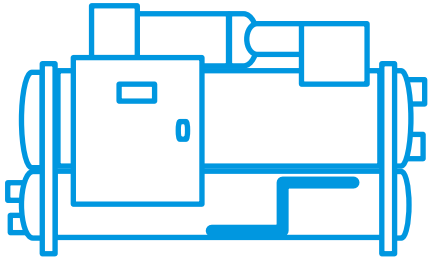
**Codes, Standards & Regulations**

**System & Design Changes**

**Include:**

- VFD/inverter compressors
- Permanent magnet motors
- Variable volume ratio compression
- Better and larger heat exchangers
- Integrated ‘free-cooling’

# Addressing Efficiency Needs



**Efficiency-Enabling Technologies**

**Codes, Standards & Regulations**

**System & Design Changes Include:**

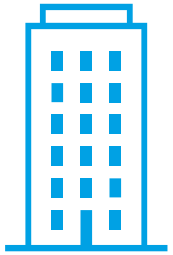
- More efficient designs
  - Load reduction (lighting, insulation, ventilation rates)
- Building recommissioning or energy audits
- Systems that share energy within the building or system
  - District systems
  - Heat recovery / Heat Pumps
  - VRF

# REGULATIONS

# Regulations and Legislation Summary

## Federal

## Various Incentives



## State

# Regulations and Legislation Summary

## Federal

**Inflation Reduction Act**

- Investment in green infrastructure

**AIM Act**

- Lower GWP Refrigerants

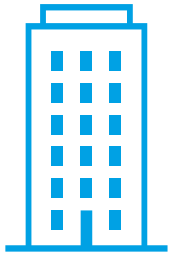
**CHIPs and Science Act**

- Invest in MFG for semiconductors and R&D for many items including clean energy

**Biden-Harris Federal Building Performance Standards**

- Electrify 30% of spaces by 2030

## Various Incentives



## State

# Regulations and Legislation Summary

## Federal

## Various Incentives

**Various financial incentives for homeowners related to efficiency and climate change**

Rebates or credits for:

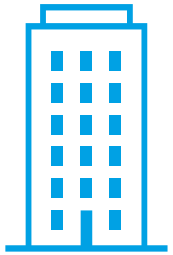
- Better windows/doors & envelope sealing
- heat pumps
- energy audits
- electric appliances like HP water heaters and clothes driers

## State

# Regulations and Legislation Summary

## Federal

## Various Incentives



## State

**Building Performance Standards**

- NYC, Washington, D.C.; St. Louis, MO; and Washington State

**Pre-wiring for Electrification**

- Washington D.C. and Boston

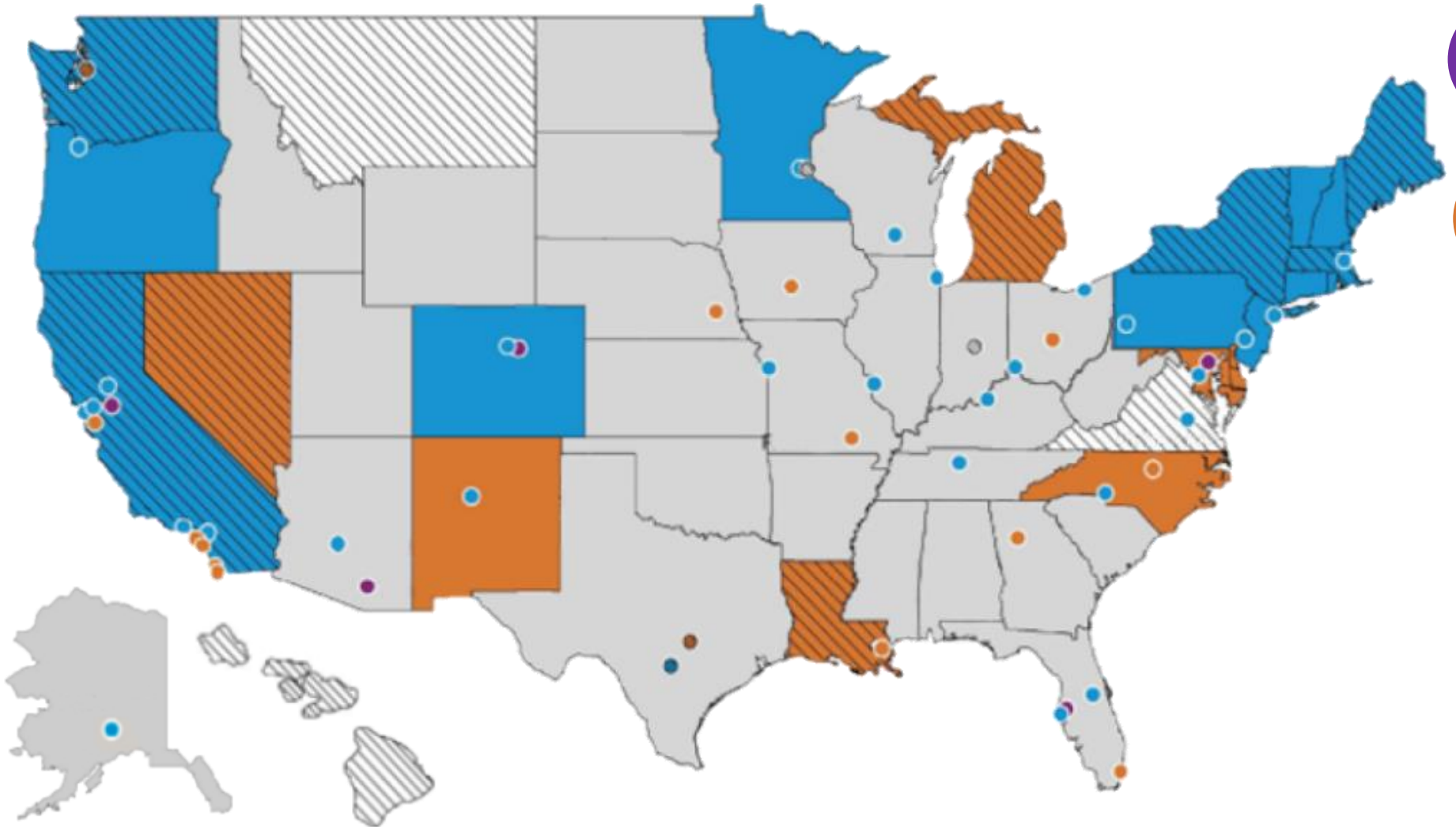
**Net-Zero Designs**

- ~11 states with current or future targets
- optimize building efficiency / minimize energy use
- Building to generate as much clean energy as it consumes

**Gas Bans**

- Various cities, some legal challenges

# State/Local GHG Reduction Goals



Under 20% Reduction by 2025

20-60% Reduction by 2035

70-95% Reduction by 2035-2050

Net-Zero or Zero Emm. by 2050

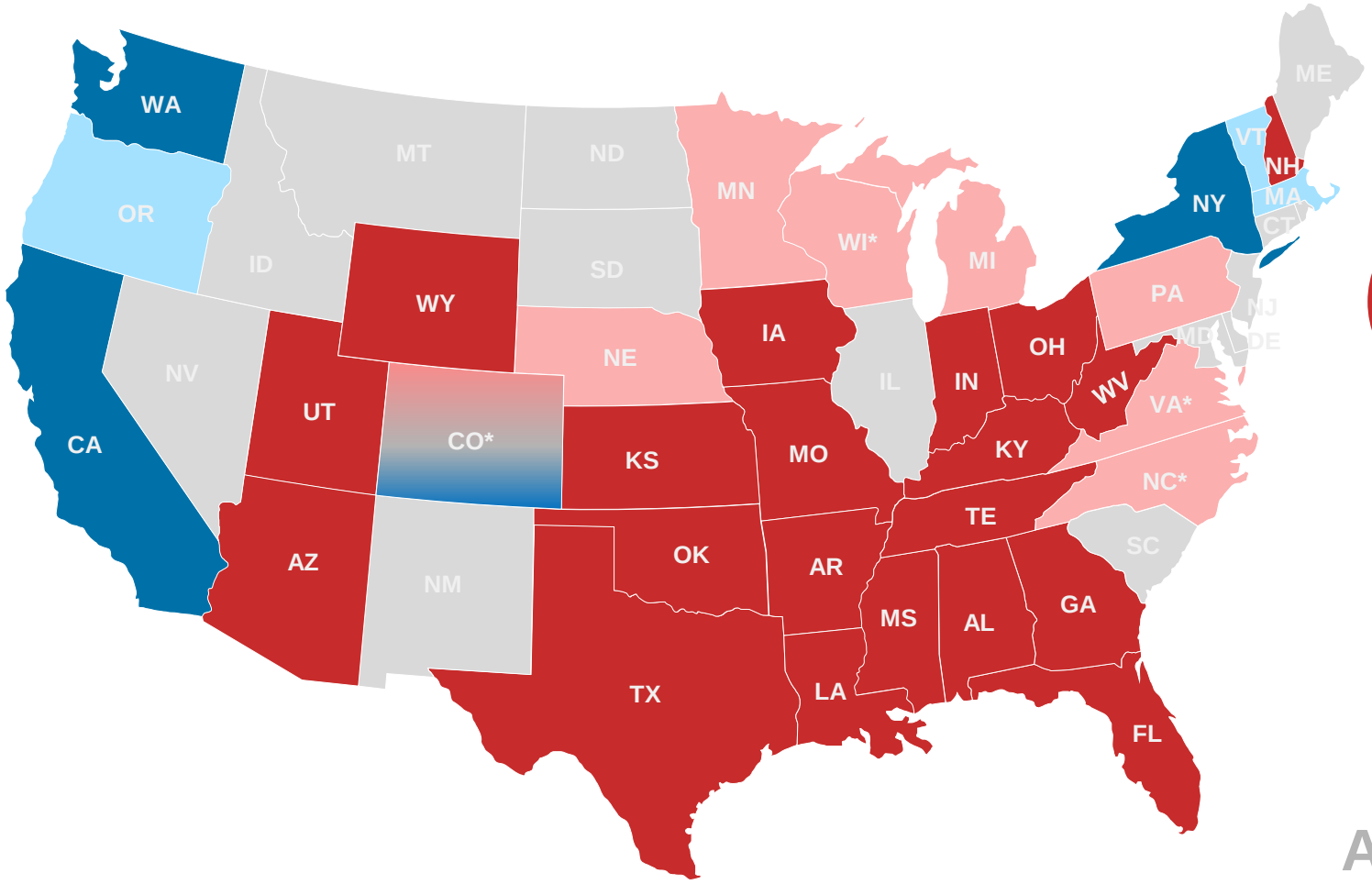
https://www.epa.gov/sites/default/files/2021-02/documents/benchmarking_building_performance_standards_section2.pdf

(as of Jan 2021)

# Gas Bans & Gas Ban 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 April 2022

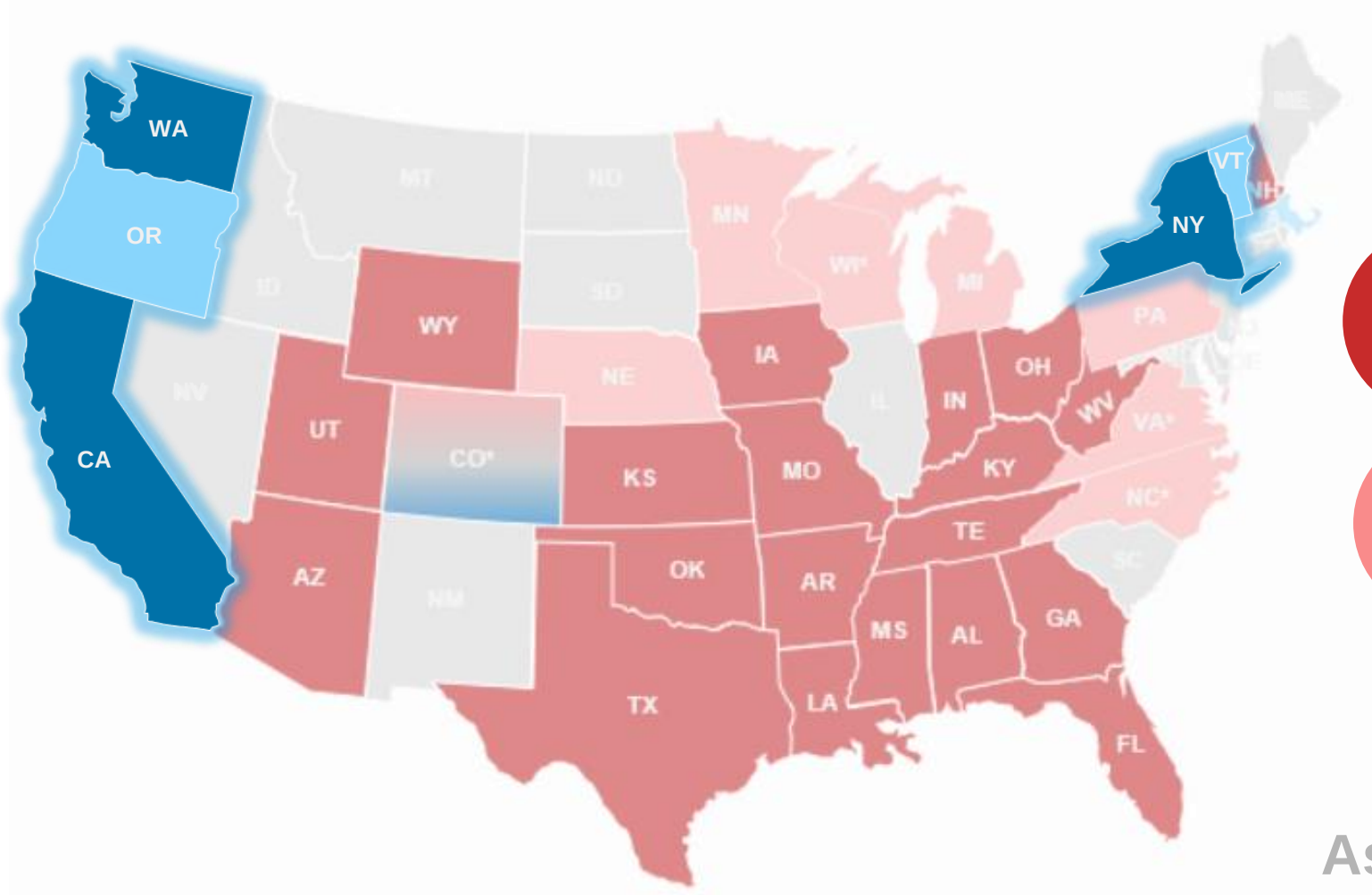
https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/states-that-outlaw-gas-bans-account-for-31-of-us-residential-commercial-gas-use-70749584

