BURO HAPPOLD

V1 | November 2021

Engineering All-Electric Buildings

Our Commitments

Global Sustainability Report (2021)

Download Here

> Buro Happold is clear in its mission to be recognized as a leader in sustainability. We must focus on delivering a sustainable and equitable built environment, delivered with the power of collective action across our industry.

Duncan Price

Partner and Global Sustainability & Climate Change Lead

Buro Happold

Reduce **our own operational carbon** emissions by 21% by 2025.

Design all **new build projects** to be net zero carbon in operation by 2030.

Reduce **embodied carbon** intensity of all new building, major retrofits and infrastructure by 50% by 2030.

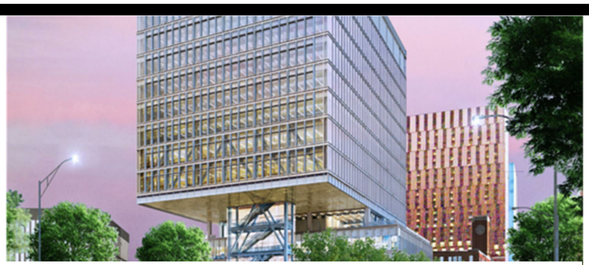
Our Portfolio

*CZ = Climate Zone

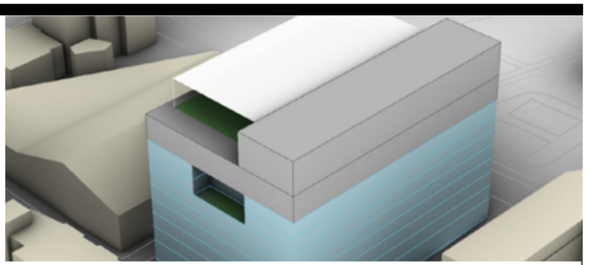
ALL-ELECTRIC READY

Office/Lab, CZ5
200,000 ft^2

Office/Lab, CZ5
900,000 ft^2



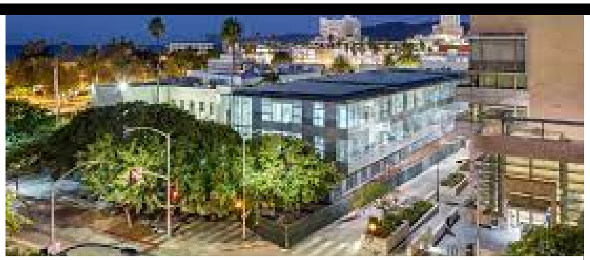
Office/Lab, CZ5
388,000 ft^2



Office/Lab, CZ4
520,000 ft^2

ALL-ELECTRIC

Office/Lab, CZ5
694,000 ft^2

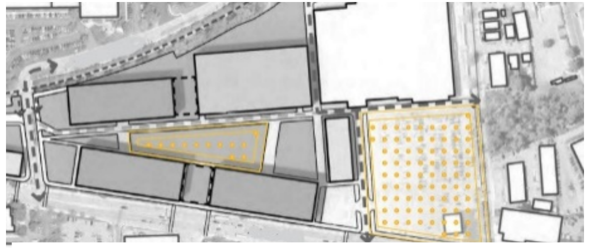


Office, CZ3
50,200 ft^2, ILFI LBC Certified

Educational Building, CZ1
7,000 ft^2, ILFI LBC Certified

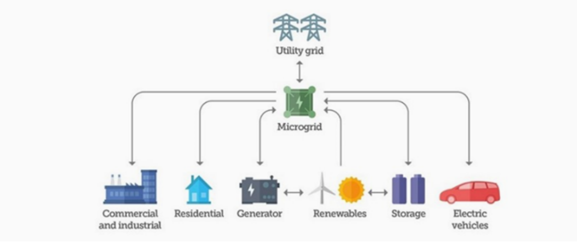
Educational Building, CZ5
9,000 ft^2, ILFI LBC Certified

ZERO CARBON MASTERPLAN



Masterplan, CZ5
1,200,000 ft^2

Masterplan, CZ5
2,900,000 ft^2



Masterplan, CZ5
5,600,000 ft^2

Masterplan, CZ1
9,600,000 ft^2

Our Climate Action Agenda

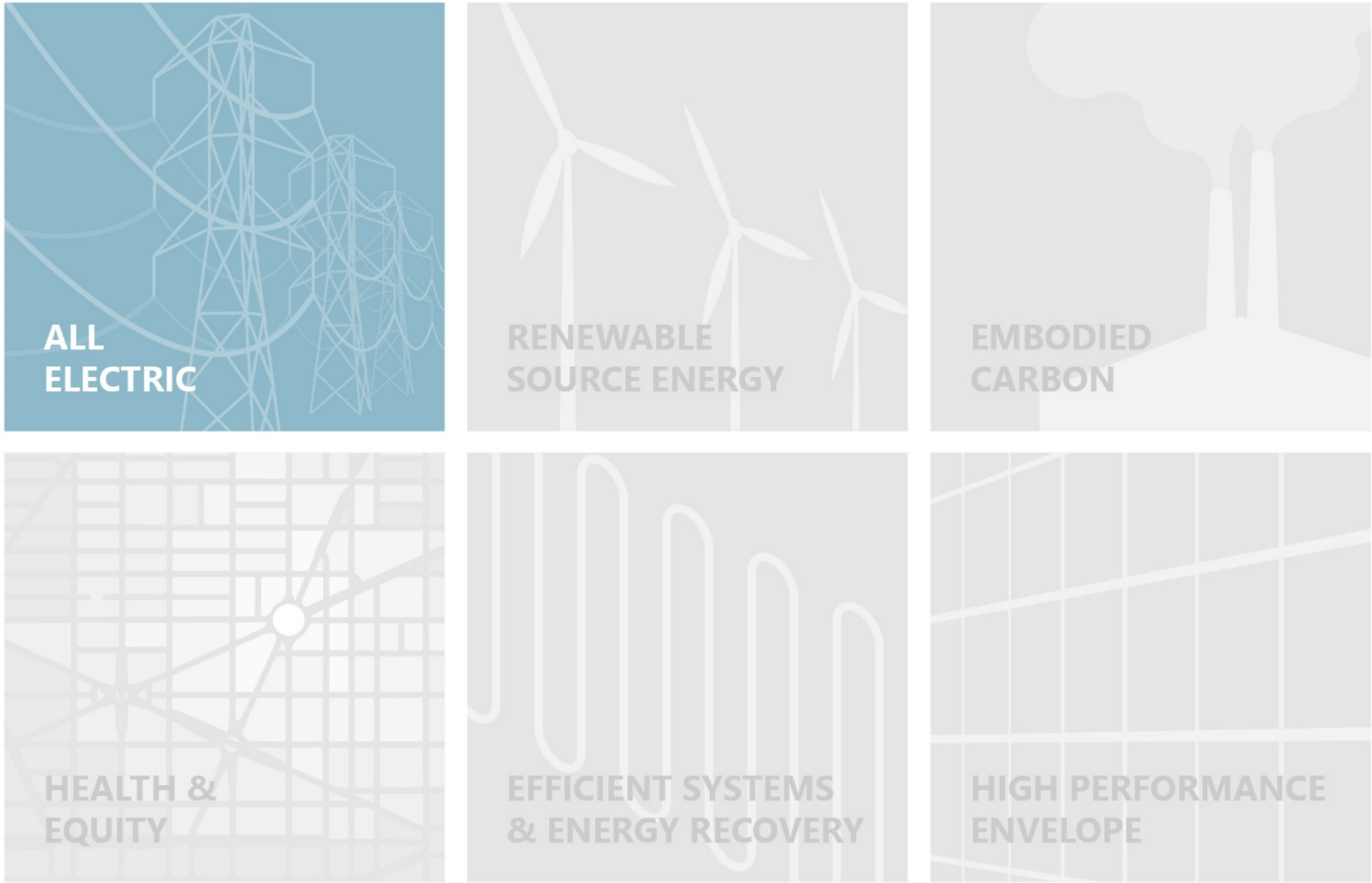
Aggressive decarbonization in the built environment is needed to reduce greenhouse gas emissions.

An important solution to support this goal:

All-electric buildings connected to electrical grids supplied by renewable energy sources.

To make this happen, high-performance envelopes, heat recovery, system resiliency, and heat pumps are critical strategies. Together, these readily available and cost-effective solutions will reduce or eliminate any additional strain to the electrical grid.

This study illustrates our holistic engineering evaluation of and approach to all-electric buildings.



Building Electrification Goals

GHG Emissions

Eliminate operational GHG emissions from the built environment

Grid Resiliency

Reduce stress on the grid in heating season, and ensure back-up power

Technology

Explore proven and innovative technology to replace fossil fuel systems

Cost

Limit present and future cost impacts to the project

A preliminary study of new construction typologies in various US cities to inform engineering solutions in support of decarbonization goals in the built environment:

What is the feasibility of all-electric buildings across climate zones and sectors?

Study Parameters

5 Locations

Boston

Los Angeles

Detroit

New York City

San Francisco

4 Sectors

Residential

Office

Laboratory
(with humidification)

Higher Education

3 Envelopes

90.1 2010

90.1 2019

High Performance

3 DHW

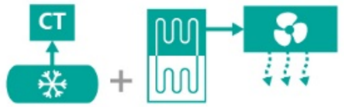
Condensing Boiler

Electric Resistance

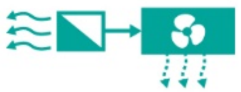
Heat Pump

4 HVAC

FF1



EL1



EL2

EL3

Many Constants

Square Footage

Window-to-Wall Ratio

Lighting Power Density

Equipment Power Density

Humidification

Infiltration

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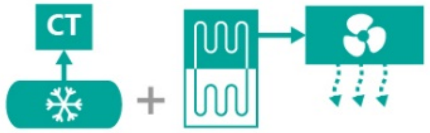
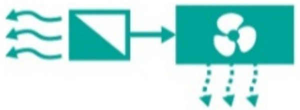
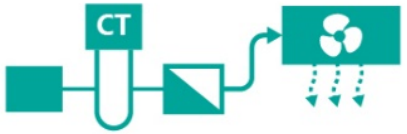
Terms

ASHP	Air-Source Heat Pump
COP	Coefficient of Performance
DHW	Domestic Hot Water
EUI	Energy Use Intensity (kBtu/ft^2)
FCU	Fan coil unit
FF	Fossil Fuel
GHG	Greenhouse Gas (emissions)
HPCH	Heat Pump Chiller
MEP	Mechanical, Electrical, Plumbing
RPS	Renewable Portfolio Standard
SHGC	Solar Heat Gain Coefficient
VRF	Variable Refrigerant Flow system

HVAC Systems

FF1	Fossil Fuel System 1: Water-cooled centrifugal chiller, Condensing gas boiler	
EL1	All-Electric System 1: Water-cooled centrifugal chiller, Heat pump chiller, Supplemental air-source heat pumps	
EL2	All-Electric System 2: Air-source VRF with heat recovery	
EL3	All-Electric System 3: Water-source VRF with heat recovery, Electric resistance supplemental heat injection	

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Greenhouse Gas Emissions

Why are all-electric buildings important?

- Buildings account for **40%** of GHG emissions globally
- **Zero** greenhouse gas emissions (GHG) can be accomplished with low-energy, all-electric buildings connected to an all-renewable grid

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Key Design Considerations

1

Assess current grid GHG factors

Grid carbon factors vary by location, due to different methods of energy generation and different GHG emissions policies

2

Design high performance envelopes

High performance envelopes reduce heating/cooling demands; Electrifying heating and DHW systems in cold climates requires high performance facades