# Gas Bans & Gas Ban 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.**

**Local Gas Bans Passed**

**Local Gas Bans In Development**

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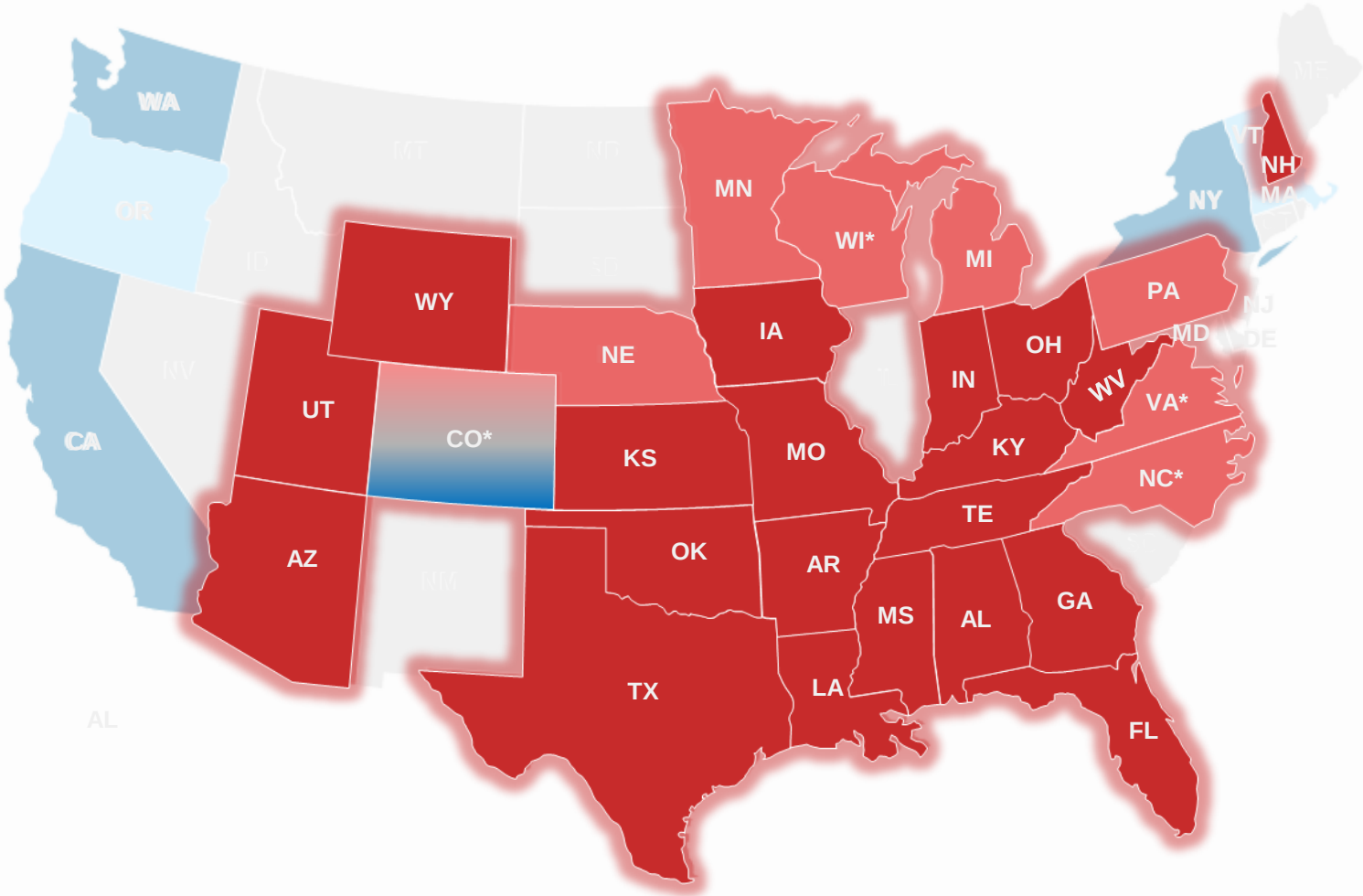
# Gas Bans & Gas Ban Bans

**On the opposite end of the spectrum, about 20 states have passed legislation that local governments cannot ban the use of natural gas at the local level, accounting for roughly 1/3rd of natural gas usage.**

**Local Gas Bans Passed**

**Local Gas Bans In Development**

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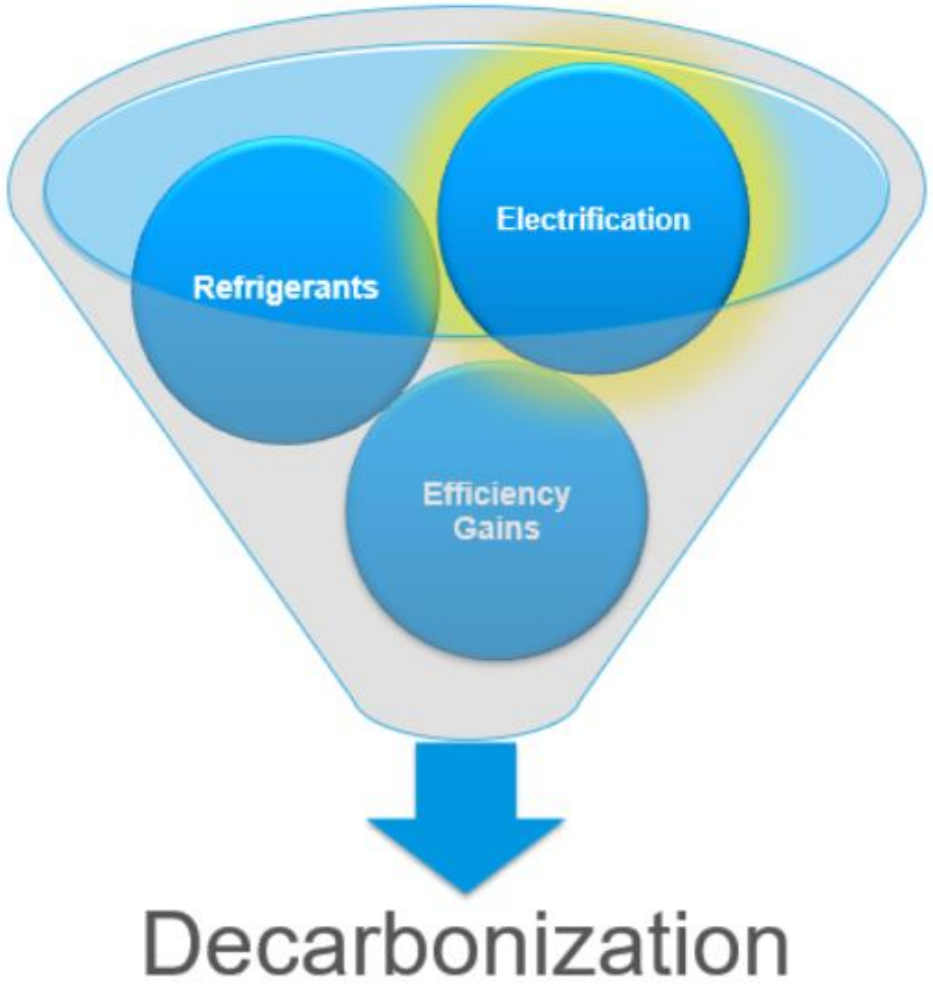
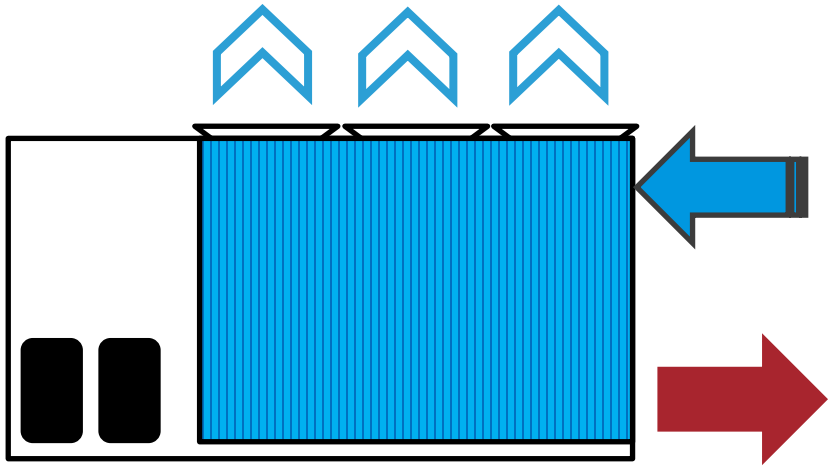
# ELECTRIFICATION



# Types of Heat Pumps

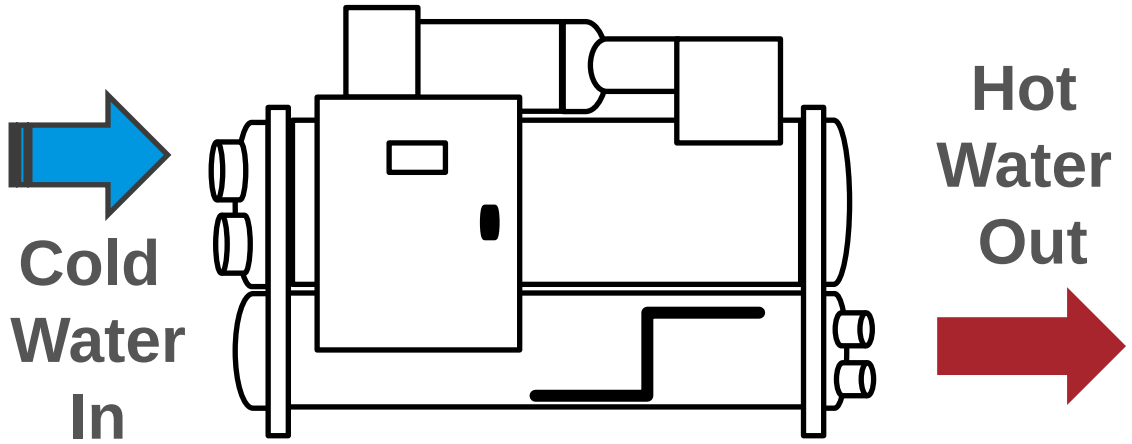
## *Air to Water* Heat Pump



Cold Air In

Hot water Out

## *Water to Water* Heat Pump

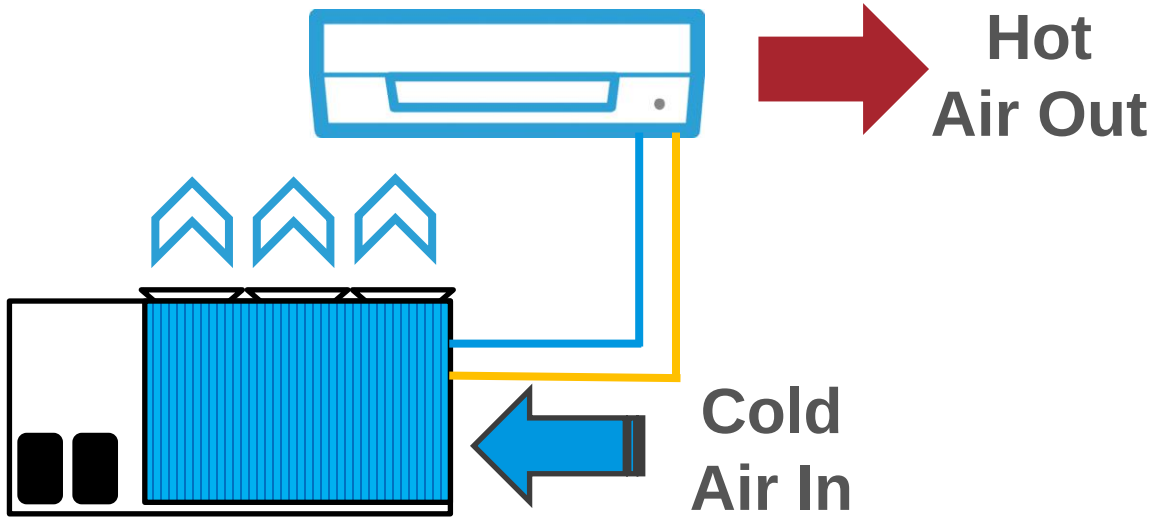


Cold Water In

Hot Water Out

# Heat Pumps Continued…

## *Air to Air* Heat Pump

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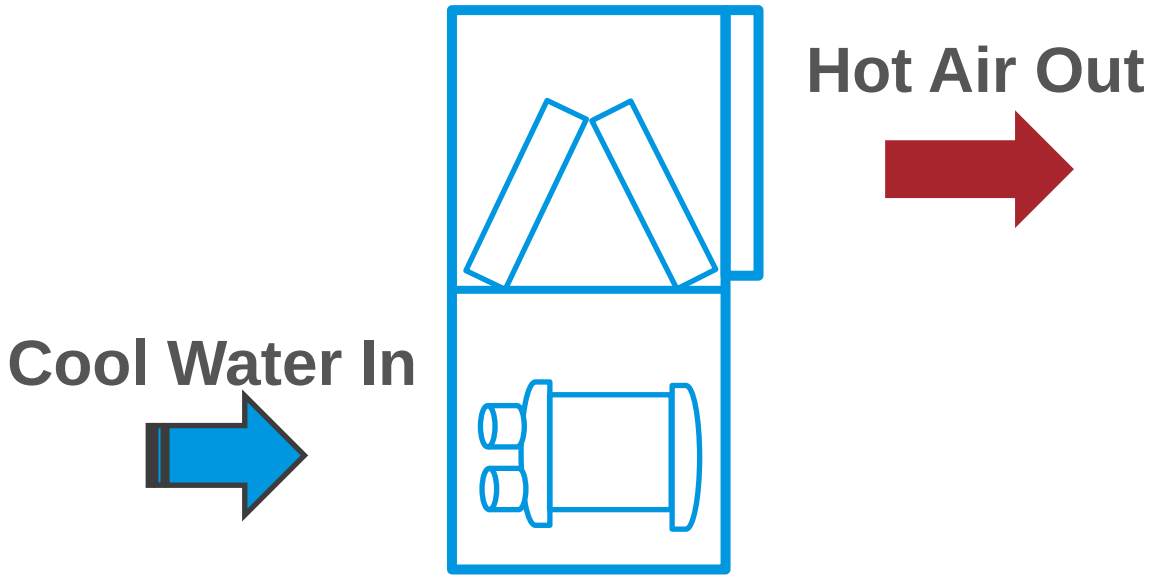
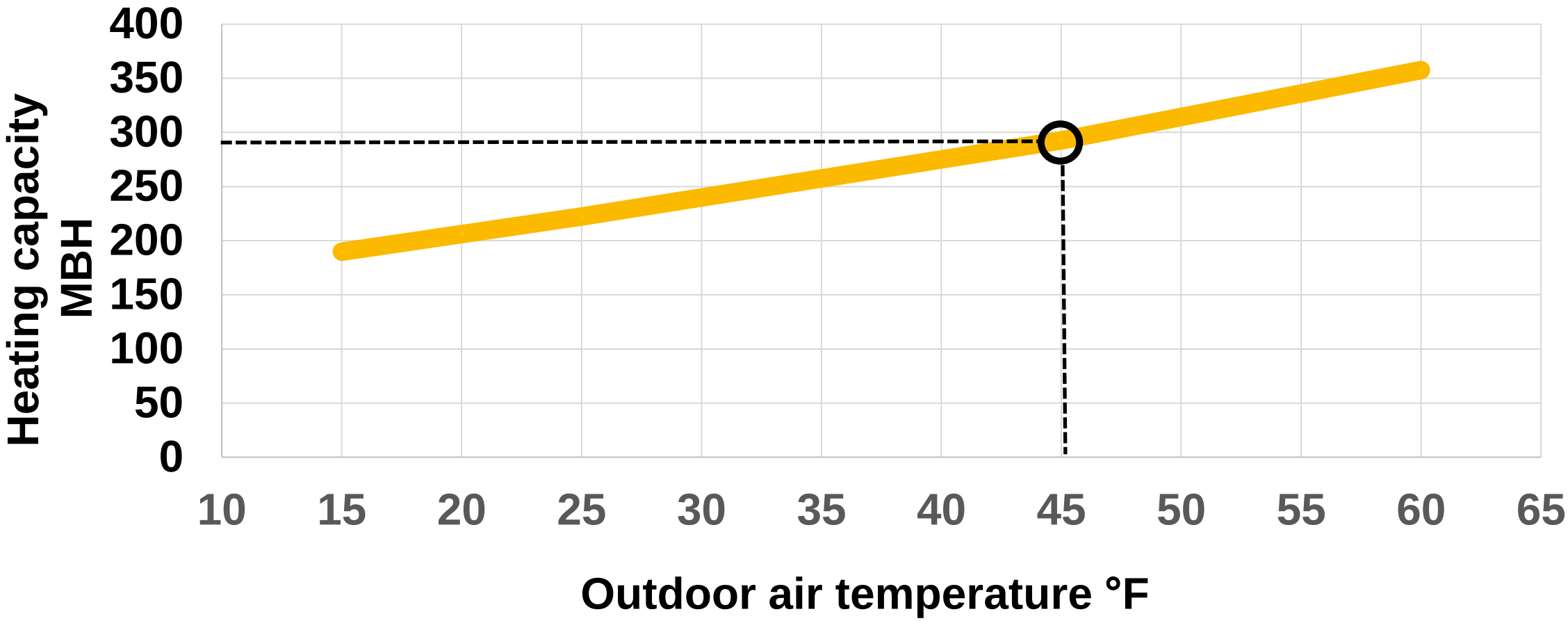


# Air To Water HP Capacity vs Ambient Temperature



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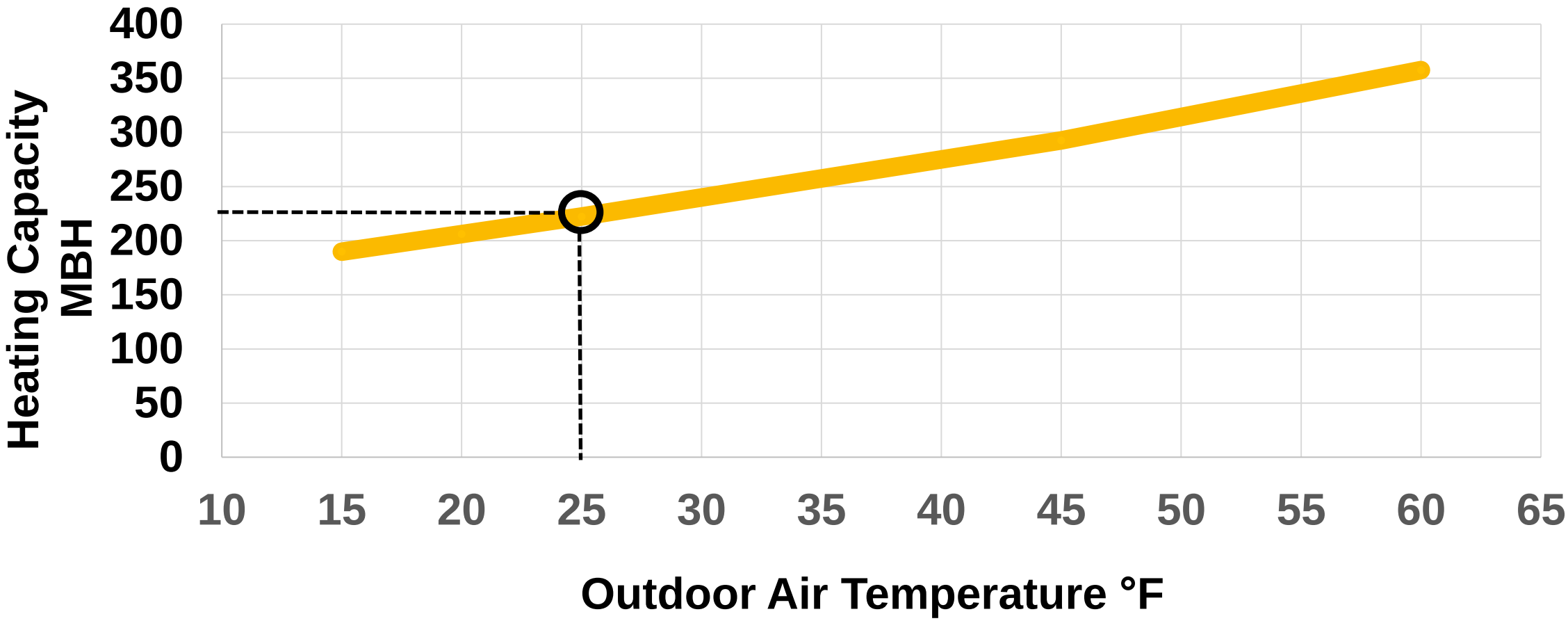

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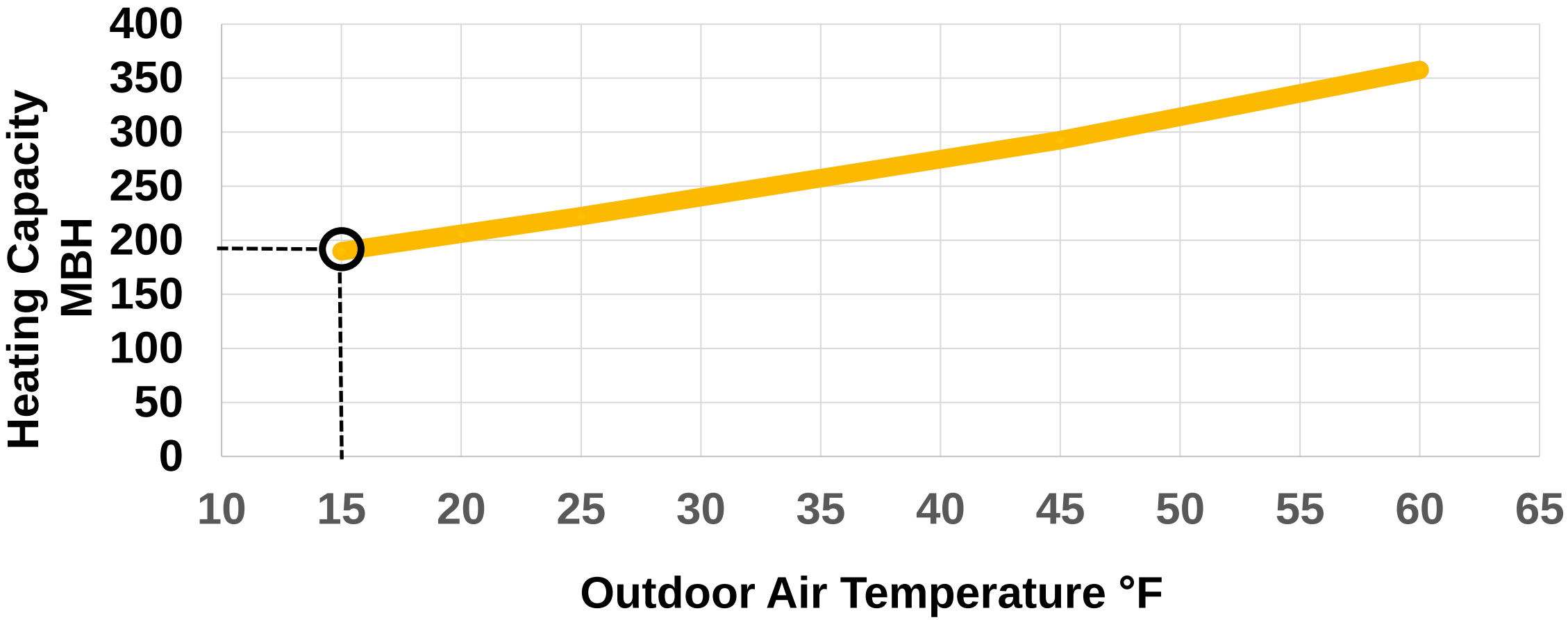
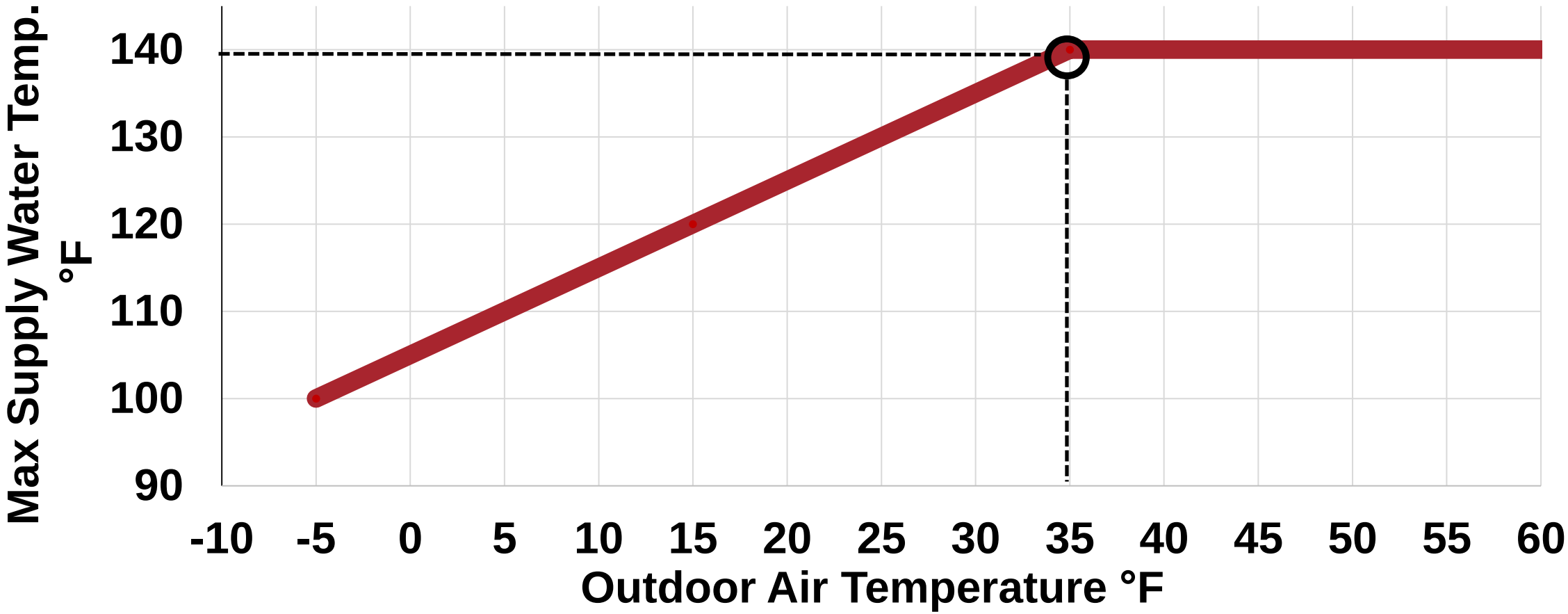