3

Design radically low energy systems

High-efficiency technology and heat recovery solutions will improve performance

4

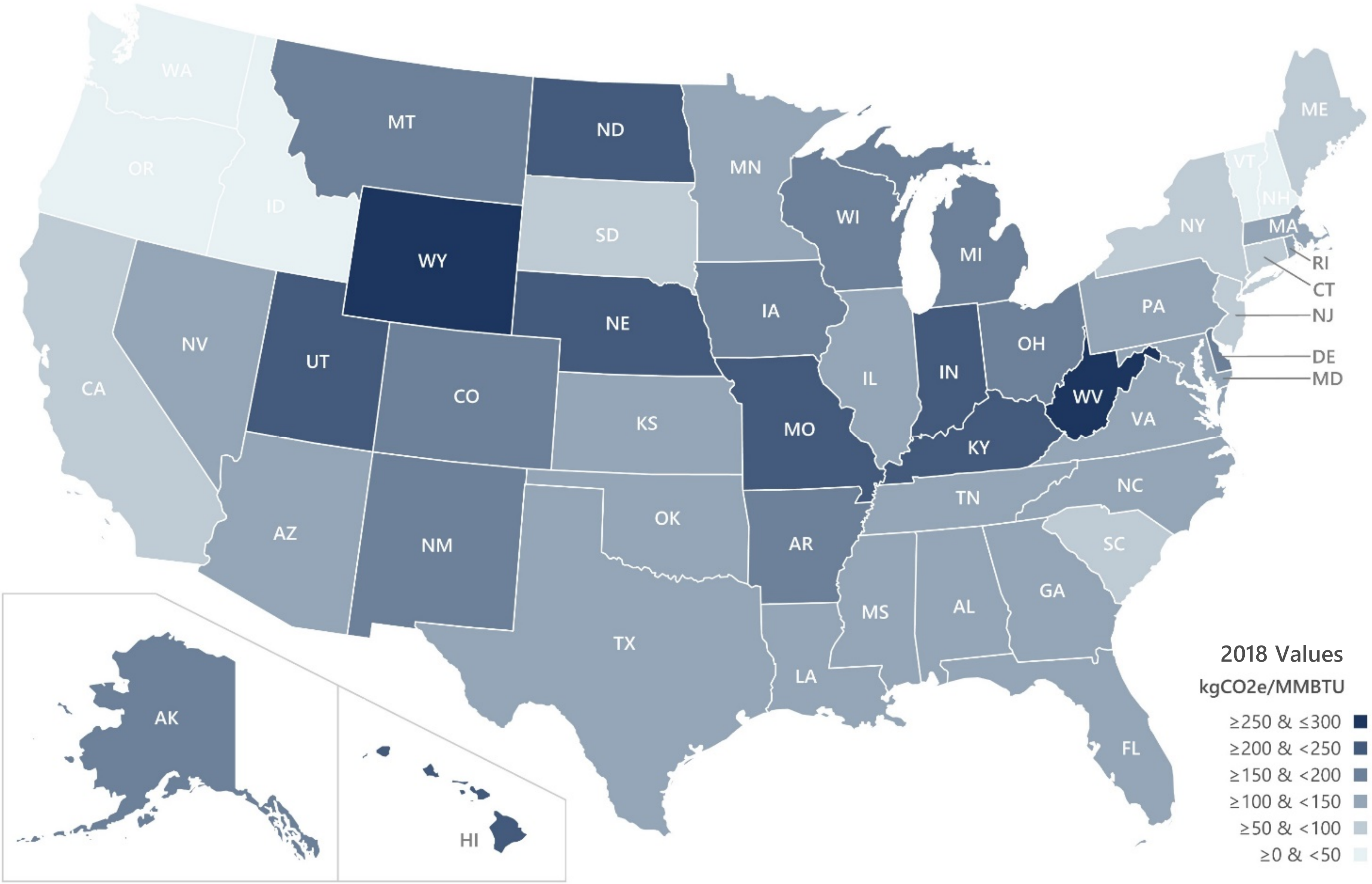
Assess long-term GHG emissions

Lifetime GHG emissions must be considered for system selection as grid emissions continue to decline

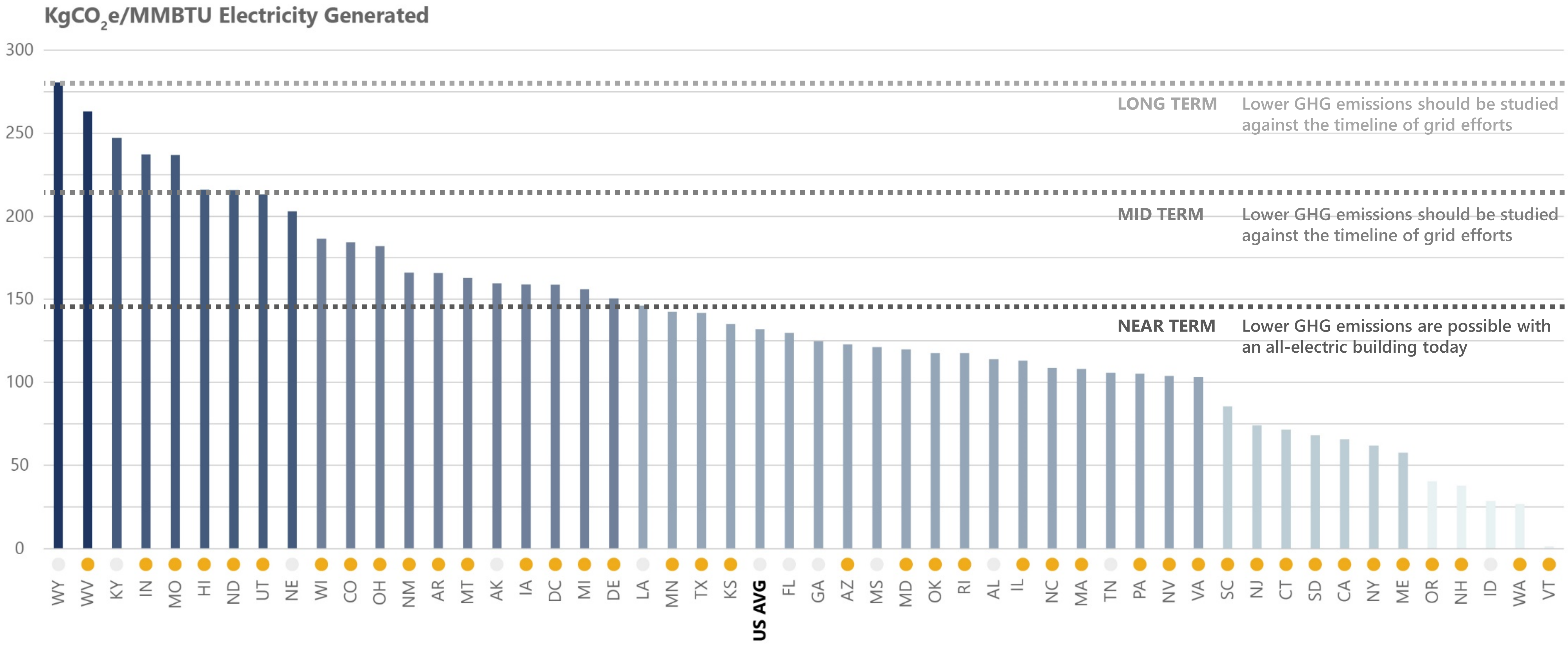
Grid Carbon Factors: USA

There is currently a wide range of carbon factors across the US.

- All projects must evaluate current carbon factors for all fuel sources based on location.
- If the local grid is not yet renewable enough, then identify renewable power procurement opportunities and all-electric preparedness.
- The next slide indicates how this might affect a near-term versus long-term approach.



Grid Carbon Factors: USA



LONG TERM Lower GHG emissions should be studied against the timeline of grid efforts

MID TERM Lower GHG emissions should be studied against the timeline of grid efforts

NEAR TERM Lower GHG emissions are possible with an all-electric building today

● Has existing RPS/climate action plan

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Grid Carbon Factors: MA

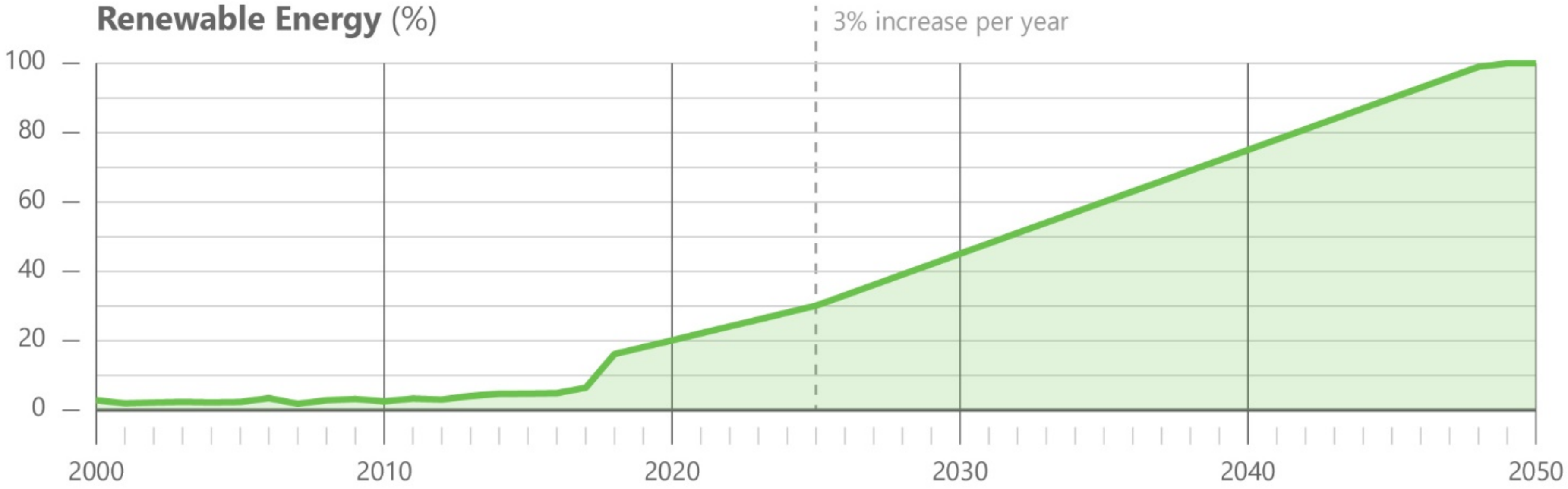
State Policy Example: Massachusetts

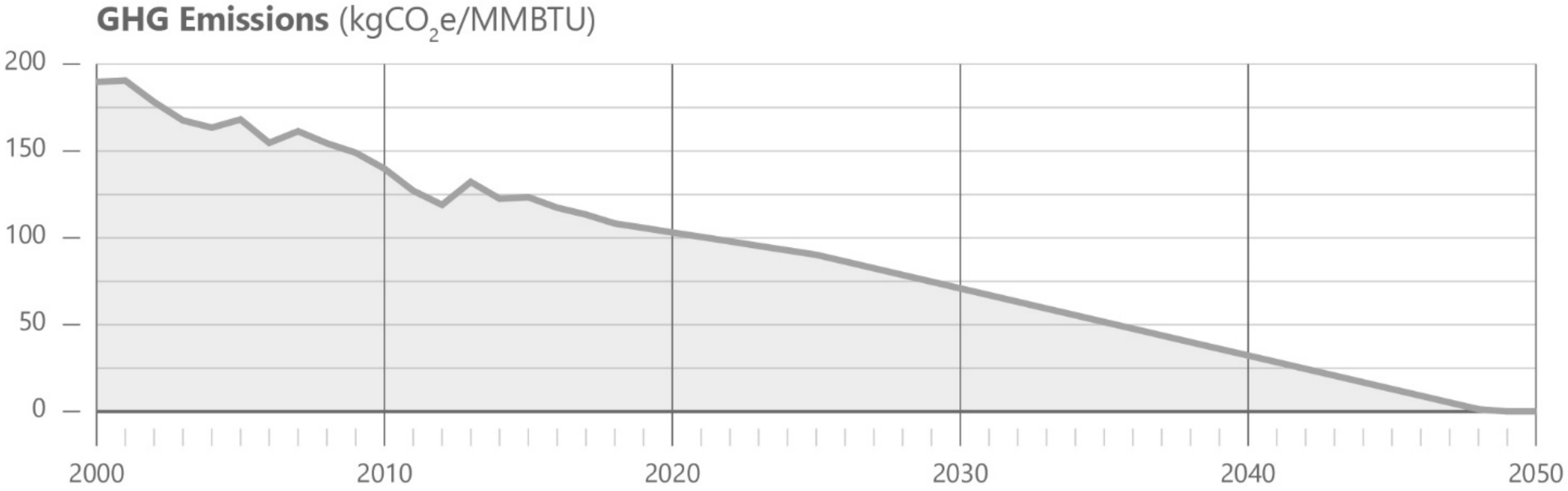
The 2021 Massachusetts Climate Bill increases the year-over-year proportion of renewables engaged on the grid from 2% to 3% starting in 2025.

Therefore:

- The GHG Emissions associated with the grid, in accordance with the Clean Energy Standard, are reduced each year.
- Ultimately, this policy results in a 100% clean grid by 2050.

Many of the following slides study all-electric feasibility in Boston, MA to illustrate implementation in a cold climate.





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Energy Efficiency

GHG | Grid | Tech | Cost

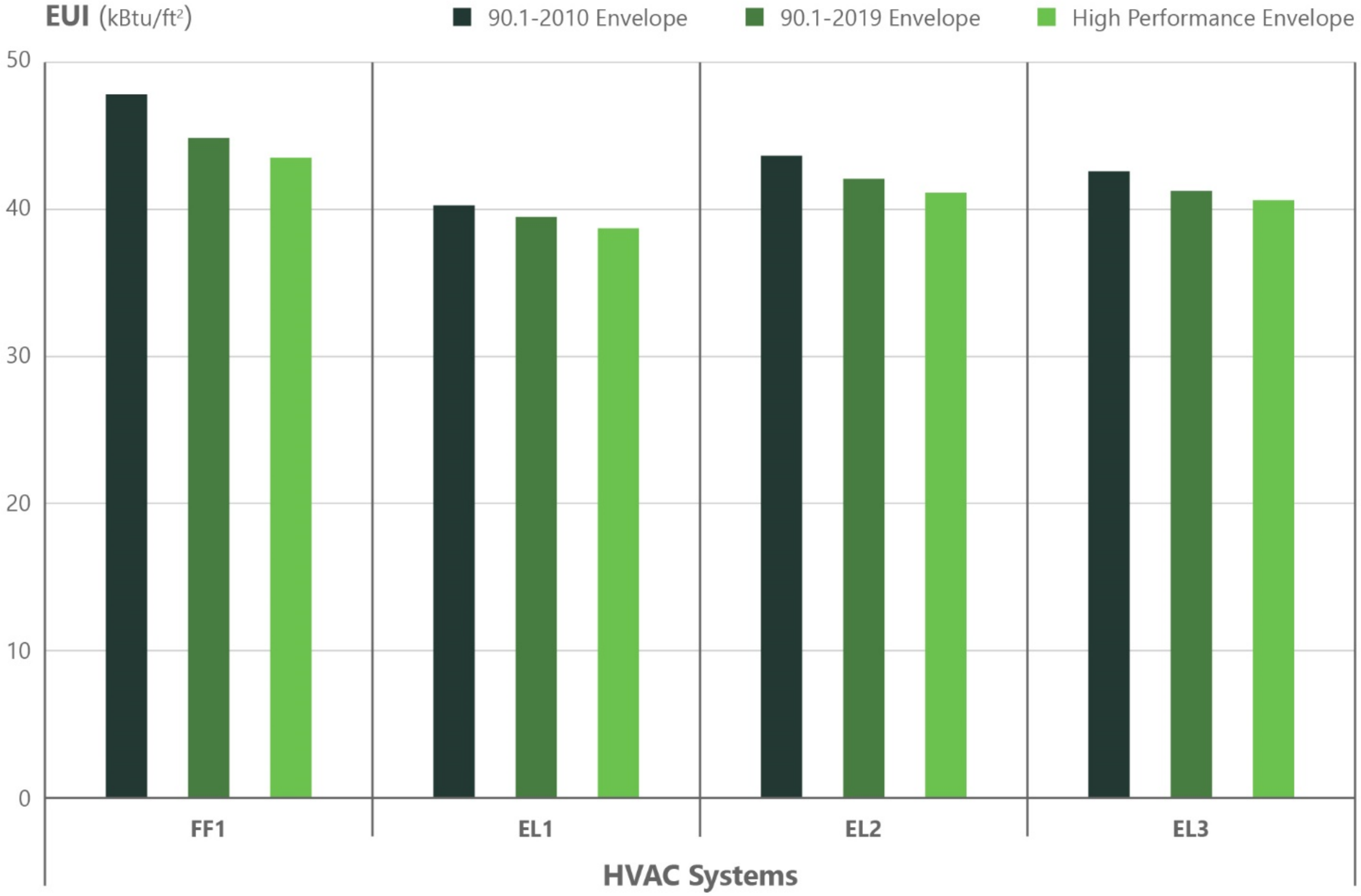
Envelope & HVAC Scenarios

Boston represents a cold climate, which poses significant challenges for all-electric buildings.

Here, we evaluate a Boston office scenario with various envelopes and systems to illustrate the beneficial impact of high-performance envelope across various mechanical systems.

Findings:

- High performance envelopes reduce energy consumption in all cases by reducing heating and cooling loads.
- The three electric systems use less energy compared to the natural gas system.



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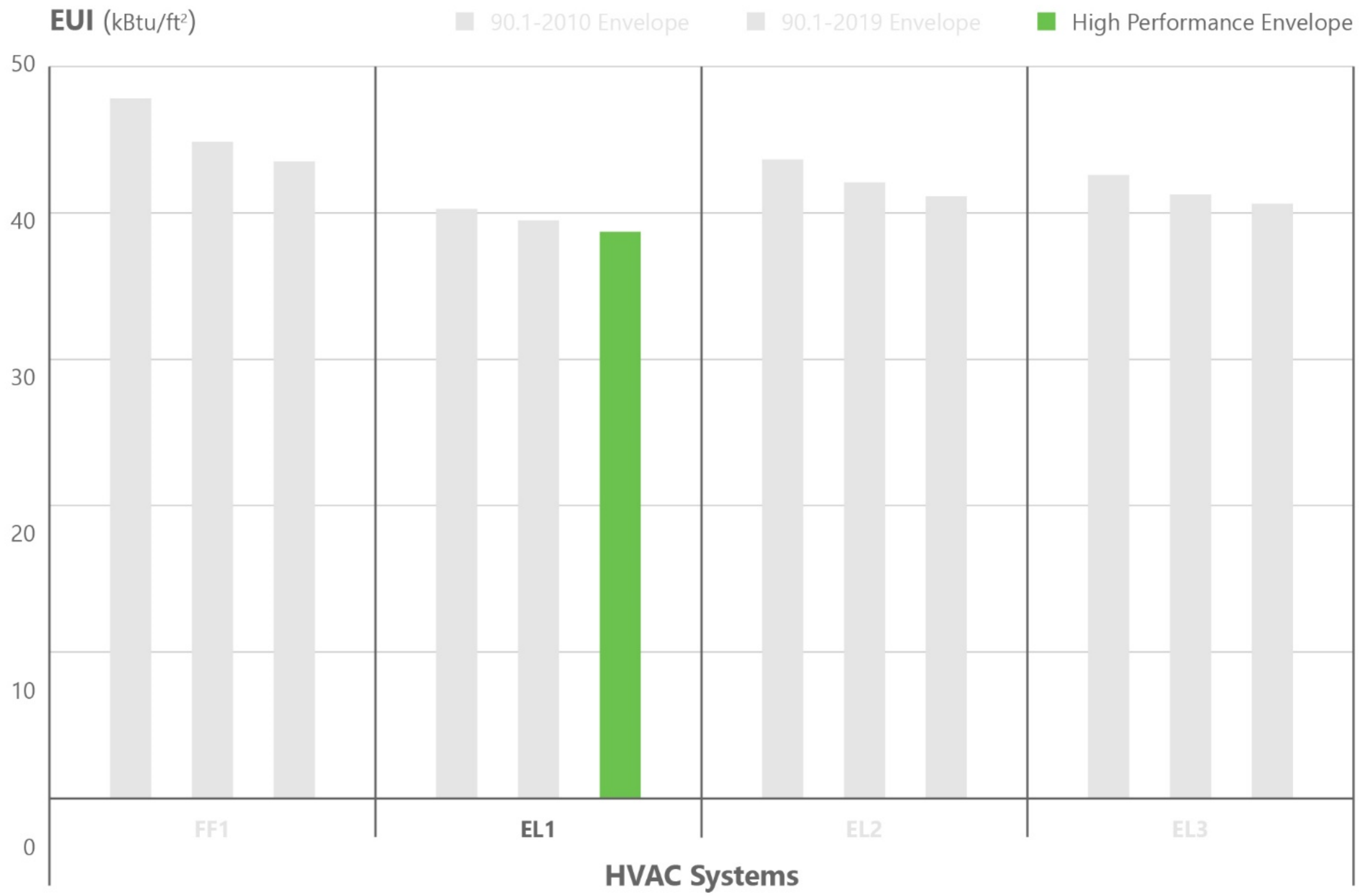
Energy Efficiency

The best performing scenario:

- A high performance envelope (HPE) combined with the heat pump chiller (EL1) all-electric system shows the best energy performance.
- The heat pump chiller system uses a combination of a heat pump chiller and centrifugal chillers with air-source heat pumps providing supplemental heating. The heating hot water and chilled water is modelled to fan coil units for space conditioning. Electric resistance boilers are assumed only for back-up and resiliency.

The EL1 scenario is therefore compared to the HVAC system using natural gas (FF1) in many of the following slides.



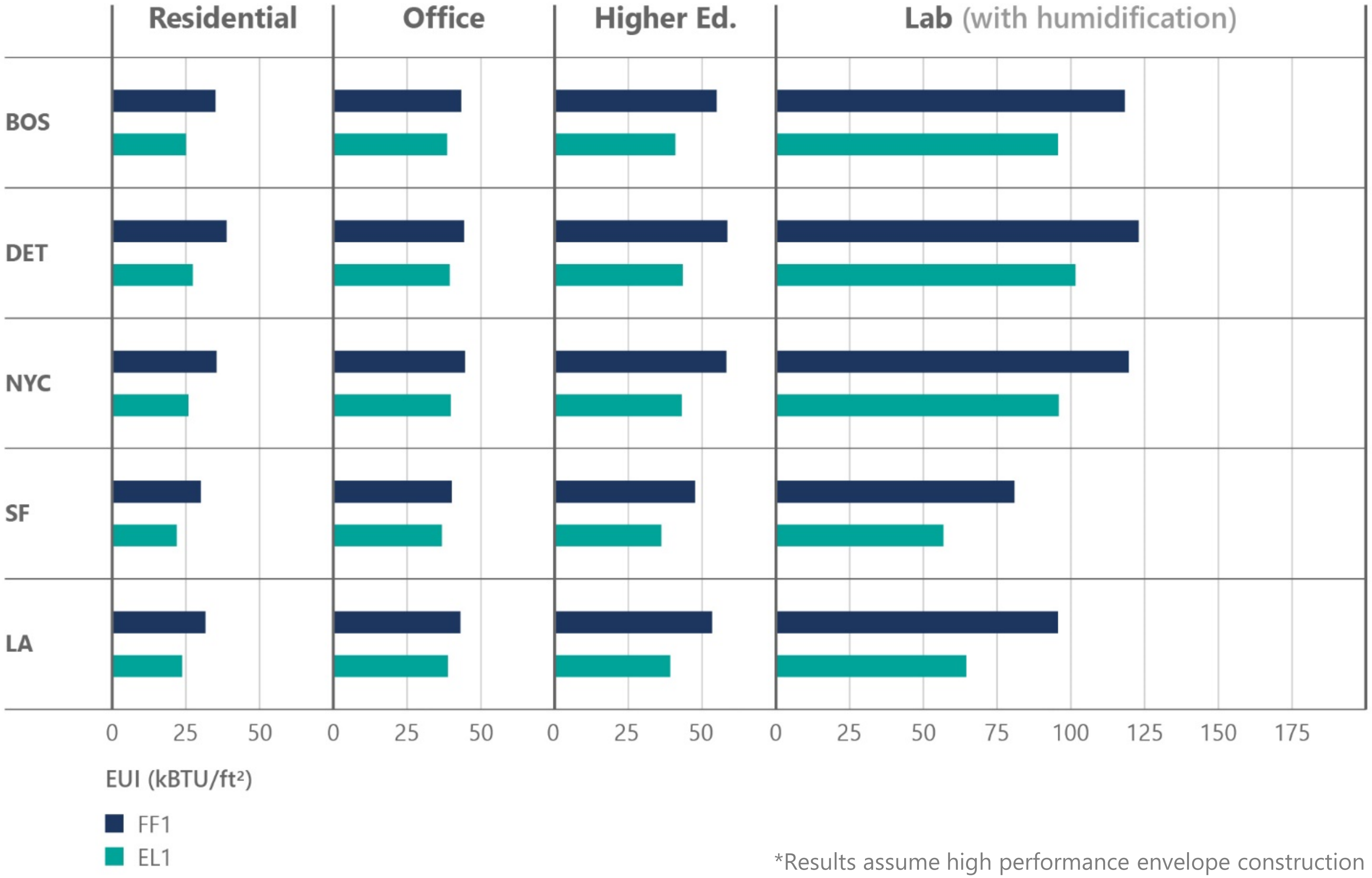
Energy Efficiency

Comparing efficiencies in all scenarios:

- To demonstrate energy efficiency performance improvements across all sectors and locations studied

Findings:

- The all-electric heat pump chiller (EL1) system is more efficient than the system that uses natural gas (FF1) in all locations and all sectors.



*Results assume high performance envelope construction

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Lifetime GHG Reductions

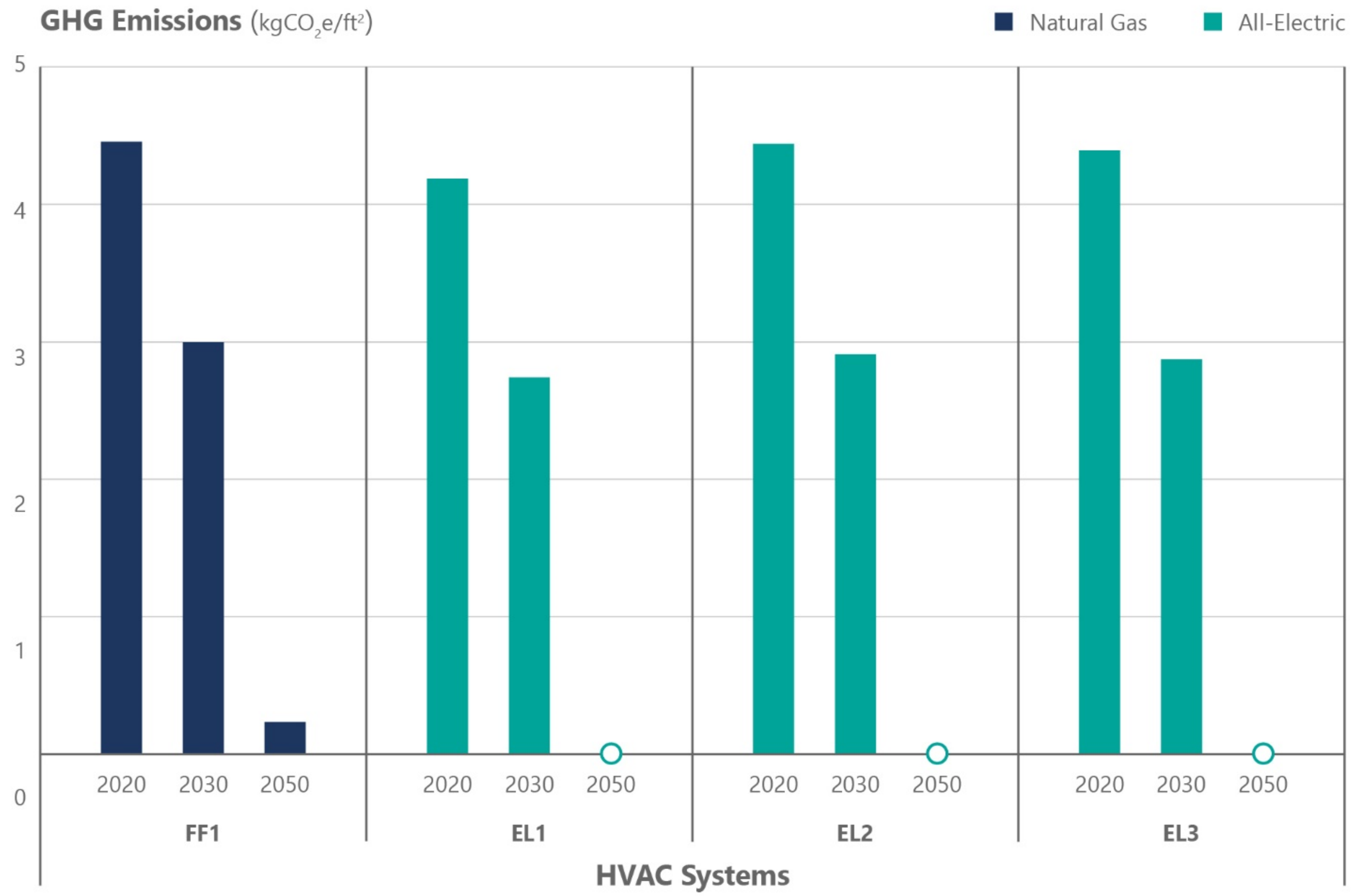
Studying the Boston office scenario from 2020-2050 for future GHG emissions:

- Shows that the all-electric systems result in lower GHG reductions, and can achieve zero emissions on a clean grid

Notably:

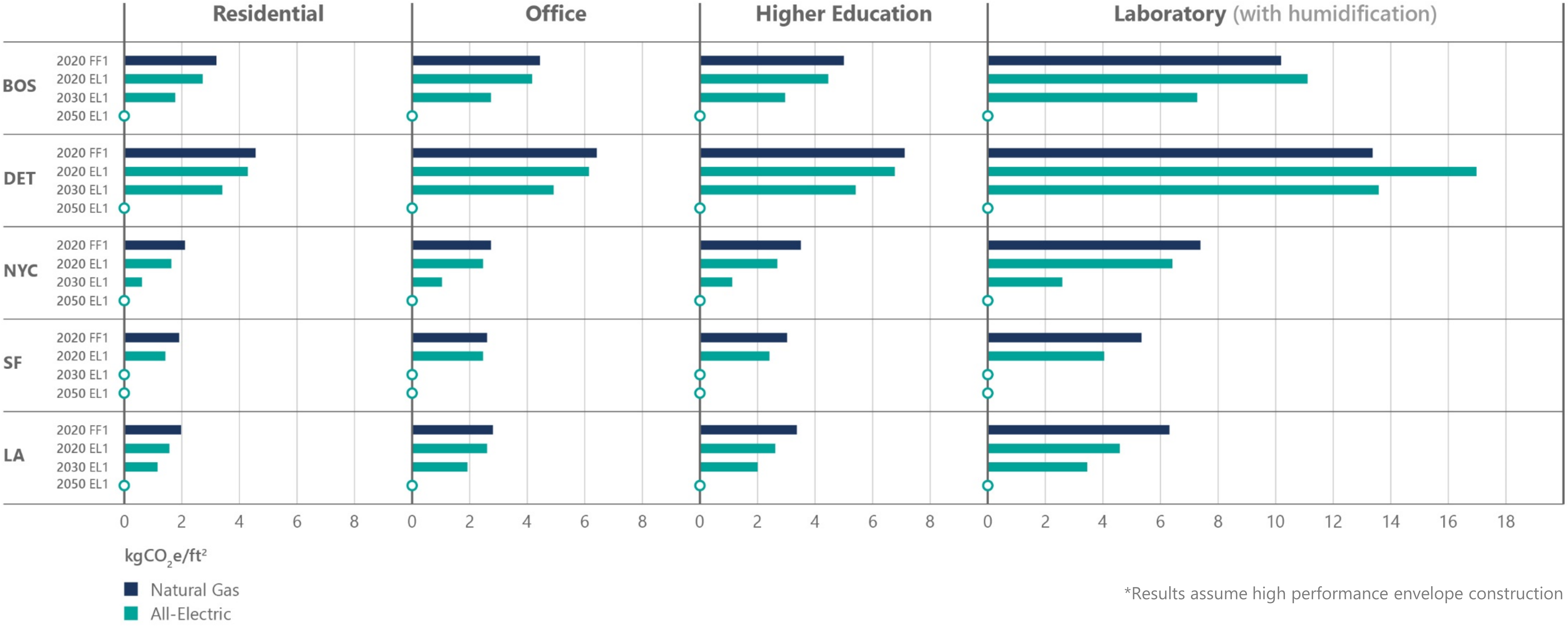
- Any and all GHG reductions in the immediate future are critical toward goals like the Paris Agreement.

The next slide illustrates lifetime reductions in all sectors and all locations. Locations with less renewables on the grid may not result in GHG reductions in the near-term.



Lifetime GHG Reductions

All-electric buildings out-perform fossil fuel in almost all iterations across climate zones.



*Results assume high performance envelope construction

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Grid Resiliency

What is the risk to the grid?

- All-electric buildings **must reduce their peak heating load** requirements to reduce the risk of overburdening our electrical grids
- **Demand management strategies** can also support a grid resiliency strategy by reducing peak loads

Key Design Considerations

1

Manage Peak Loads

Building peak load requirements must be managed to avoid overburdening the grid

2

Understand Demands

Electricity demands are typically driven by cooling systems, but may shift to heating in all-electric buildings

3

Implement Demand Management

Energy can be stored on site to create a more stable use pattern

4

Avoid Peak Demand Times

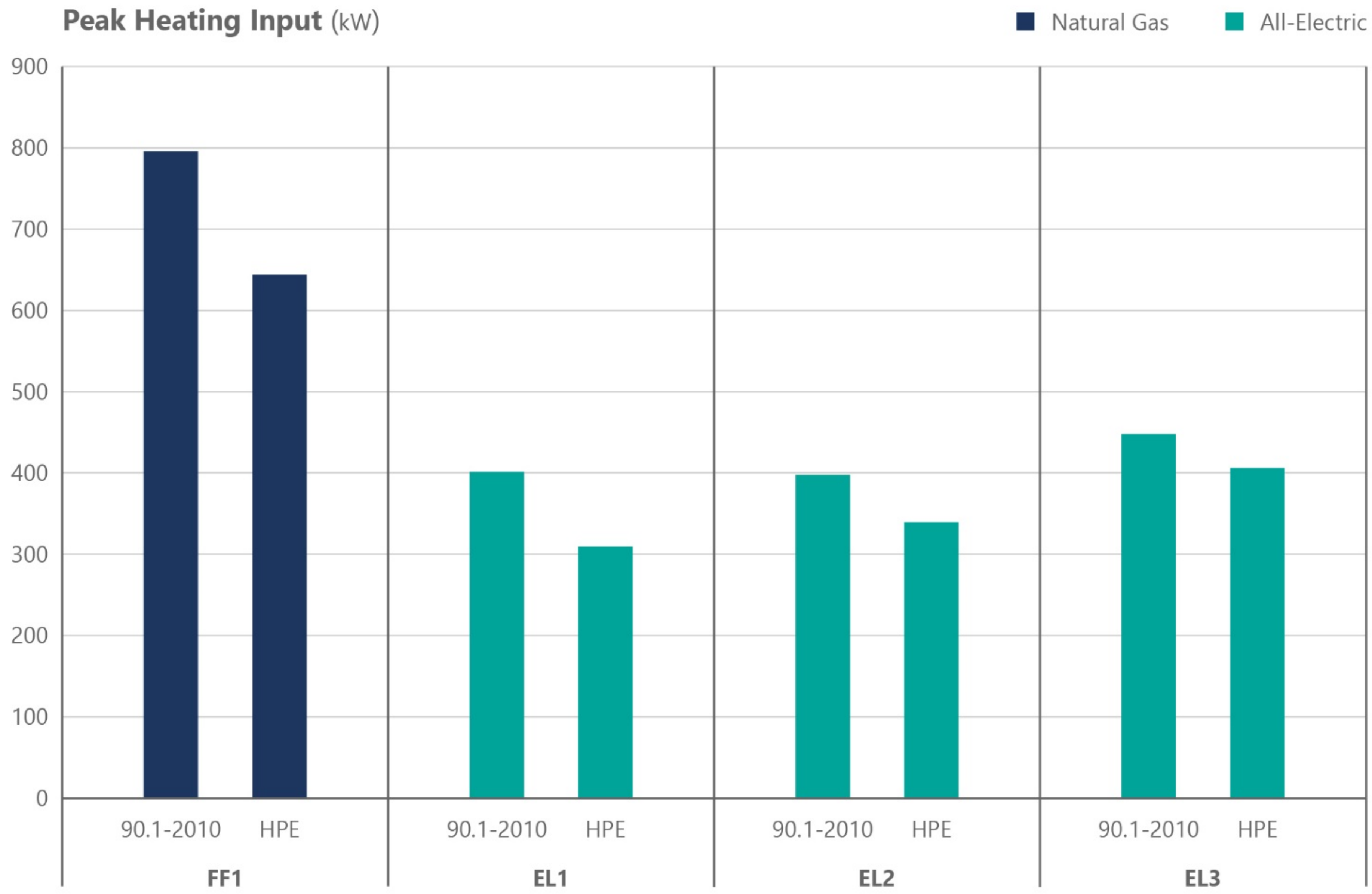
Power production in times of peak demand relies on carbon-intensive sources

Managing Peak Electrical Loads

A Boston residential study shows:

- A high-performance envelope and high-efficiency systems can meaningfully reduce peak heating loads

This supports the management of peak heating loads and therefore the feasibility of all-electric buildings, particularly in cold climates where it may be a life safety risk to overburden the grid.



Managing Peak Electrical Loads

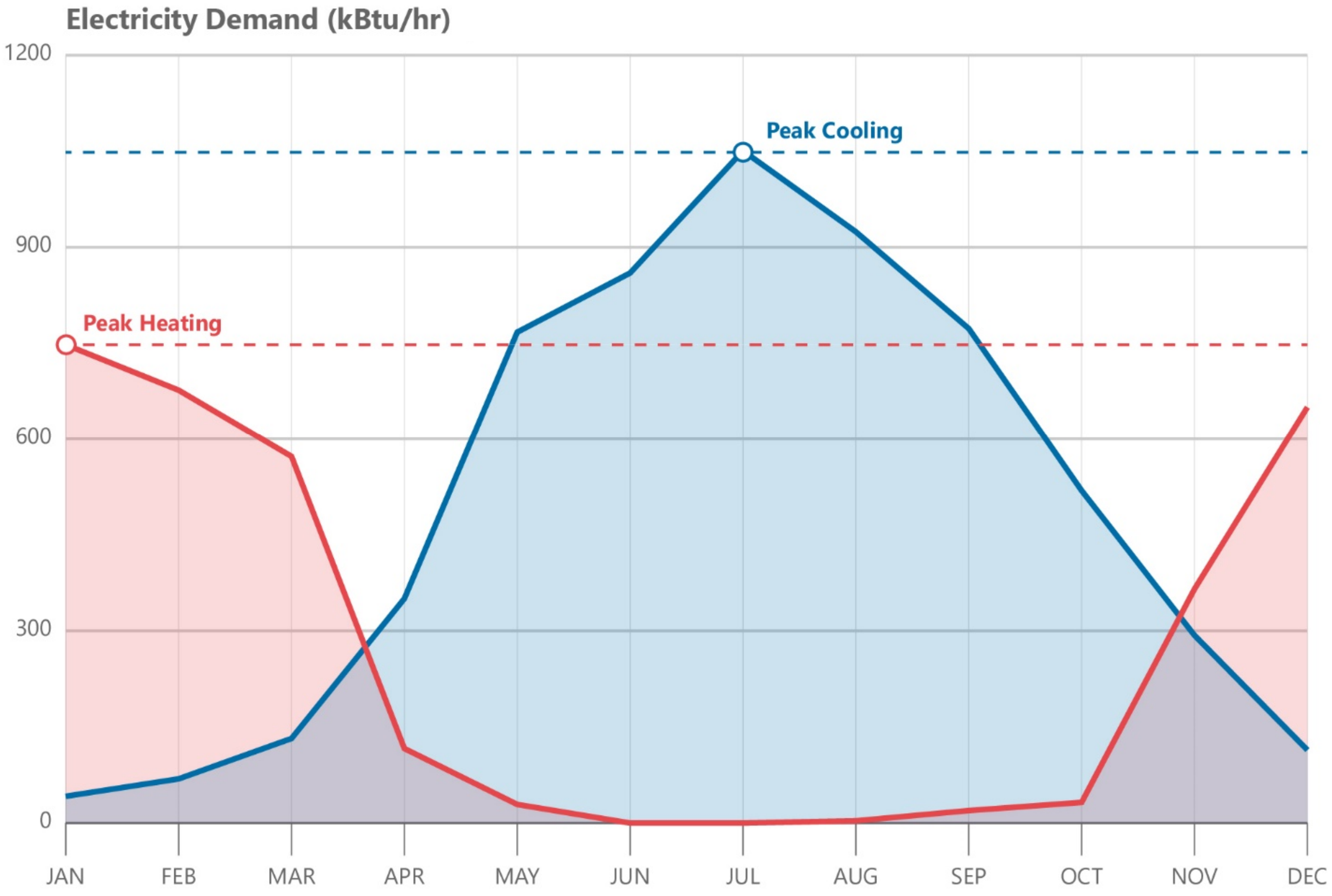
An all-electric office building in Boston and its peak loads:

- Illustrates that the peak cooling load in the summer governs the electrical service and the demand on the grid

Findings:

- This indicates that new construction may not introduce a larger peak burden to the grid. Existing buildings, by contrast, will require high-performance envelope retrofits to pursue a similar outcome.