# Supply Temperature vs Ambient Temperature



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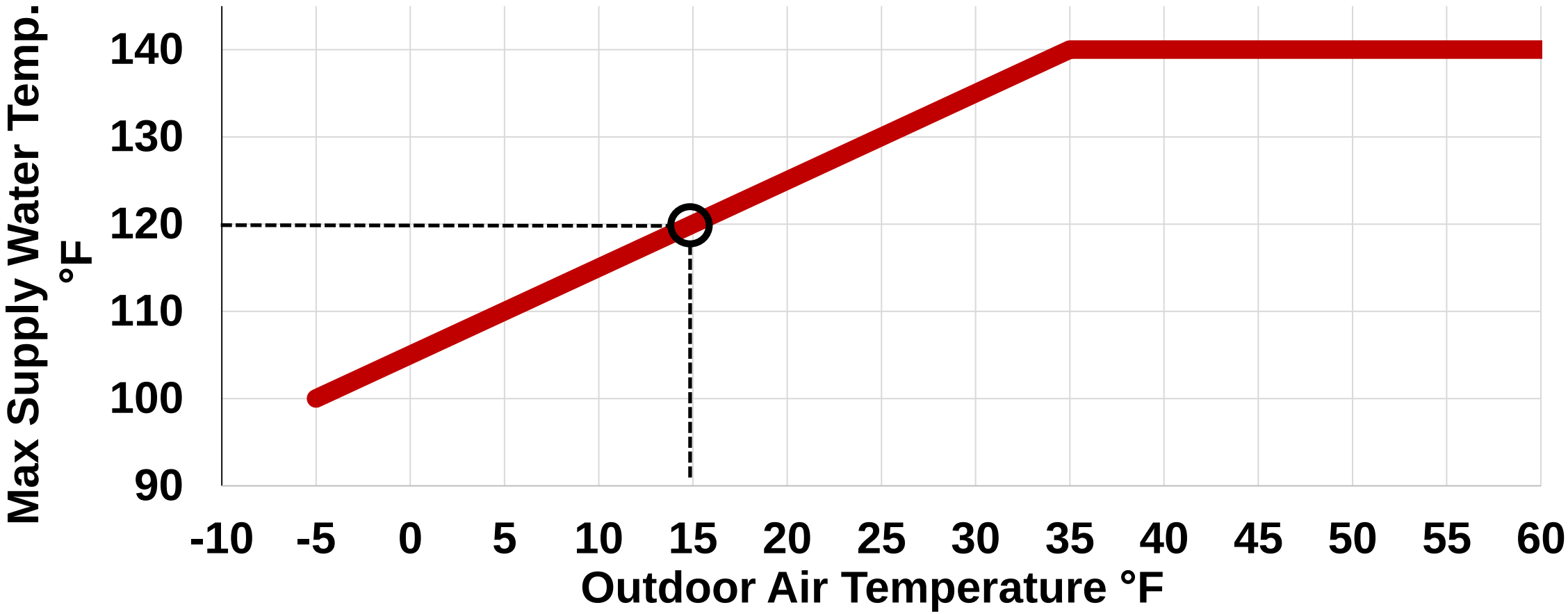

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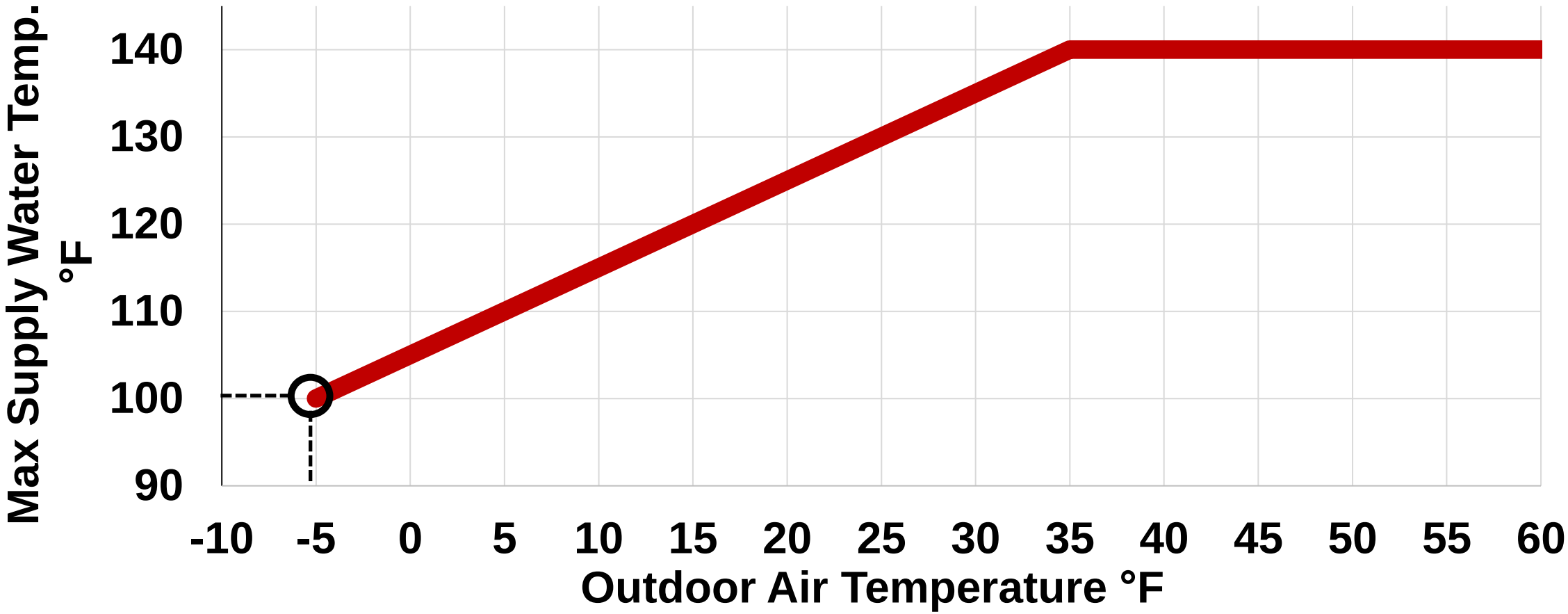
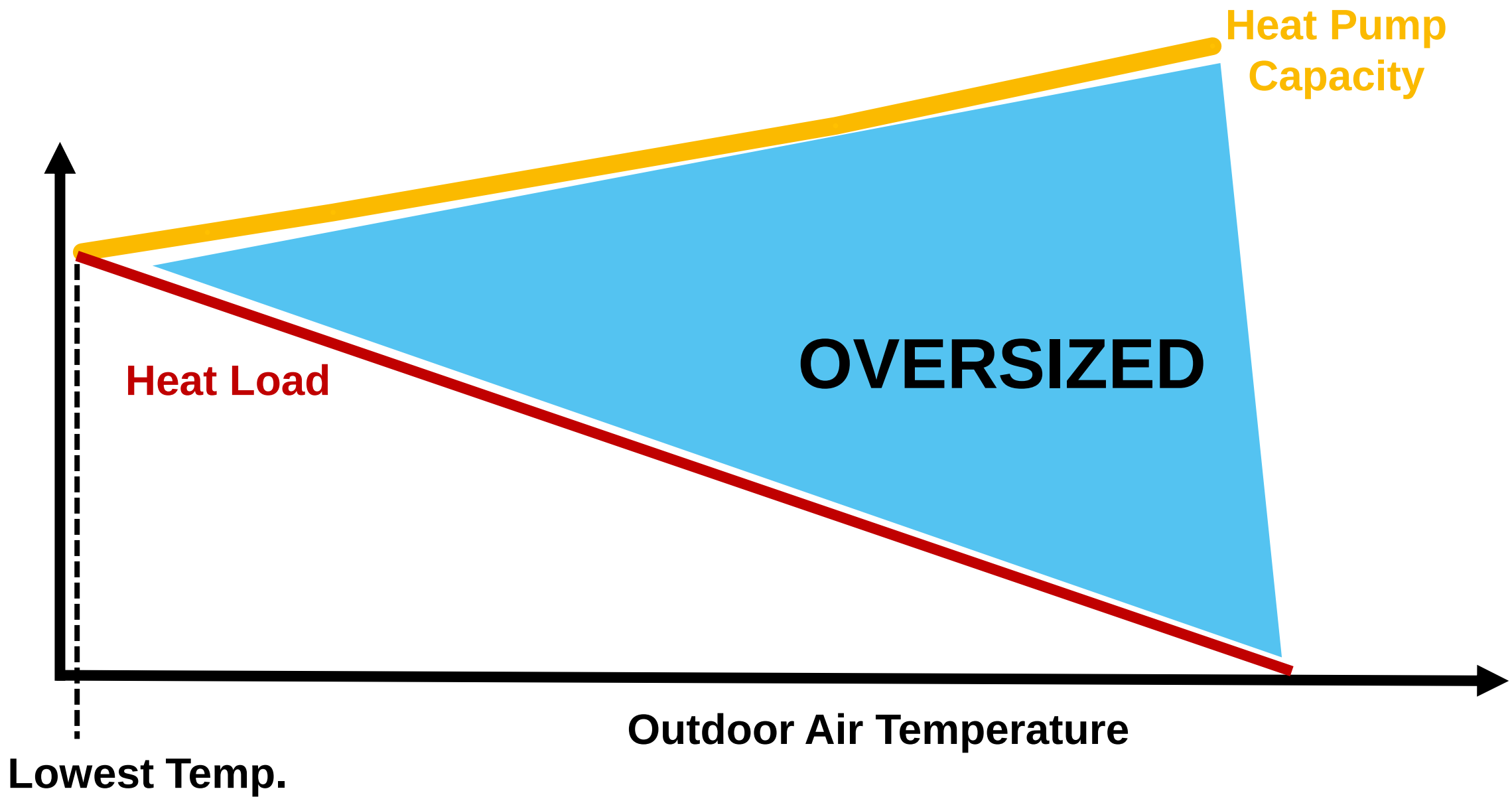
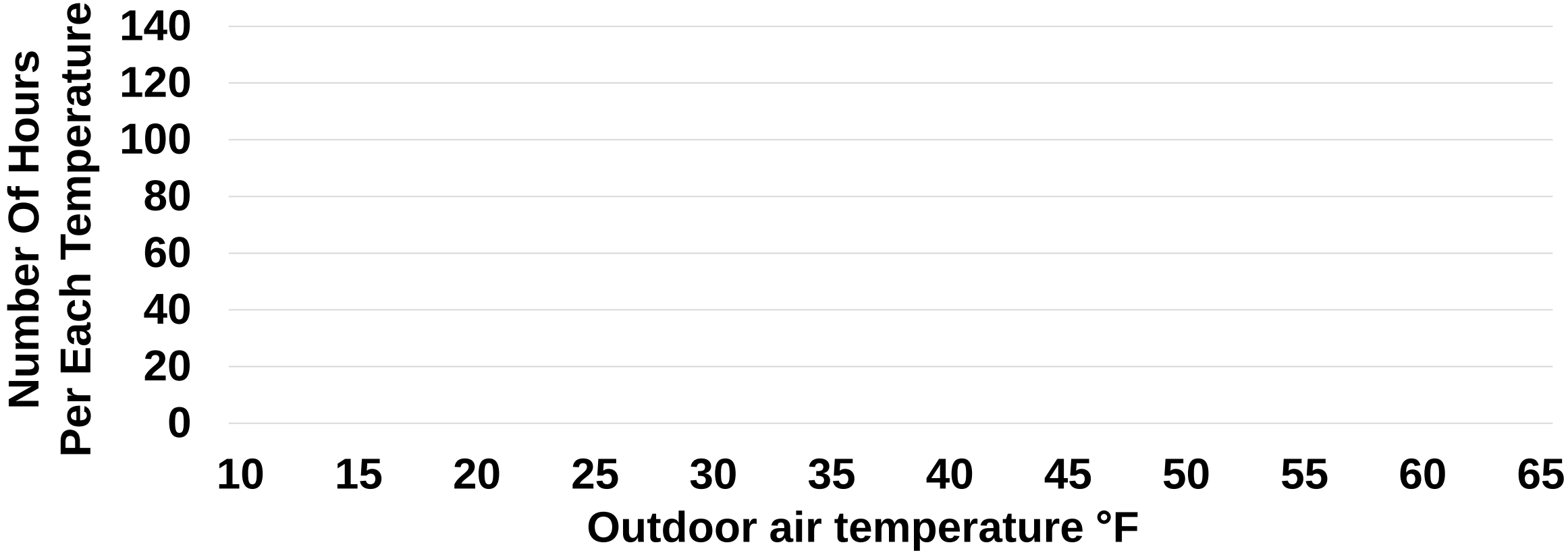