Can an all-electric building in various cities and sectors be designed to keep peak heating below peak cooling? The following slides evaluate this question.



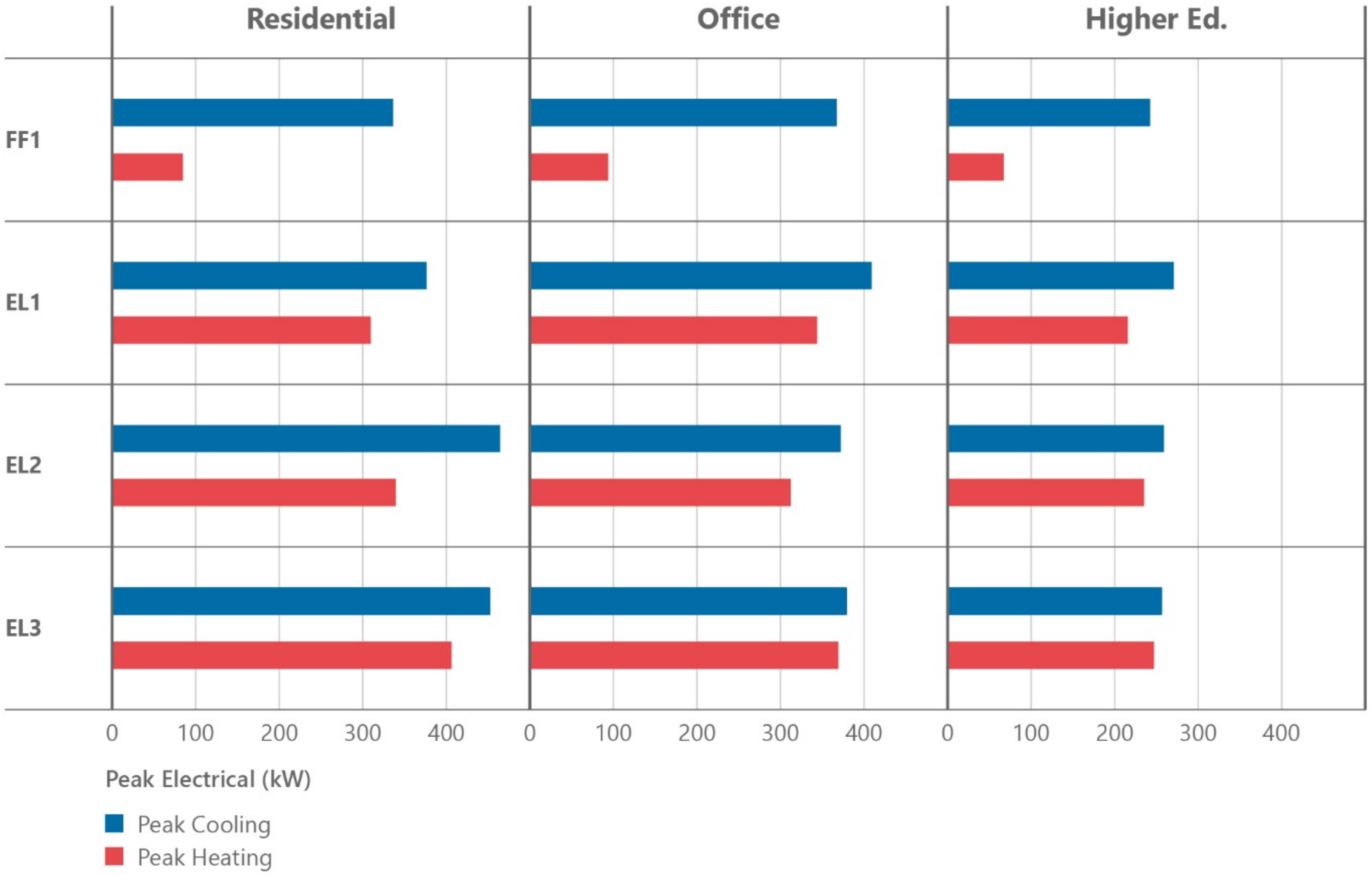
Understanding Demands

Evaluating peak heating and cooling demands within the Boston climate:

- Shows that all system options and building types shown at right demonstrate peak cooling exceeding peak heating

Findings:

- While this illustrates the feasibility of a new all-electric building having the same electrical service size as a fossil-fuel heated building, this study must be done on a project-by-project basis to account for project-specific demands.
- For adaptive reuse projects, deep energy retrofits will be required to effectively reduce peak heating loads.



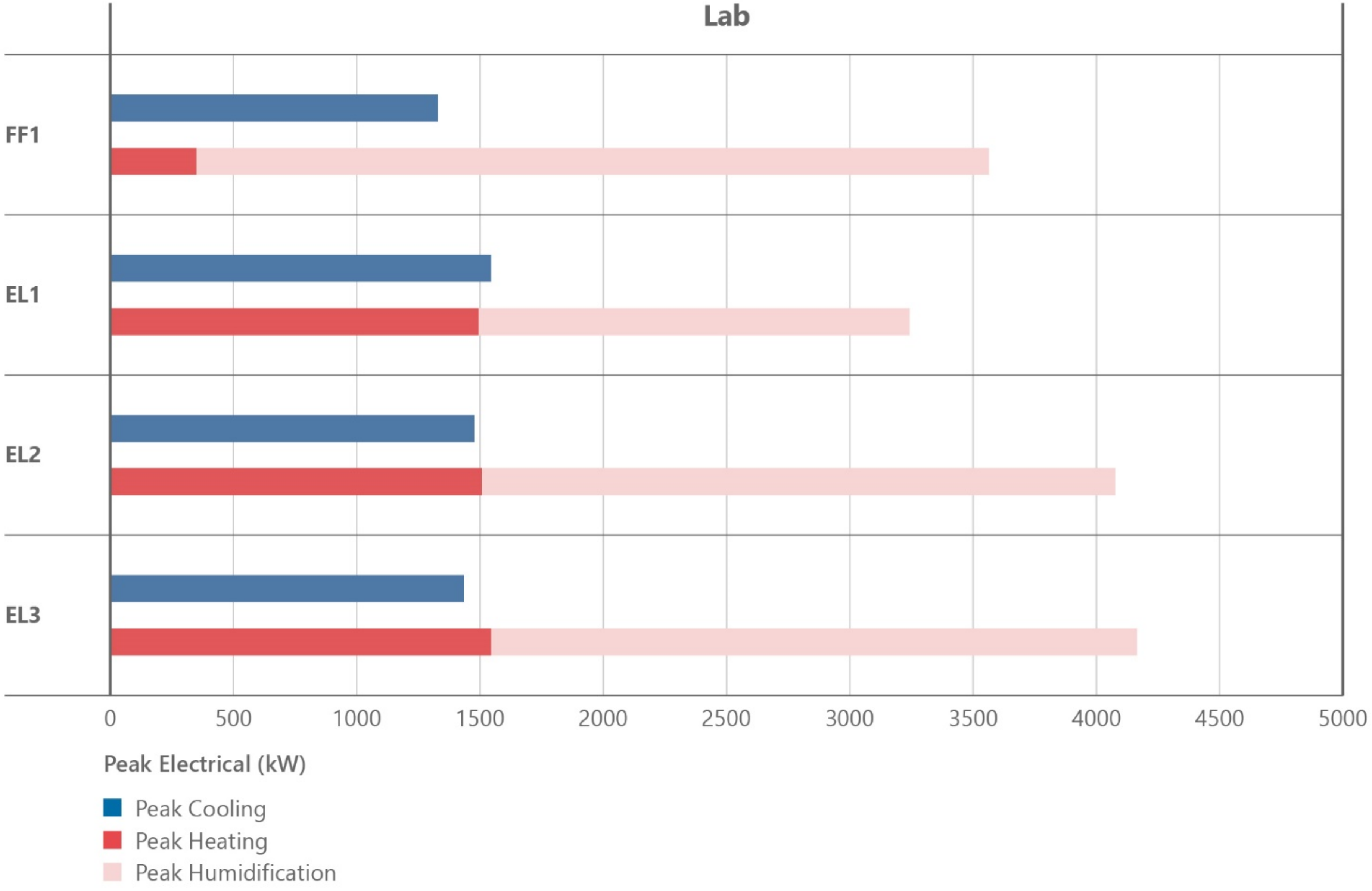
Understanding Demands

Evaluating peak heating and cooling demands within the Boston climate:

- Shows that - by comparison - humidification requirements may govern the connected load for laboratories, among other special criteria not studied here

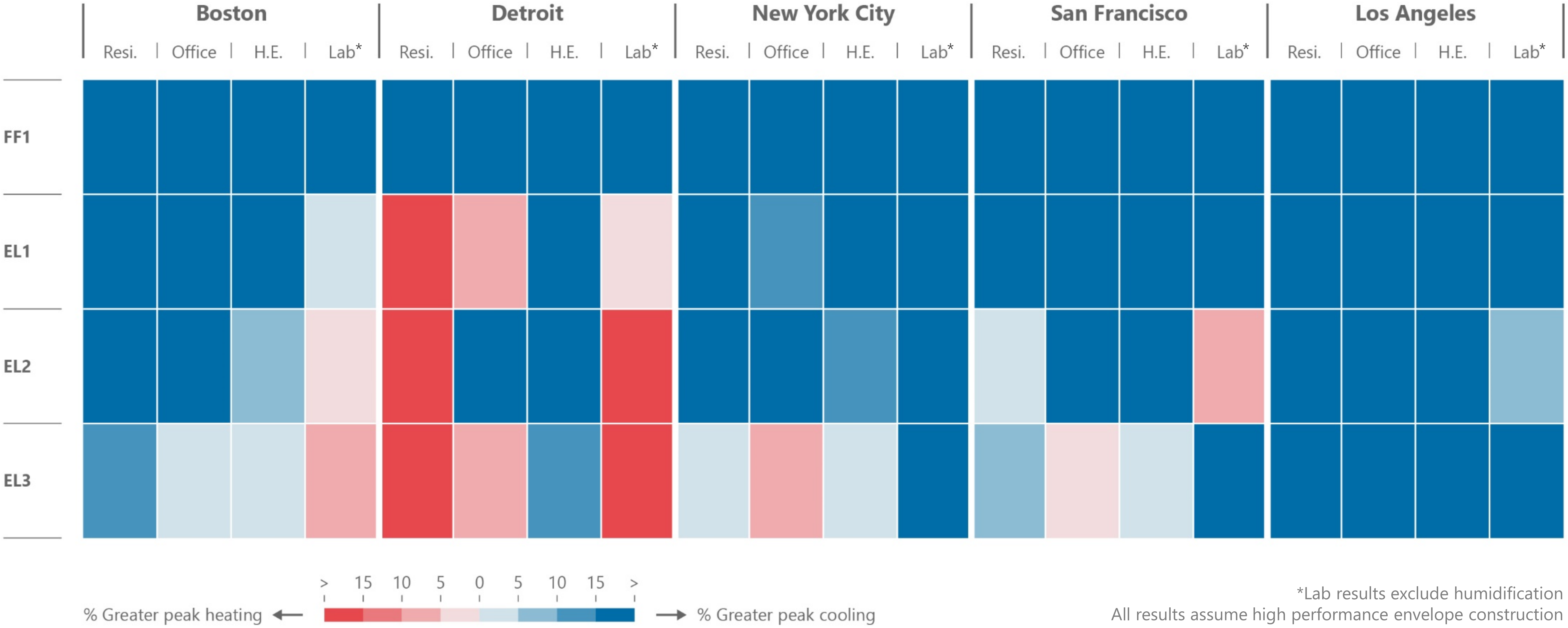
Findings:

- The peak heating and peak cooling loads for a non-humidified laboratory are similar in the all-electric systems scenarios.
- Adding humidification requirements can show a significant increase in peak heating; the type of lab and extent of special criteria is critical to understand these relationships.



Understanding Demands

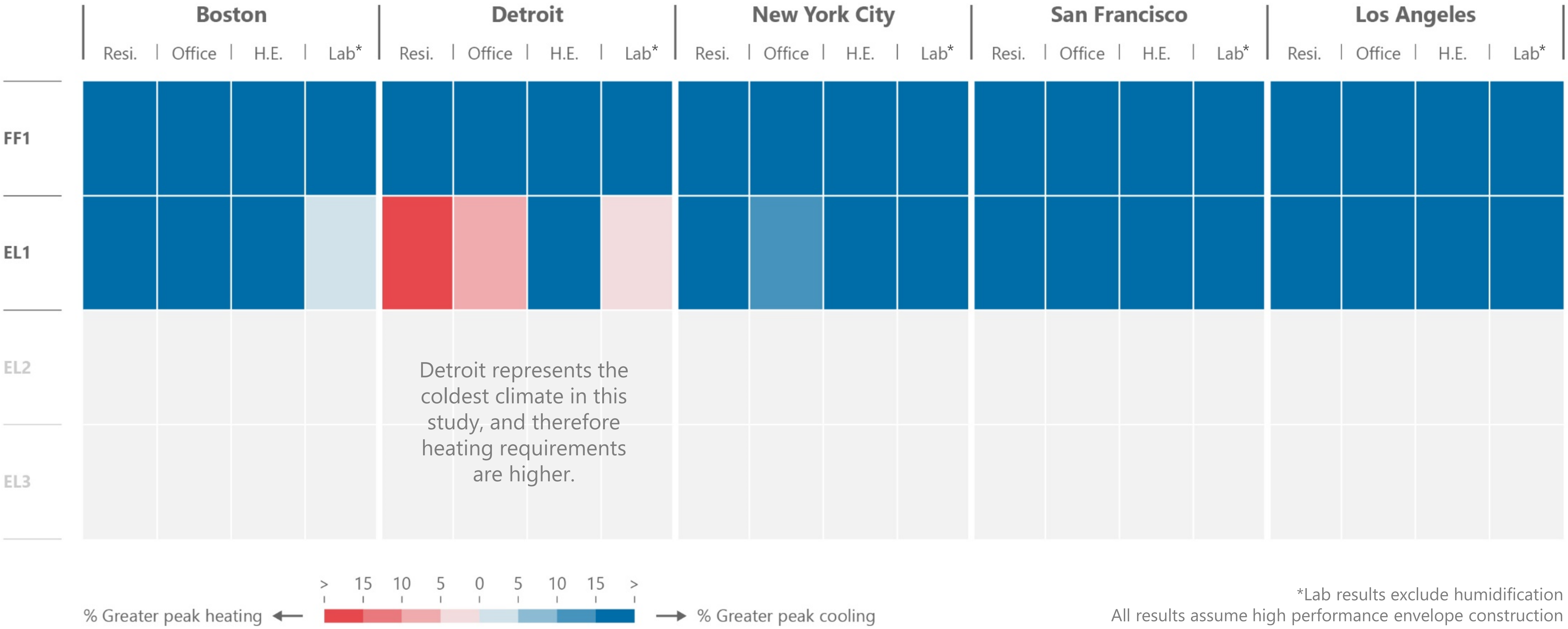
Peak cooling loads govern new construction service connectivity in a majority of all-electric scenarios.



*Lab results exclude humidification
All results assume high performance envelope construction

Understanding Demands

FF1 and EL1 demonstrate the basis of the scenarios included in this feasibility study.

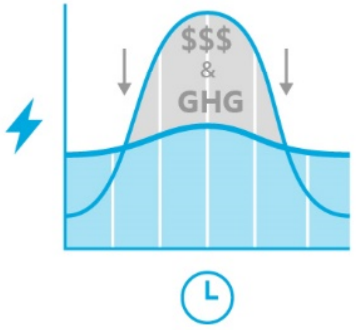


Detroit represents the coldest climate in this study, and therefore heating requirements are higher.

*Lab results exclude humidification
All results assume high performance envelope construction

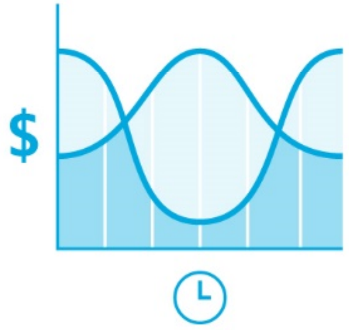
Demand Management

Building design and operational strategies can also reduce peak electricity demands.



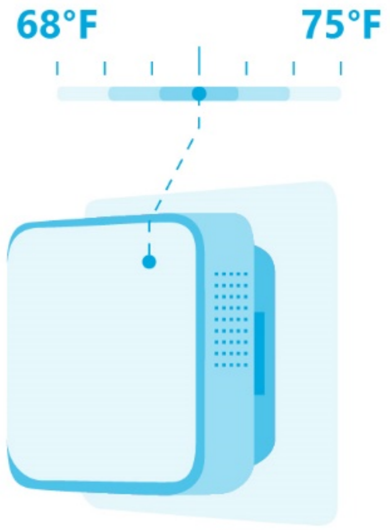
Flatten the Curve

Reducing peaks can reduce both utility costs and greenhouse gas emissions when some high-carbon "peaker plants" are used.



Time of Use Pricing

In addition to lower utility bills where customers are charged for time-of-use, some municipalities offer related demand management incentives to avoid peak use times.

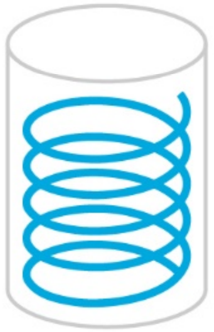


Adaptive Thermal Comfort

Temperature setpoints shouldn't be extremely cold or warm, nor cater to the most extreme comfort conditions. A relationship to the outdoor temperature is appropriate.

System Zoning

The number of zones in a system can be studied to maximize flexibility where needed, and to manage comfort and set-back conditions to reduce energy use.



Thermal Storage

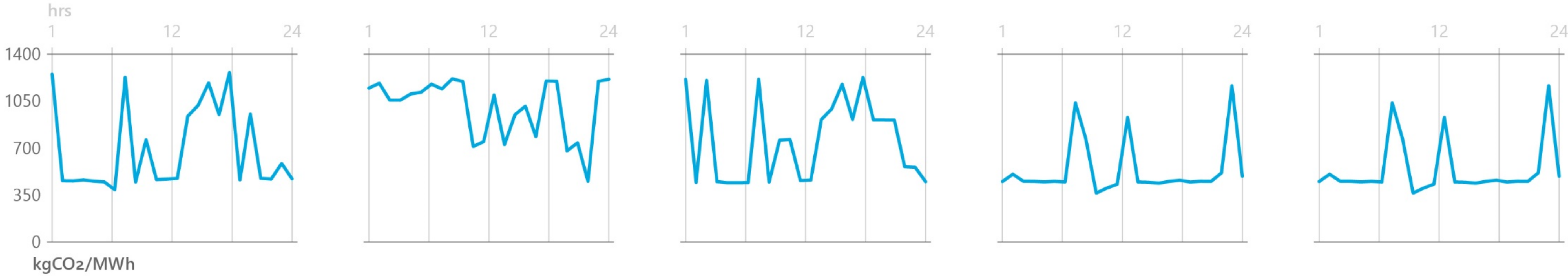
Equipment and materials can be used to store energy generated at the lowest use-time of day for use later at peak times to avoid demand on the grid during peak.

Controls & Process Loads

Controls can be used for systems and equipment to be shutdown or managed more carefully, especially during peak times of day/season.

Demand Management

Avoiding peak times can have financial and GHG emissions benefits.



Boston, MA

Electrical Utility: Eversource Energy (NSTAR Electric)

Capacity DM Incentive: $35/kW; MassSave

Detroit

Electrical Utility: Detroit Thomas Edison (DTE)

Capacity DM Incentive: $13.82/kW

New York City

Electrical Utility: Con Edison (NSTAR Electric)

Capacity DM Incentive: $25/kW

Event DM Incentive: $1/kWh

San Francisco

Electrical Utility: Pacific Gas and Electric Company (PG&E)

Capacity DM Penalty: $6/kWh

Event DM Incentive: $.10/kWh

Los Angeles

Electrical Utility: Los Angeles Department of Water and Power (LADWP)

Capacity DM Incentive: $12/kW

Event DM Incentive: $0.25/kWh

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Technology

What all-electric & high performing technology is available?

- **Heat pump** technologies are a high-efficiency electric option for heating and hot water
- **Heat recovery** helps to offset the heating needed
- **Envelope** performance needs to be tailored to the climate with appropriate levels of insulation

Key Design Considerations

1

Heating Technology

Space heating and domestic hot water are typically driven by fossil fuel end uses and are therefore the target for electrification

2

Heat Pump Technology

Heat pump technologies are highly efficient electrification solutions

3

Redundant Back-Up

Emergency back-up is dominated by fossil fuels, and large-scale battery storage options are still emerging

4

Benefits of Non-Combustion

Non-combustion systems improve human health and air quality

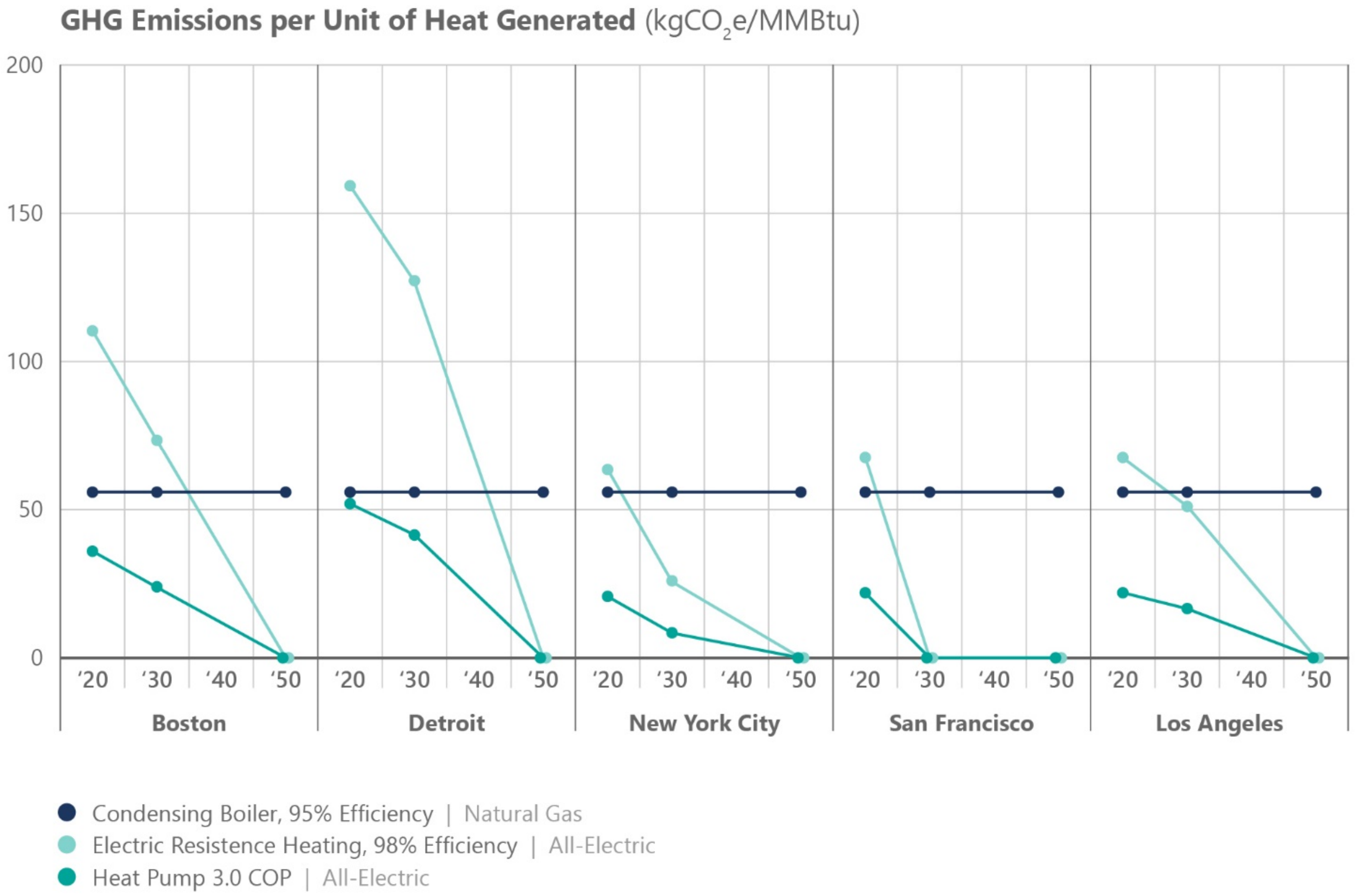
Heating Technology

An evaluation of three heating technologies in five US Cities:

- Illustrates that on a per-unit of heat generated, a heat pump has a lower carbon footprint today through 2050

COP, or Coefficient of Performance, is a metric for the efficiency of mechanical systems. A higher value means more energy output for each unit of energy input; higher is better.

The condensing boiler and electric resistance boiler each have a COP of approximately 1, compared to an air-source heat pump with COP 3.0.