# How To Select

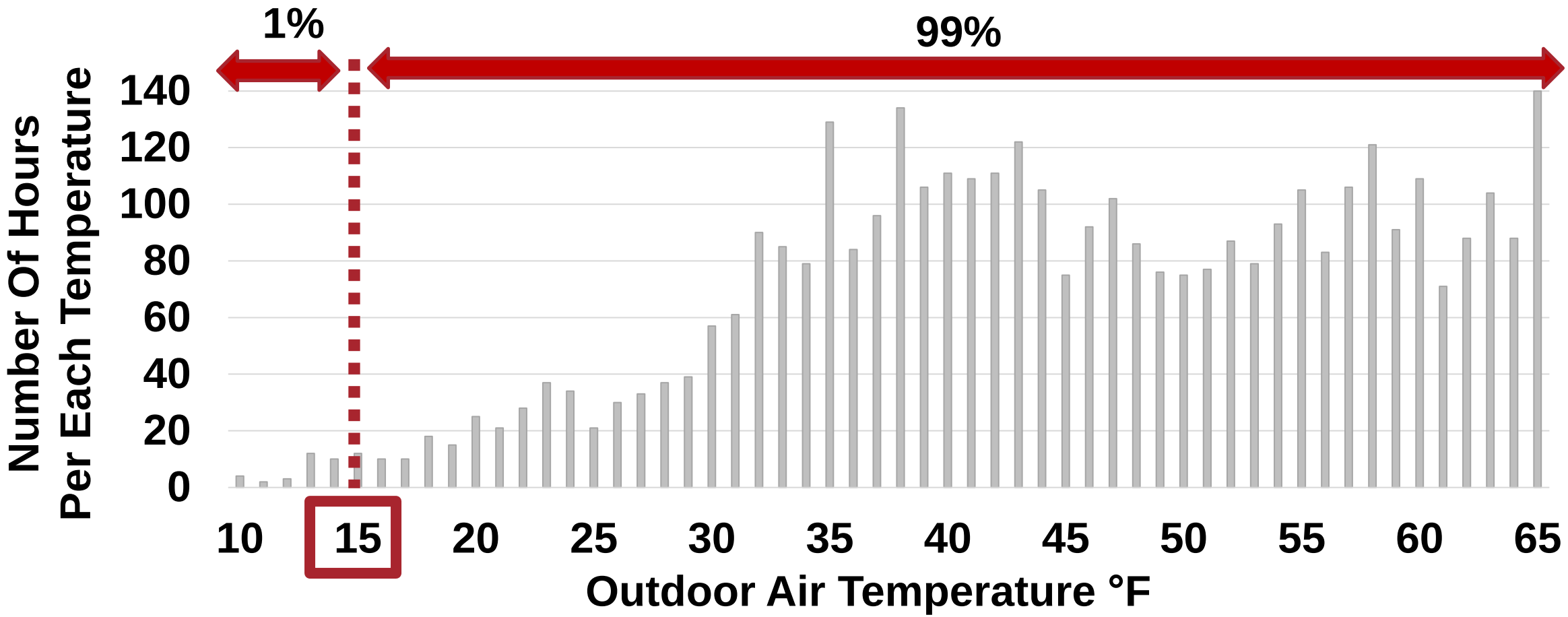


# Design Conditions

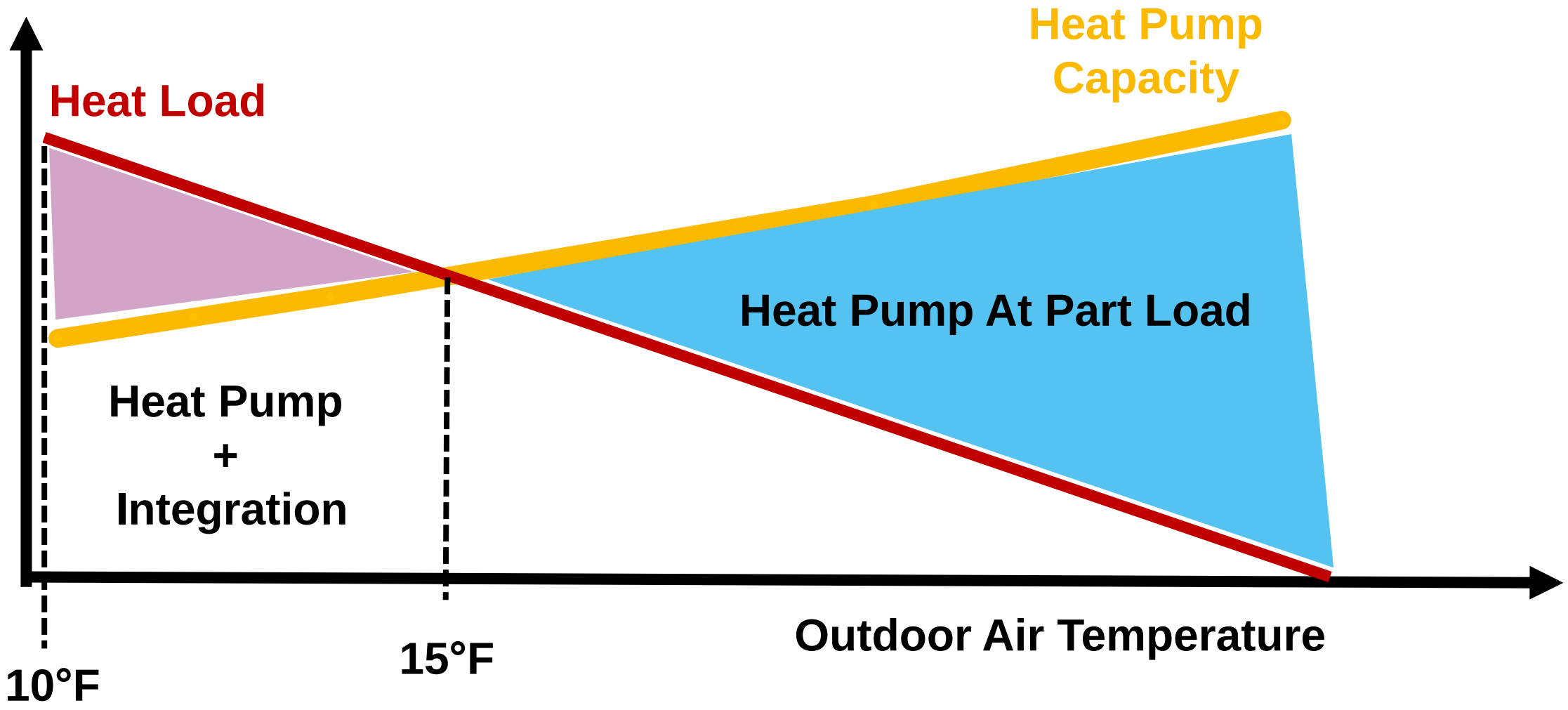


# Design Conditions

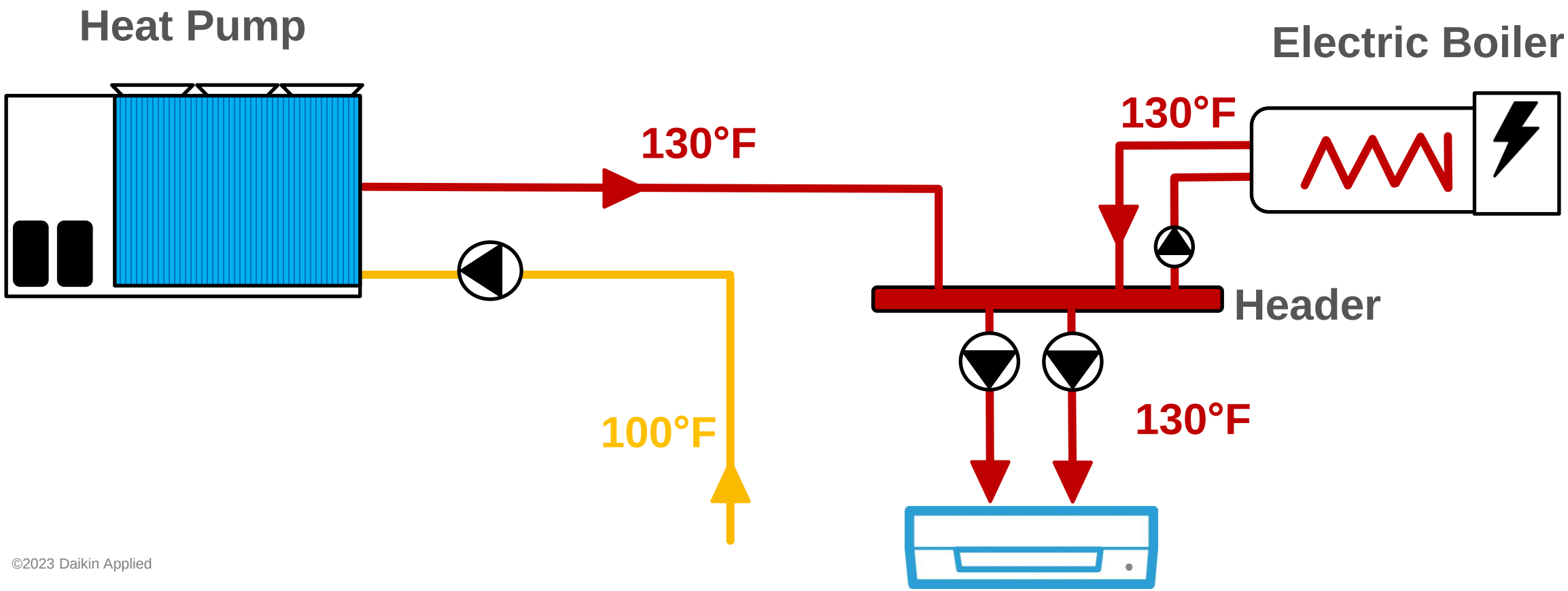
"Don't let the perfect be the enemy of the good"



# Selecting Heat Pumps



# Heat Pump Plus Boiler Integration



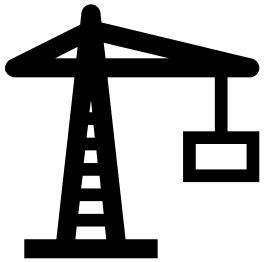
# COLD CLIMATE CONSIDERATIONS

# Lift, Ambient Temp, and Leaving Hot Water Temperature

- **Colder climates are a challenge for HPs**
  - Gas density
  - Motor cooling
  - Capacity / efficiency
- **Higher LWT Operation**
  - Reduces HP efficiency
  - Increases lift
- **To operate HPs in cold climates, you need to do any/all of these:**
  - Improve unit operating envelope
  - Boost capacity
  - Lower the hot water temperature
  - Share the lift
  - Reduce the load