GHG Emissions per Unit of Heat Generated (kgCO$_2$e/MMBtu)

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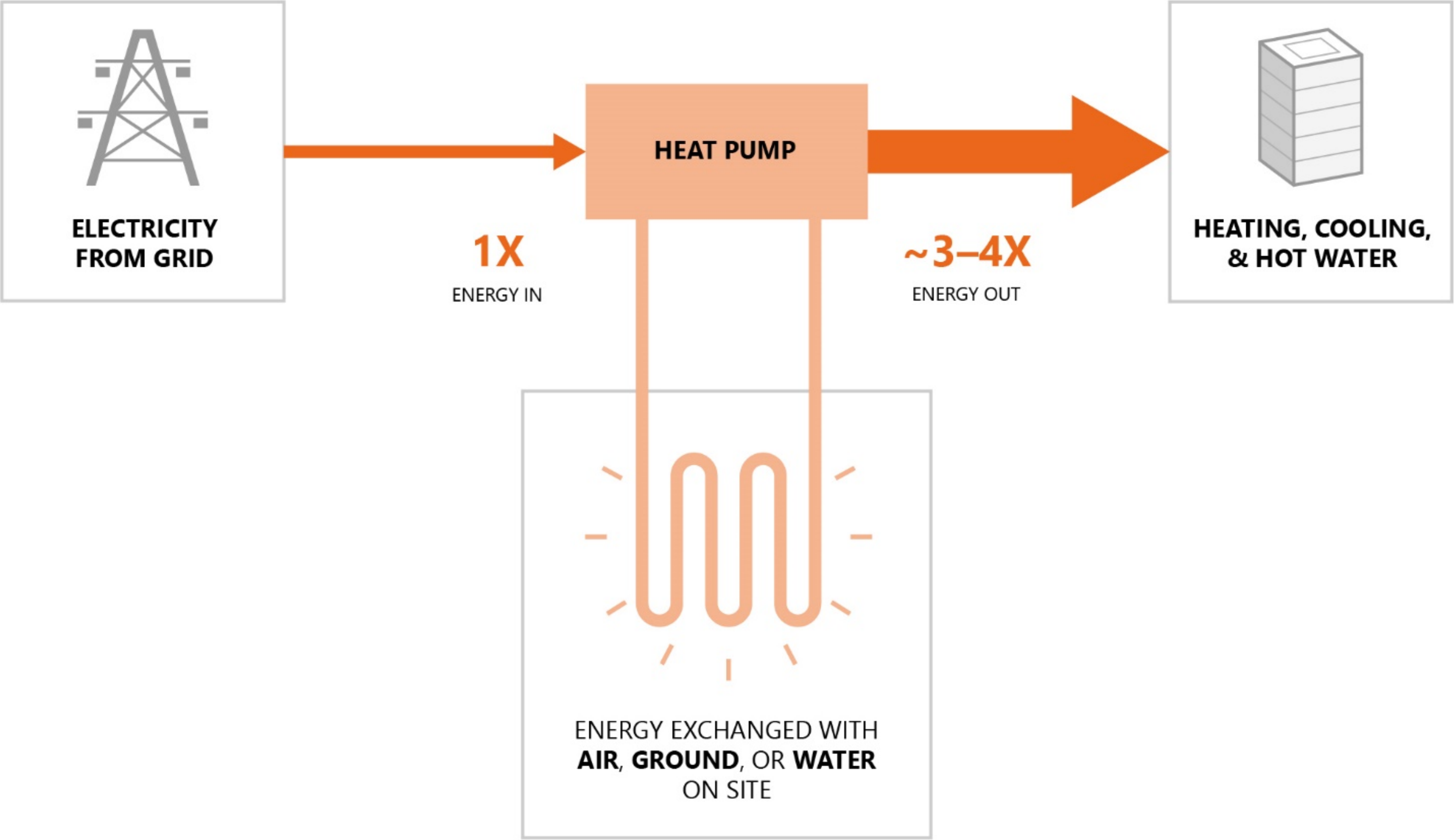
Heat Pump Technology

- Heat pumps run on electricity to exchange thermal energy with the ground, the air, or water.
- When operating in heat recovery mode, modular and VRF-type heat pumps can also move “free” thermal energy from one space in a building rejecting heat to another space receiving heat.
- Heat recovery mode is highly efficient, and simultaneous heating and cooling is beneficial for buildings with many different use types.
- Heat pumps are becoming more capable of operating in very cold conditions, like -13º F.



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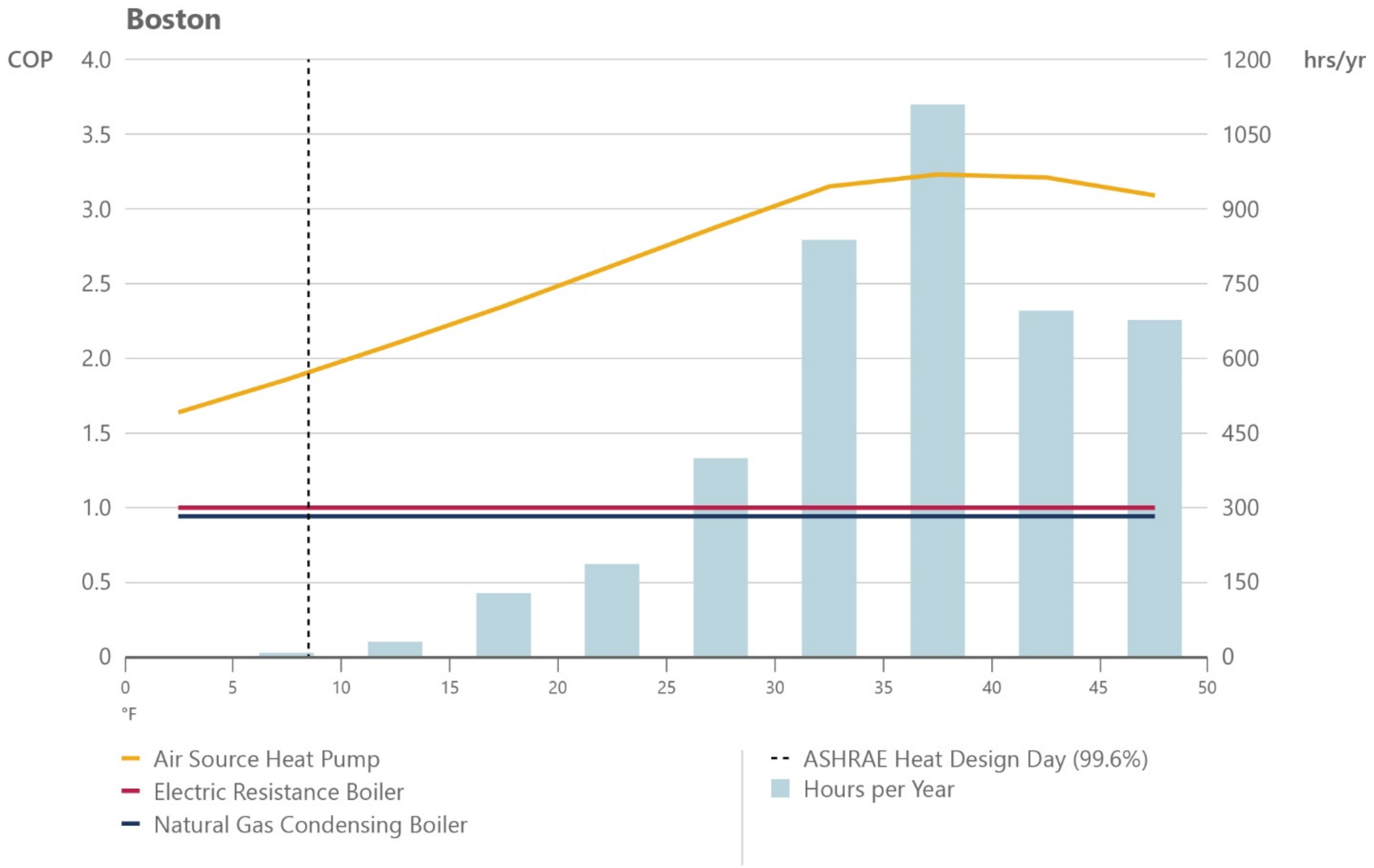
Heat Pump Technology

A study of how the air-source heat pump COP changes depending on the outside temperature:

- Shows for over 82% of heating hours in the Boston climate, a COP of 3.0 or higher can be maintained

Findings:

- Despite the derated performance in cold climates, air-source heat pumps are highly effective for a majority of hours in the heating season.
- Cold climates require careful consideration for back-up solutions.
- Heat pump technology enhancements are trending toward handling even lower temperatures.



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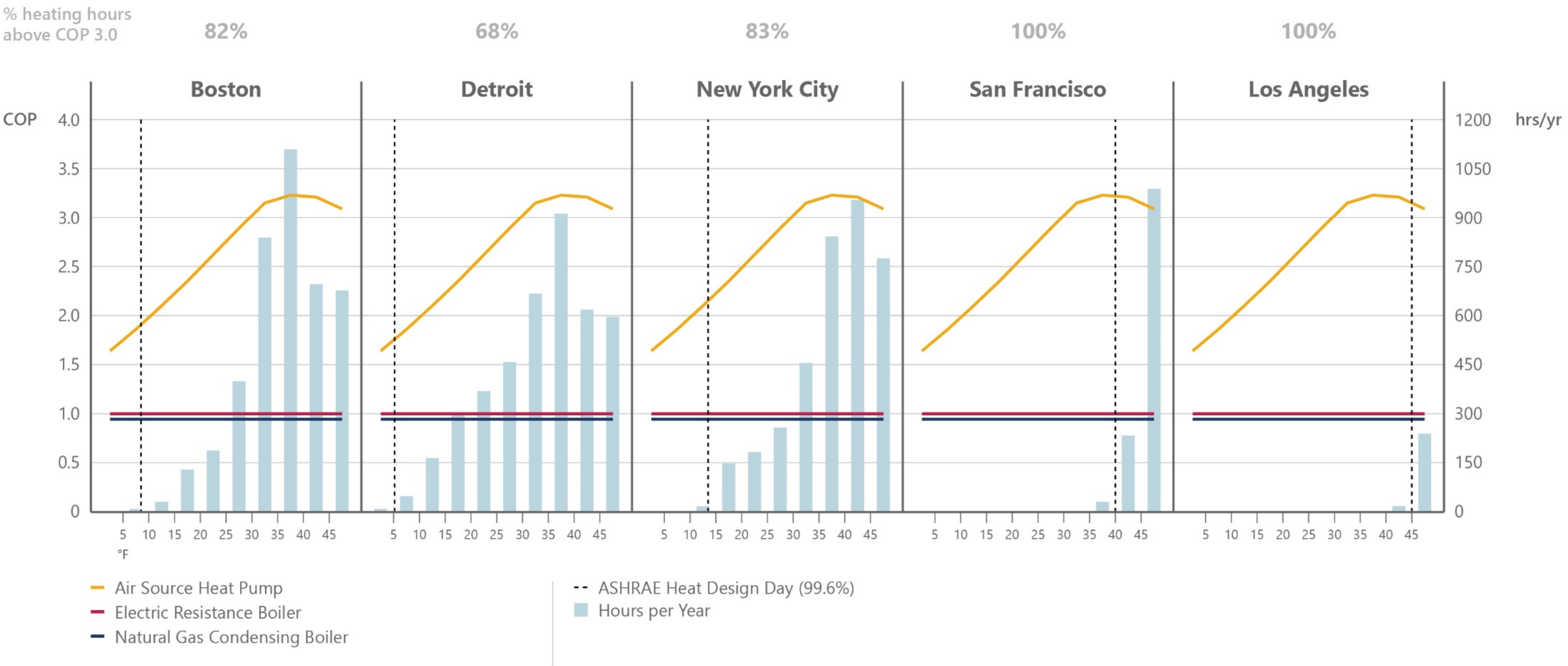
Heat Pump Technology

Most US climates are appropriate for heat pump technology.



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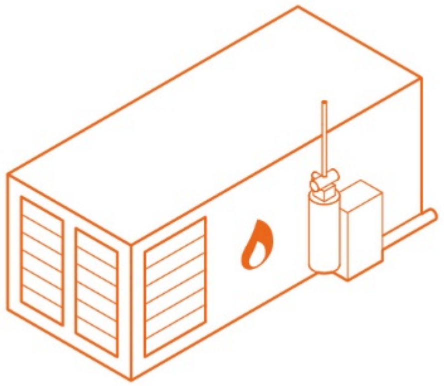
Redundancy & Resiliency

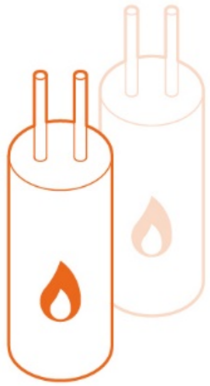
Many options are available to engineer back-up power to maintain building operations.



Large Generator (fossil/bio fuel)

Fossil Fuel

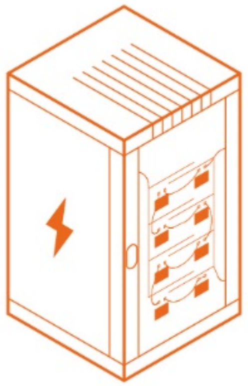
Fossil fuel generators are currently industry standard, and biofuel options are becoming available.



Back-Up Natural Gas Boilers

Fossil Fuel

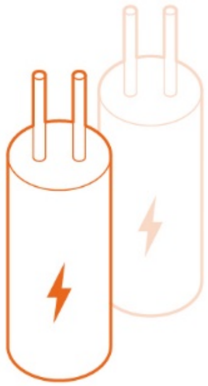
Maintaining gas boilers in a system for back-up only can limit large generator upsizing for electric heating systems.



Batteries (small, large)

Electric

Technological improvements and cost reductions will support the ongoing feasibility of large battery back-up. Reliability must include appropriate time period for backup (e.g. 3 days).



Back-Up Electric Resistance Boilers

Electric

These boilers may be applicable for back-up only in cold climates where air-source heat pumps may be challenged in the coldest temperatures. This would require careful consideration for peak electrical loads.

Microgrids

Various

Deployed at building or district scale, dynamic controls can island their energy supply in the event of a power disruption.

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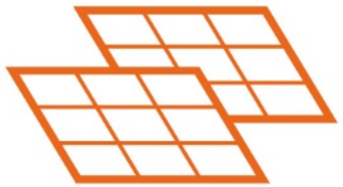
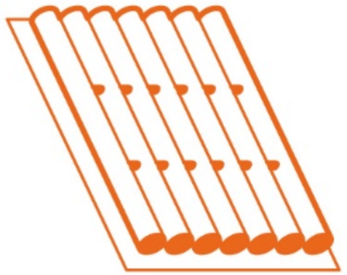
Alternative Technologies

Many additional technologies can support a holistic all-electric building design.



Photovoltaics

A solar PV array produces on or off-site renewable electricity with minimized inverter losses.

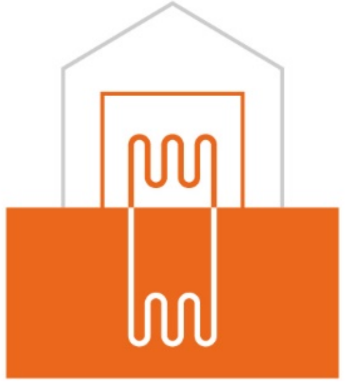


Solar Thermal

Solar thermal harnesses solar heat to produce domestic hot water (DHW), a solution best used with a consistent annual base load.