Temp

Capacity



Load & Lift

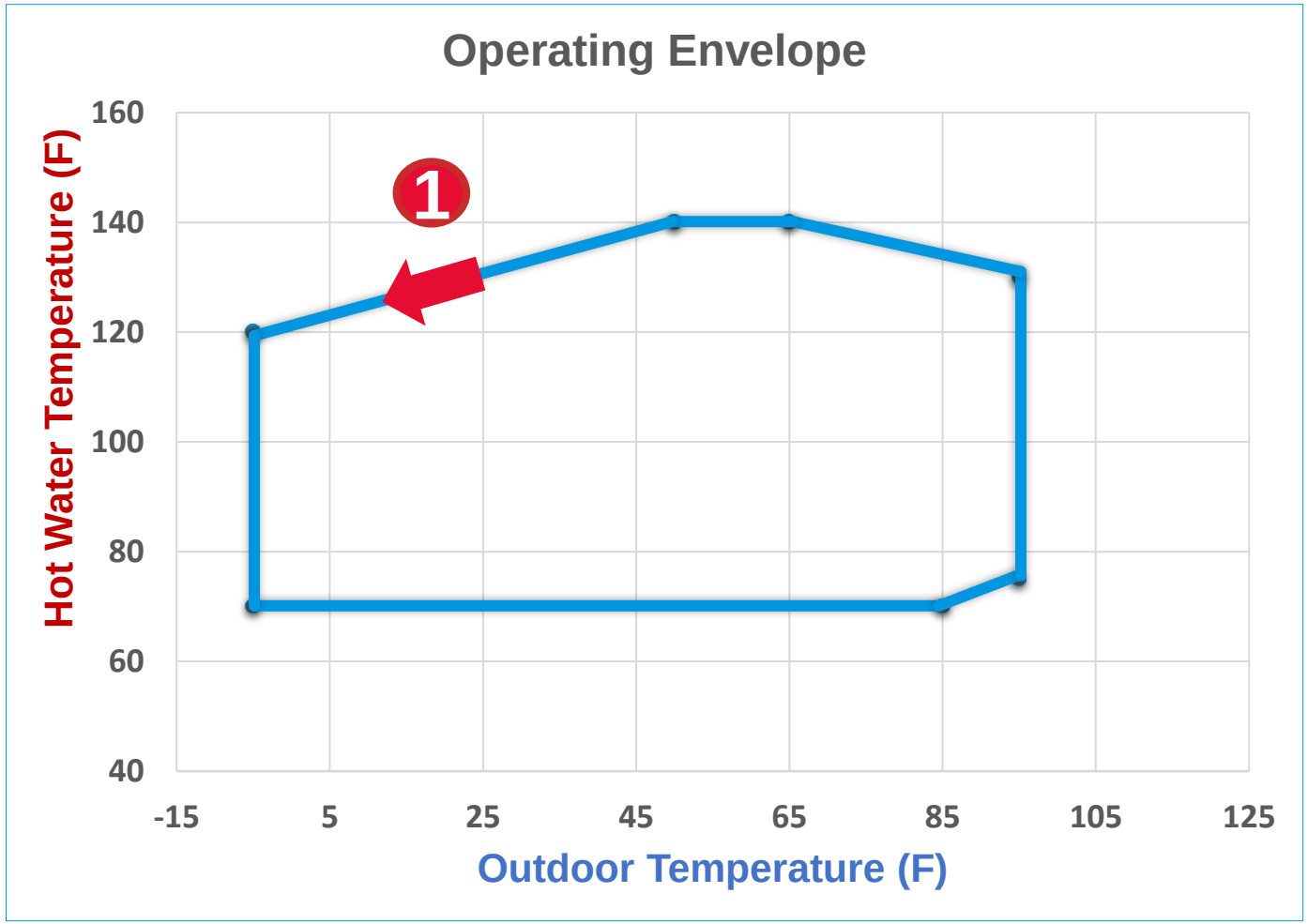
# Why Are Cold Climates Difficult For Heat Pumps?

- **Lower gas density and pressure**
  - Compressors capture and compress a certain volume of refrigerant per revolution
  - Lower refrigerant gas density reduces the mass moved per RPM; therefore, the mass flow rate / capacity is reduced
  - For refrigerant cooled motors, this also reduces motor cooling
- **Refrigerant choice**
  - Refrigerants must be able to have manageable pressures at the extremes of temperature
  - One size won't fit all
  - More than one refrigerant may be needed in a system (cascade system)
- **Increase in lift**
  - Higher lift = lower efficiency; lower capacity
- **Lubrication difficulty**
  - Difficult for standard fan motor bearing grease to work properly at extreme ambient temps


# Why Are Cold Climates Difficult For Heat Pumps?

- **Operating Envelope**
  - Function of:
    - Motor cooling
    - Discharge temp
    - Motor HP
    - Other factors
  - Each corner of the envelope is limited by a different set of considerations

The hotter the water we need to make, the sooner we reach the limit of minimum ambient temperature 1



# Why High LWT HPs Aren't The Perfect Answer

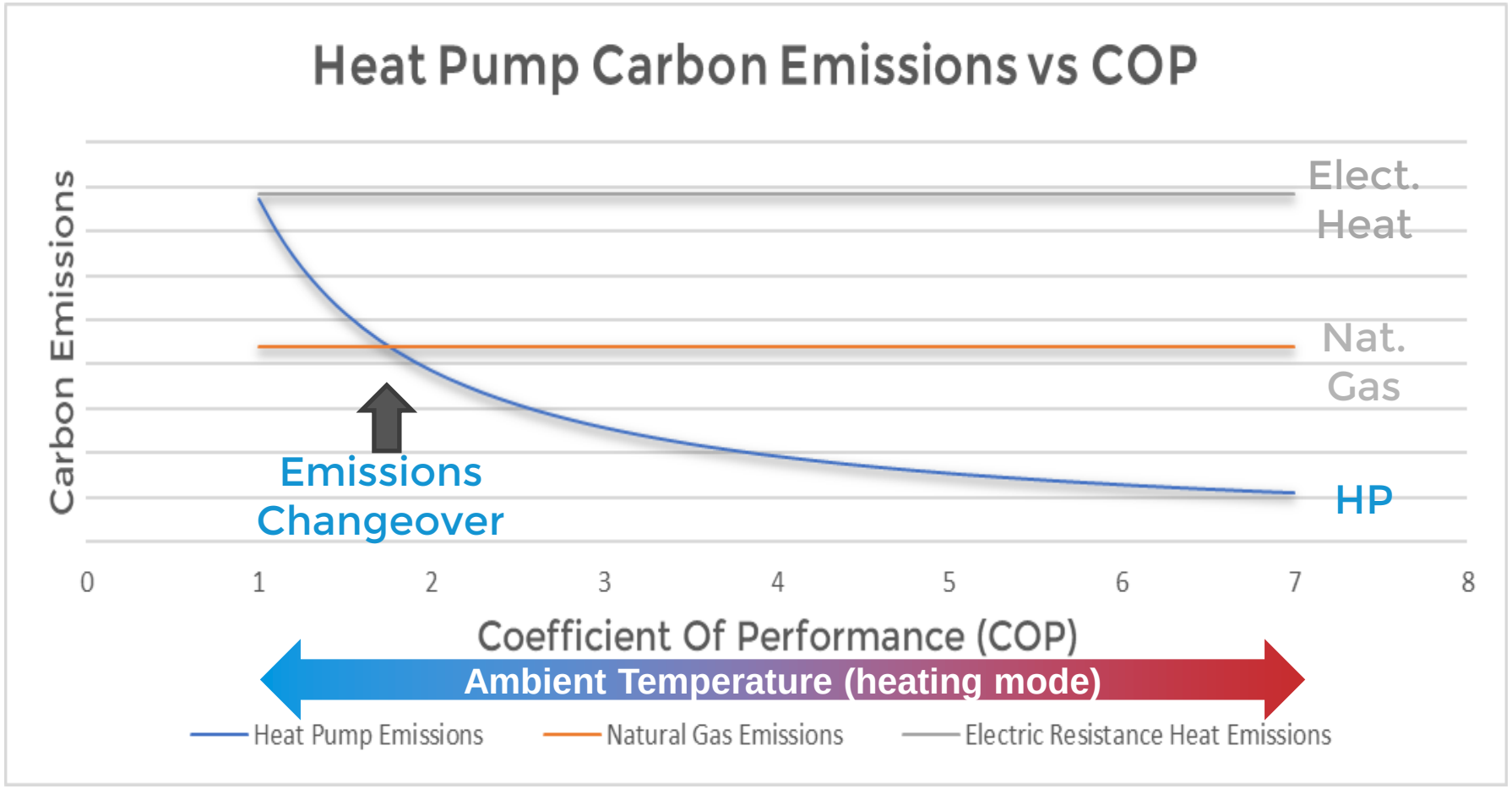
- **Historically, high heating water temperature wasn't such a big deal**
  - Limited impact on gas / elec resistance efficiency and reduces coil/pipe size
  - Many systems use 180F or warmer hot water, or even steam

- **Retrofitting these systems with HPs may be more difficult**
  - HPs are lift sensitive; the warmer the hot water, the worse the efficiency and capacity
  - Lower LWT is more efficient, but may require new pipe and heat emitters
  - Simply retrofitting high temp heat pumps may not be the best overall option if environmental concerns are a design goal

- **Not all HP systems are equally difficult to retrofit**
  - Rooftop units may be much easier to convert from gas to HP than high temp hot water systems
  - The main changes on RTUs are larger electrical service and unit size

# HP Emissions vs Gas

## Highly grid dependent, results will vary by location

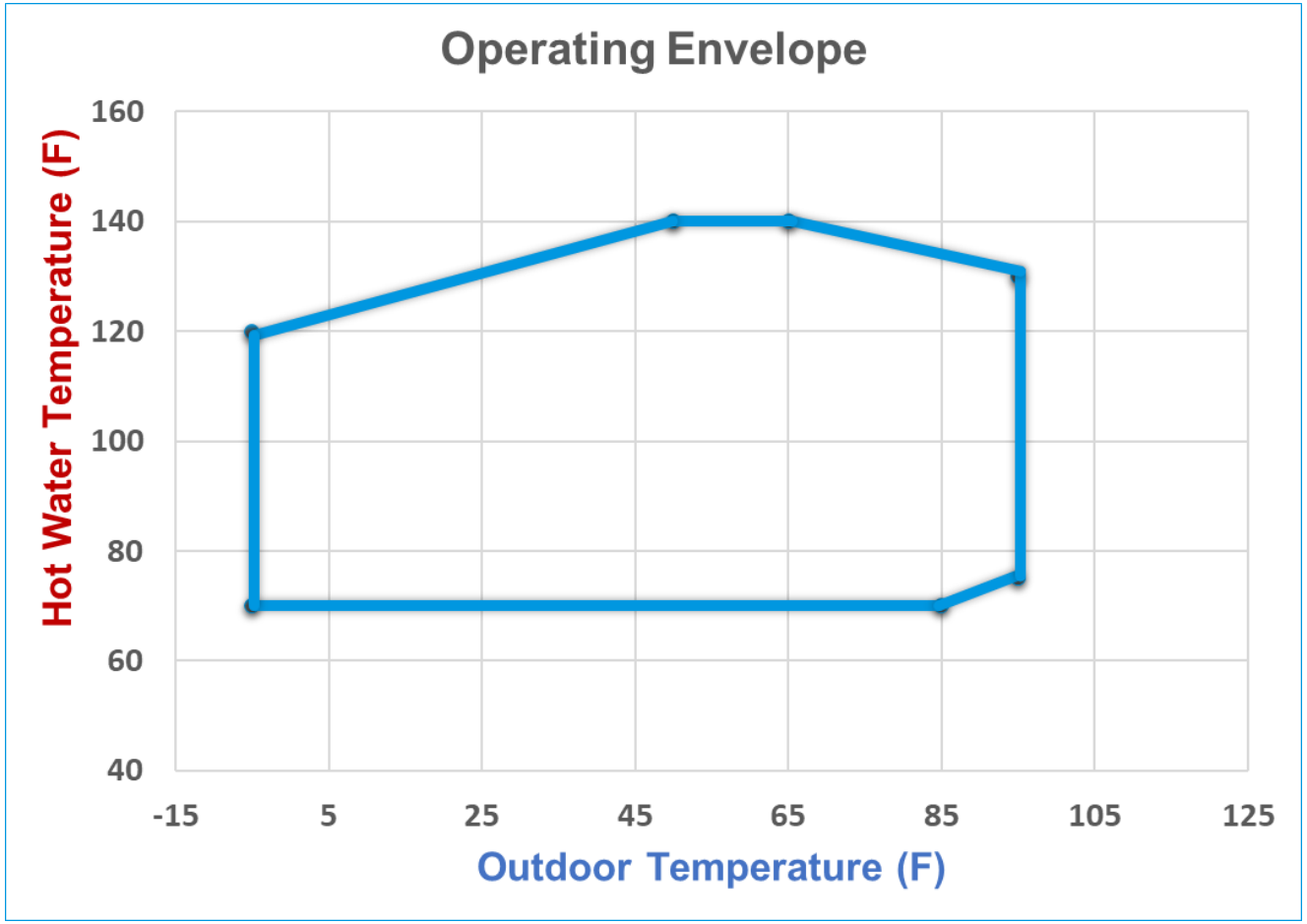



| Assumptions | |
|---|---|
| Natural Gas Efficiency: | 85% |
| Electric Resistance Efficiency: | 99% |
| Grid Emissions Factor: (gram/kWh) | 387 |
| Natural Gas Emissions (lbs/therm) | 12.1 |

# BOOSTING COLD CLIMATE PERFORMANCE

# Improving Operating Envelope

- **Inverters**
  - Boost speed to increase capacity at low temps
  - Boost unit efficiency
- **Compressor design**
  - Motor cooling & HP
  - Discharge temp management
  - Testing and controls
- **Refrigerant choice**
  - Pressure
  - Discharge temperature
- **Vapor injection**
  - Helps increase lift capability
  - Improve capacity



# Improving Capacity

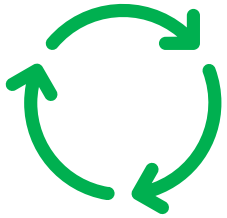
- **Inverters**
  - Overspeed at low temps
  - Reduced speed at normal temps to manage electrical draw / EER

- **Boiler / backup heat integration**
  - Avoid oversizing HPs for infrequent conditions
  - Heat source redundancy
  - Boilers relatively inexpensive, but electrical draw and utility demand charges should be considered for electric backup
  - With current electrical grid, gas emissions may be lower than electric heat

- **System design**
  - Share heat within the building
  - Reduce peak loads

# IMPACT TO HVAC SYSTEMS

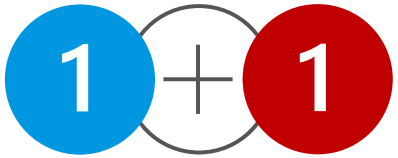
# HVAC Systems – Changes We May See



## System Efficiency &The Need To Share Energy

**Includes:**

- Heat recovery
- Hydronic Cascade
- Water-to-water or water-to-air HPs
- District systems
- Energy storage systems
- Ventilation reduction (IAQP)




## Dual-Fuel Integration

**Include:**

- Chiller HPs + Gas or Electric Boilers
- Rooftop HPs + Gas or Electric Heat
- Can an entirely electric solution be cost effective?

## Complexity Management

**Include:**

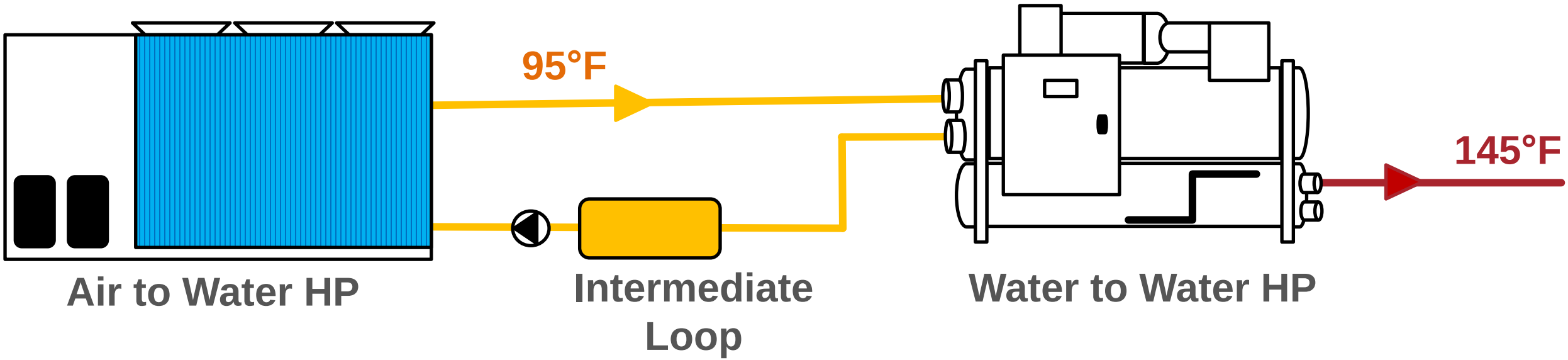
- Systems may grow in complexity as we drive to share energy
- Do we:
  - Hire and train more people to manage these complex systems?
  - Try to simplify through controls?
  - Move such systems out of the building to the district level?

# SHARING ENERGY MORE EFFICIENTLY – CASCADE AND DISTRICT SYSTEMS

# Cascade System

## Sharing the lift

- Improve A2W HP low ambient performance
- Share and store energy in the building for comfort or domestic hot water needs

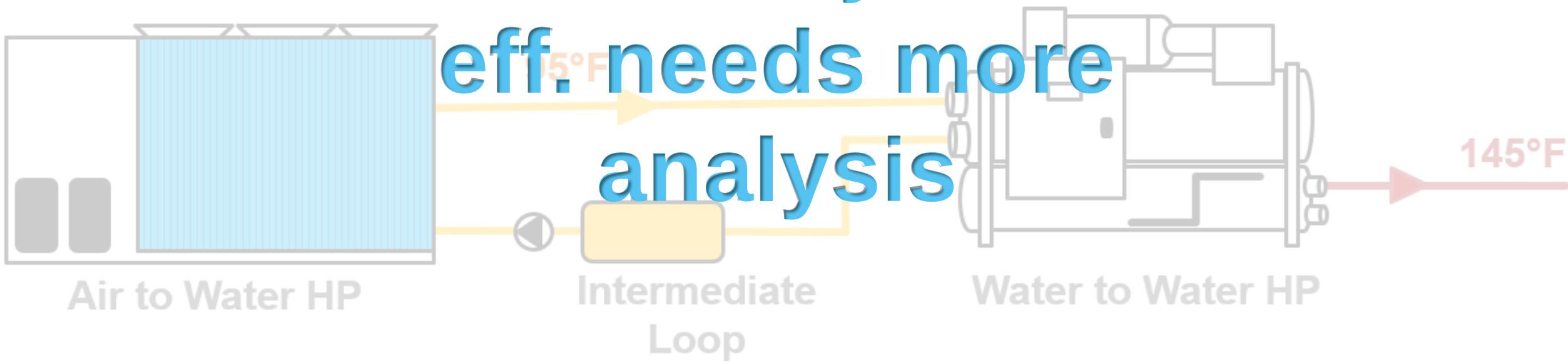


# Cascade System

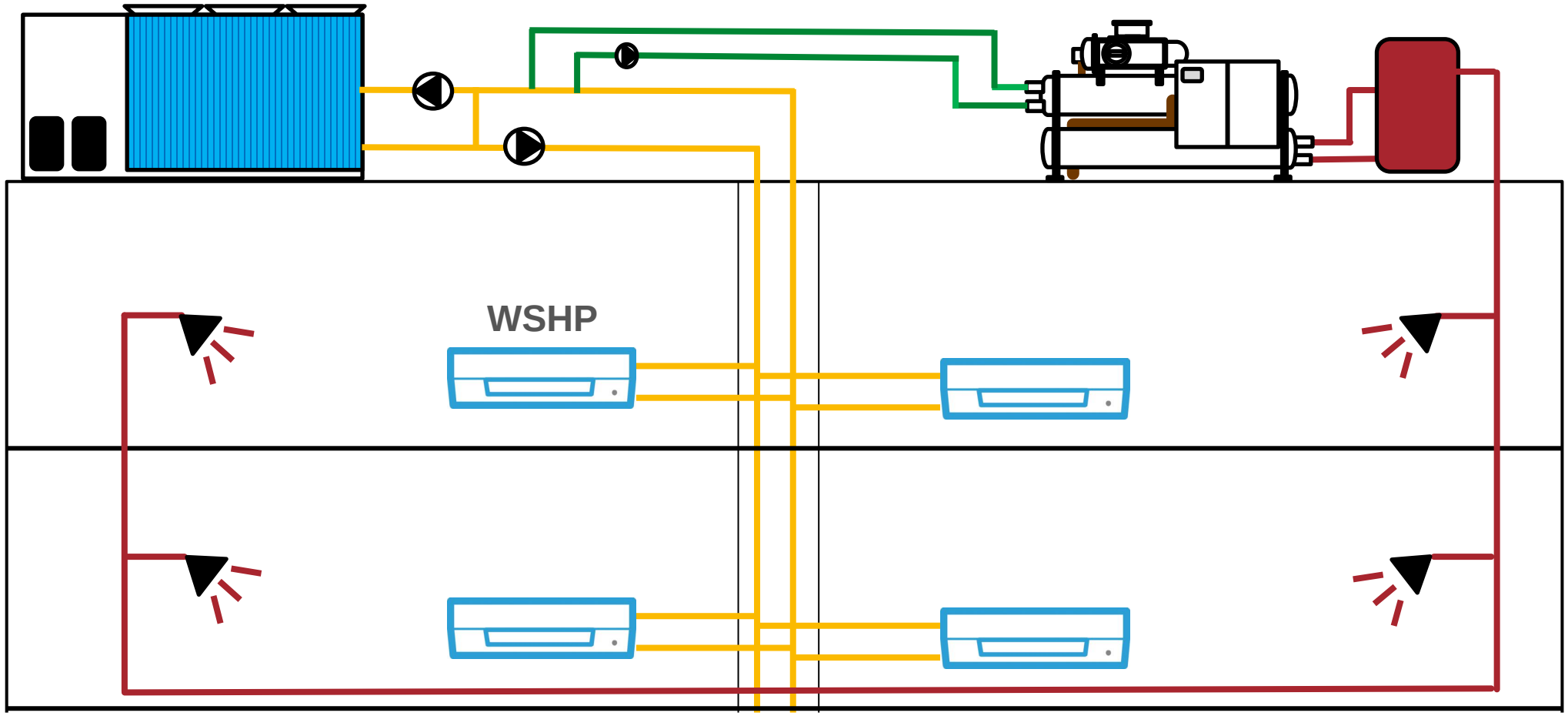
## Sharing the lift

- Improve A2W HP low ambient performance
- Share and store energy in the building for comfort or domestic hot water needs

**Overall system eff. needs more analysis**



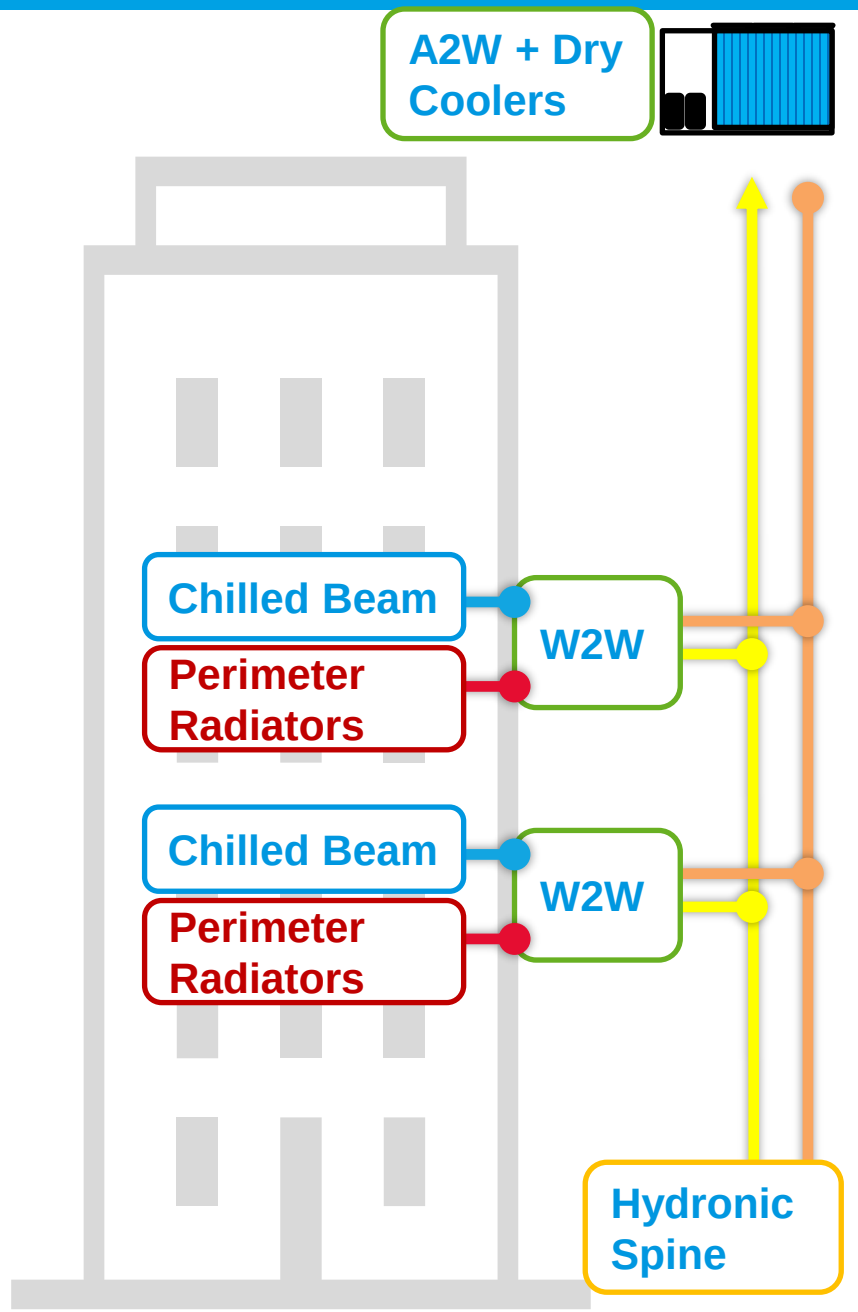
# Full Electric Centralized Solution For Comfort And DHW



# An Example Building - 345 Hudson Building – NYC

- **Deep energy retrofit to address building energy use and emissions**
  - Address building insulation and envelope
  - Cascade HP system
    - A2W HP + Dry Cooler: Serve as heat adder/remover with hydronic spine for entire building – share energy between floors
    - Floor by floor W2W HPs serving perimeter radiators for heating and chilled beams for cooling
    - Separate DOAS system to address latent load
- **Expected Outcomes:**
  - By 2032, 50% energy use reduction
  - 85% carbon emissions reduction
  - Peak heating and cooling loads reduced by 92 and 63%, respectively

Read more here: https://be-exchange.org/case_study/high-rise-low-carbon-partner-profile-345-hudson/



# Geothermal District Heating

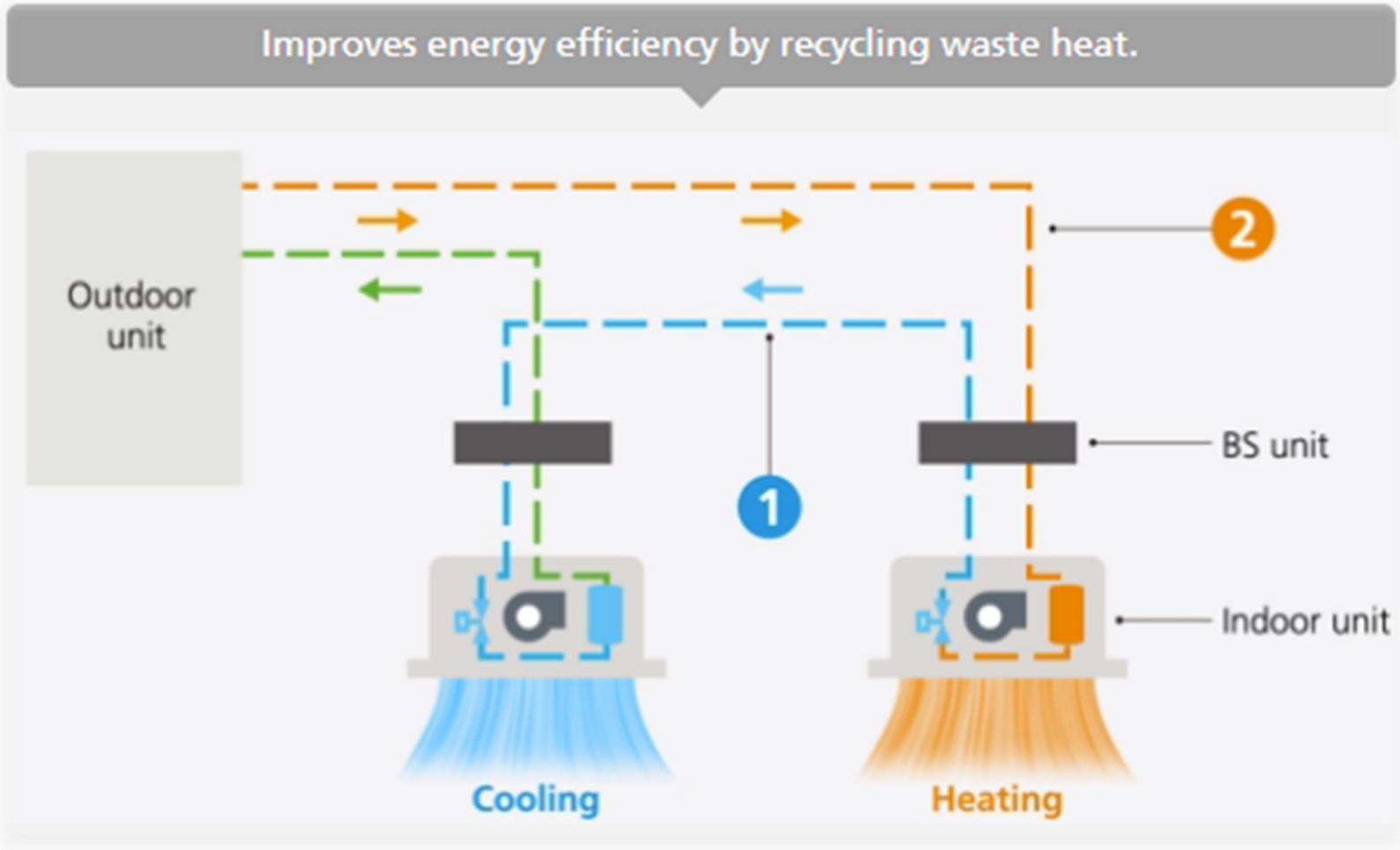
- **Avoids air source HP challenges**
- **Sharing heat between buildings**
- **Could combine with data centers for heating**
- **DOE Funding:**
  - $300,000–$13 million
  - projects that help communities design & deploy geothermal district heating/cooling systems



https://www.energy.gov/eere/geothermal/articles/community-geothermal-heating-and-cooling-design-and-deployment

# Heat Recovery VRF

- Allows sharing energy between zones
- Avoids losses of heat transfer between refrigerant and water
- Less feasible to store energy when loads are time shifted



# LOAD REDUCTION

# The Foundation: Building Envelope

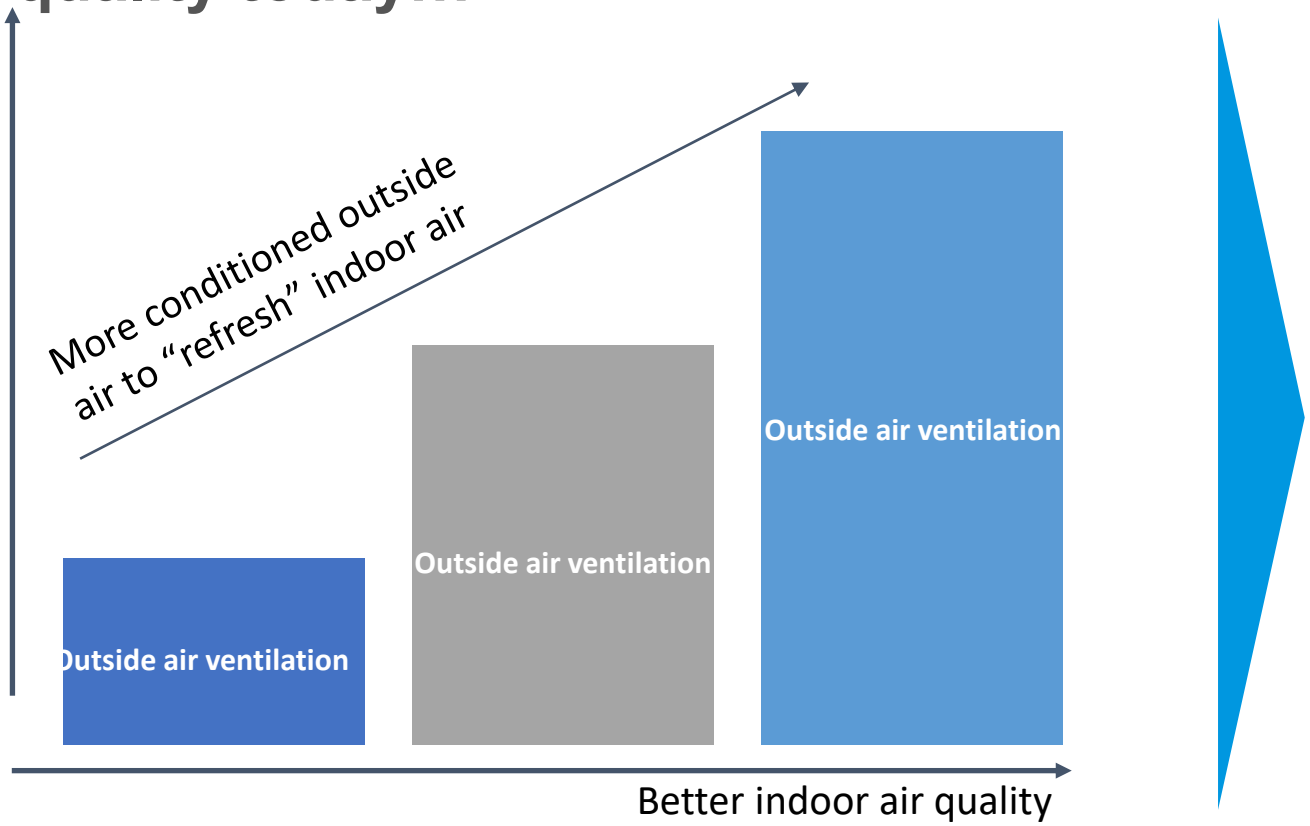
- **To reduce HVAC emissions, we need a solid foundation**
  - The most efficient way to heat or cool a building is to not need to heat or cool it
    - Good design
    - Envelope / sealing
    - Efficient windows

- **Controls to operate the building efficiently and effectively**
  - Design vs reality
  - Recommissioning

- **About 30-40% of HVAC load can be for conditioning ventilation air**
  - Addressing ventilation can yield reductions in load, equipment size, and emissions

# **IAQP:** More Outside Air = More Carbon Emissions and Cost

## How buildings ensure good indoor air quality today…




## …results in higher emissions & more cost

- Larger and more expensive HVAC systems
- Higher energy use and carbon emissions
- Increased operating costs
- What if the outside air is polluted?

**Relying on only outside air ventilation to deliver good indoor air quality is energy intensive and costly in many climates**

# ASHRAE Allows for Less Outside Air with Air Scrubbing

**ASHRAE Standard 62.1 includes two mechanical ventilation procedures:**

| | **Ventilation Rate Procedure (VRP)** | **Indoor Air Quality Procedure (IAQP)** |
|---|---|---|
| Methodology | Prescriptive:<br>Outside air based on area and occupancy without accounting for air cleaning. | Performance-based:<br>Outside air based on IAQ design targets and source-control and removal measures. |
| Indoor Air Quality | Depends on quality of outside air and any unusual indoor air contaminates. | Equivalent or better than VRP, especially when outside air is polluted or unusual contaminants. |
| Energy Intensity | Higher in many climate zones because IAQ is achieved using only outside air. | Often lower because a portion of the outside air may be replaced with cleaned indoor air. |

"**The IAQP may allow for a more cost-effective solution to providing good air quality**, as all design strategies may be considered and compared..."

*- Standard 62.1-2019 User's Manual, Pg. 100*

# ENABLING TECHNOLOGY

# Technology Enablers

| Challenge | Potential Technology/Solution Enablers |
|---|---|
| HP efficiency/payback | Inverter to improve efficiency |
| HP low ambient temp | Inverter to overspeed |
| Peak utility demand | Inverter to limit capacity or inrush, IAQP to reduce design capacity |
| Boiler substitutes | A2W or W2W HP in cascade or with expanded envelope |
| Rooftop defrost | Mixed air defrost or defrosting 1 circuit at a time |
| Energy cost of ventilation | Ventilation reduction with IAQP |
| System efficiency | Hydronic energy storage + HPs or geothermal district heating |
| System complexity | Controls solutions to simplify operation of complex, efficient systems, or district level heating/cooling |
| Footprint of A2W HPs | Geothermal or district systems, energy storage |
| High temperature boilers | Replace coils with larger to use lower LWT, cascade and electric resistance boost |

# Wrapping Up!

- **3 main enablers of Decarbonization in HVAC systems**
- **Legislative drivers**
- **HVAC Systems will need to change**

**To operate HPs in cold climates:**

- **Improve unit operating envelope**
  - Compressor design & refrigerant choice
- **Boost capacity**
  - Inverters to overspeed and improve COP
  - vapor injection
  - Reduce the load though envelope and ventilation design (IAQP)
- **Lower the hot water temperature**
- **Share the lift**
  - Cascade systems & backup heat

# THANK YOU!

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