Wind

Building or campus-scale wind turbines can be studied for on-site renewable energy production.

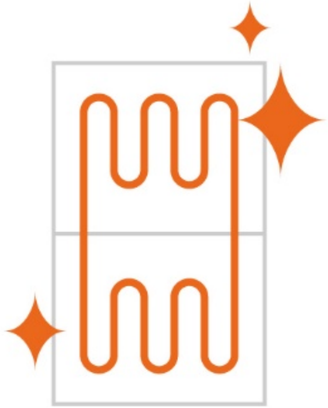


Geothermal/ GSHP

The ground can be an optimal source for heat pumps to exchange thermal energy in both heating and cooling modes.

Thermal Mass

Thermally dense materials can be used to absorb heat or coolth, and slow the temperature swing in a space.



Low GWP Refrigerant

Refrigerants with low or no-global warming potential are available today, and should be used in every instance possible to reduce the embodied carbon footprint of a cooling system.

Health/Equity Benefits of Non-Combustion

The combustion emissions from the U.S. building sector now contribute to the largest share (37%) of premature deaths associated with air pollution. (RMI 2020; MIT 2020)

Indoor

Outdoor

What are the cost implications?

- All-electric buildings are becoming increasingly **cost-competitive**.
- Key cost factors to evaluate include: space planning, capital cost, utility cost, and carbon penalties.

Key Design Considerations

1

Space Planning

Strategic space allocation can optimize leasable area, equipment maintenance space, and rooftop amenity space

2

Life-Cycle Costs

Capital costs, utility costs, and maintenance costs are important to assess together for a long-term outlook

3

Cost of Implementation

Fully electric systems are becoming increasingly cost-competitive

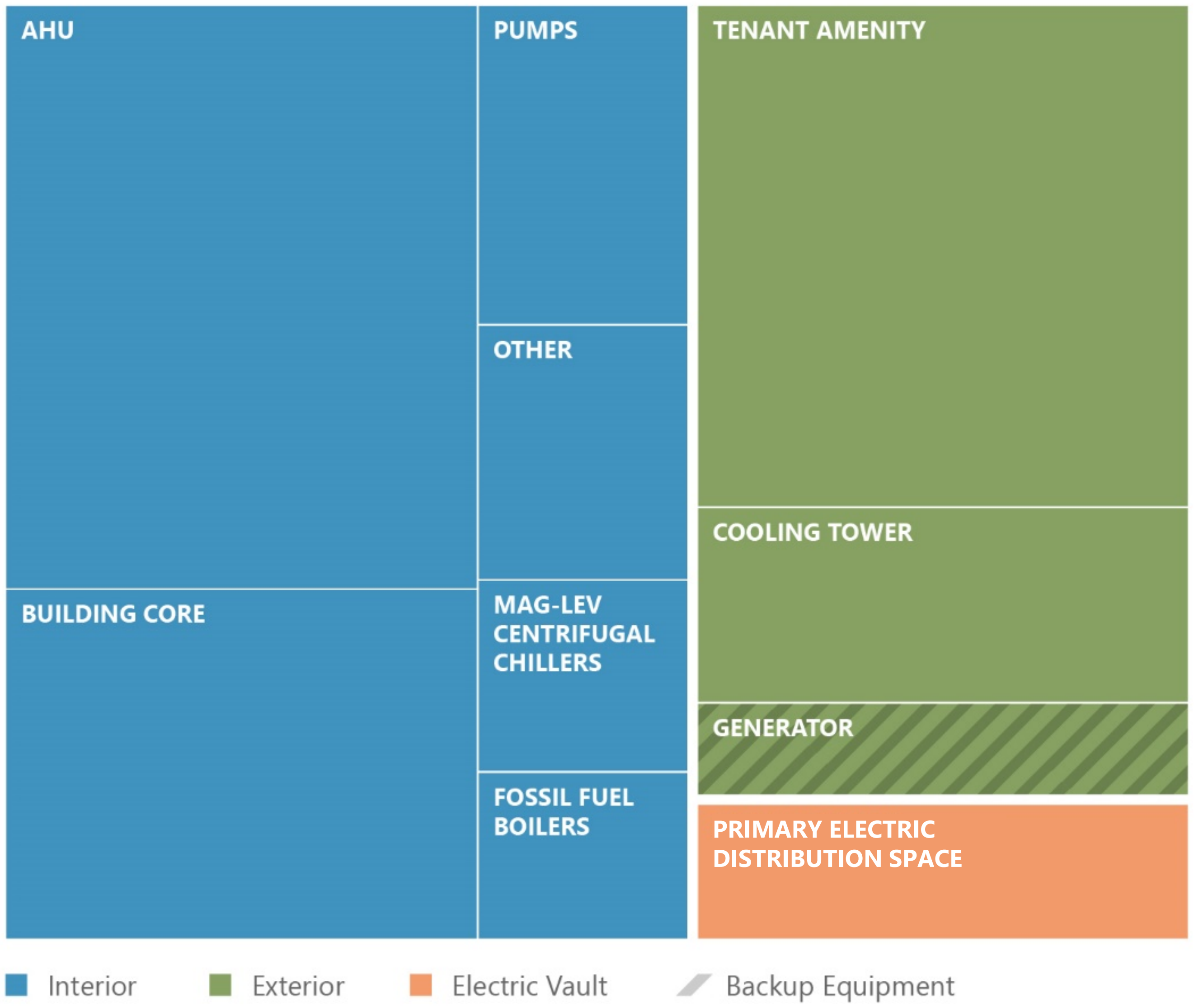
4

Engaging in the Market

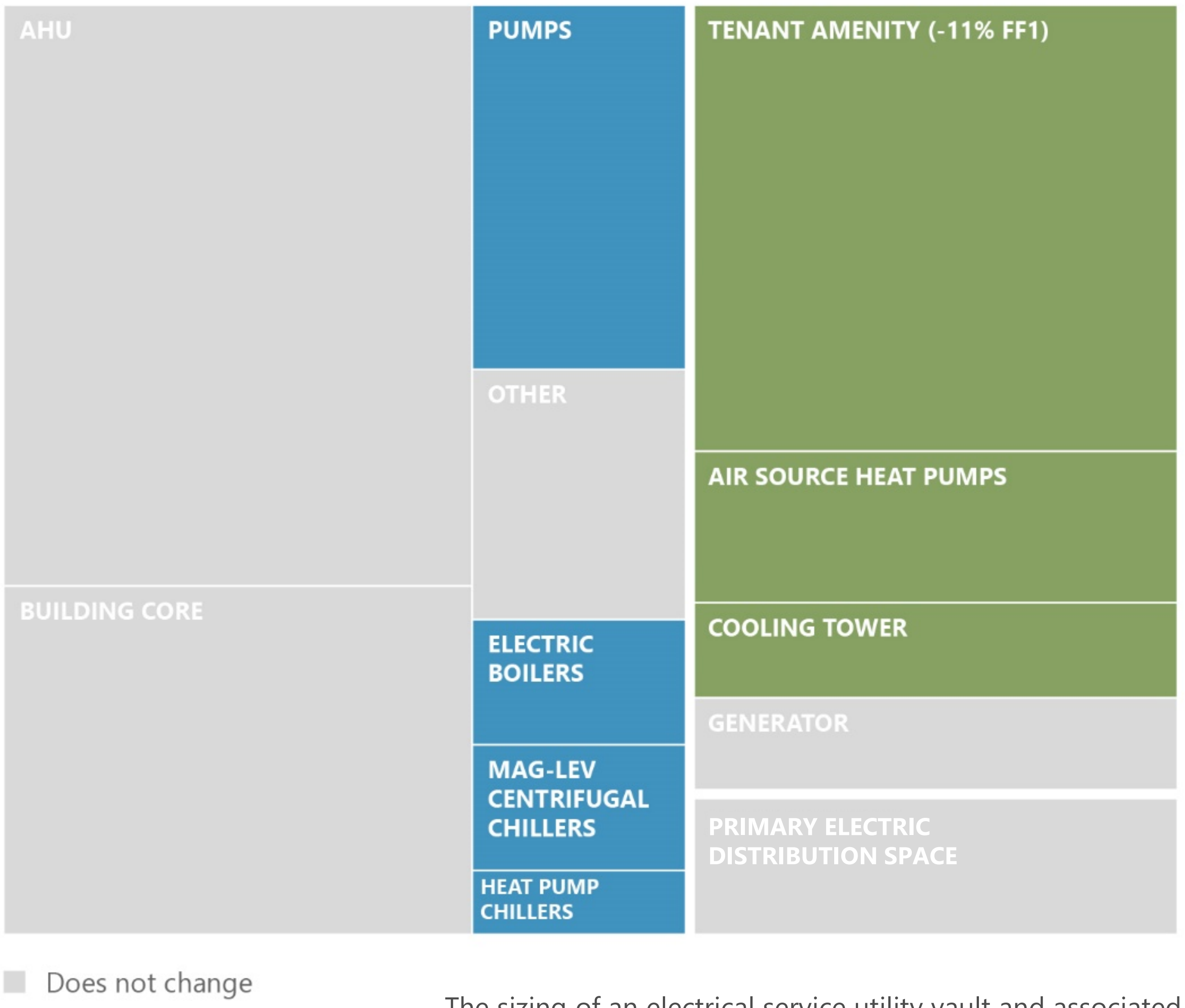
Power purchase agreements and RECs can secure operational costs in the short and long-term; Increase in demand for heat pump technology will drive competition in the market

Space Planning: Boston Office Example

FF1 | 37,500 ft^2



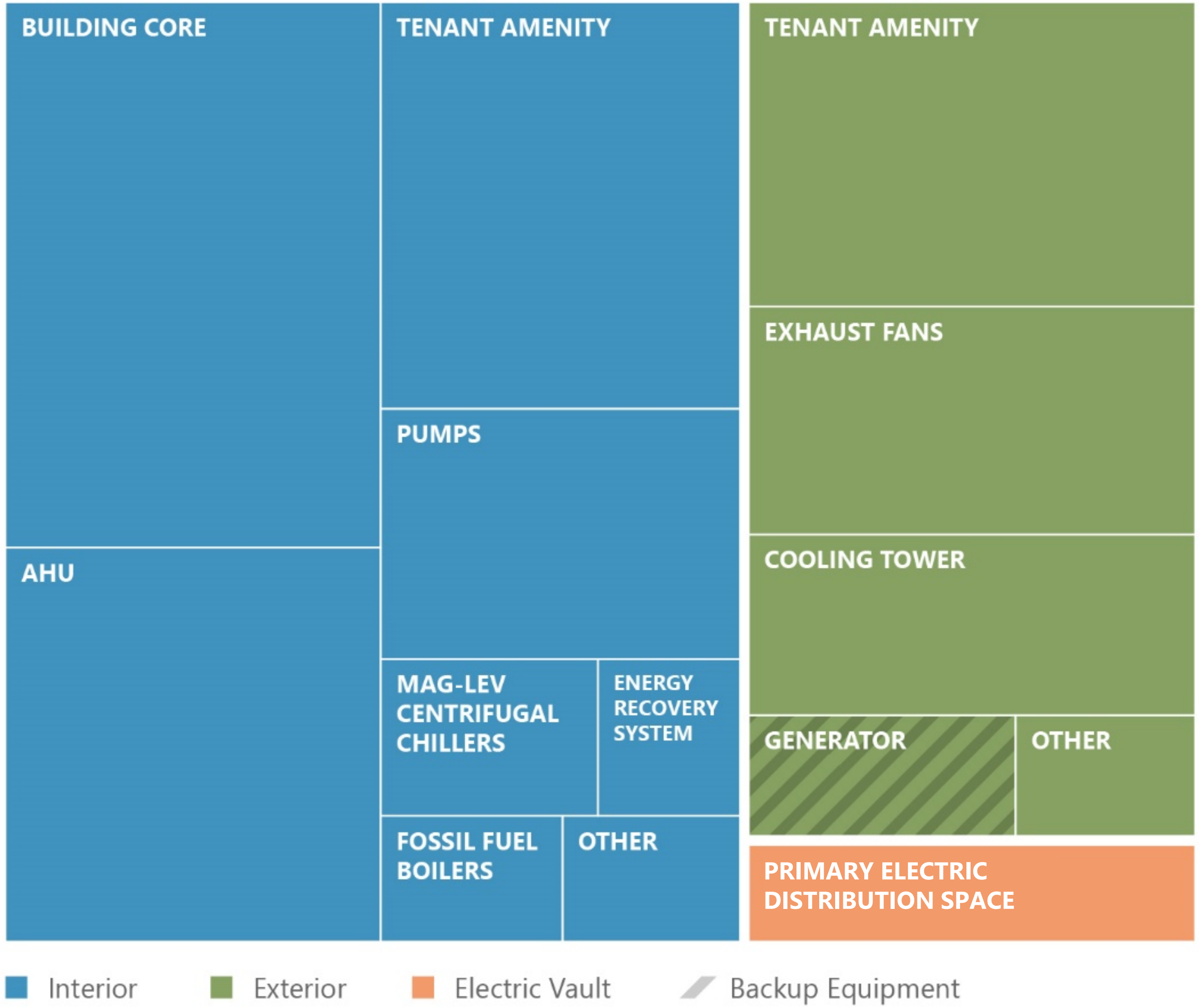
EL1 | 37,500 ft^2



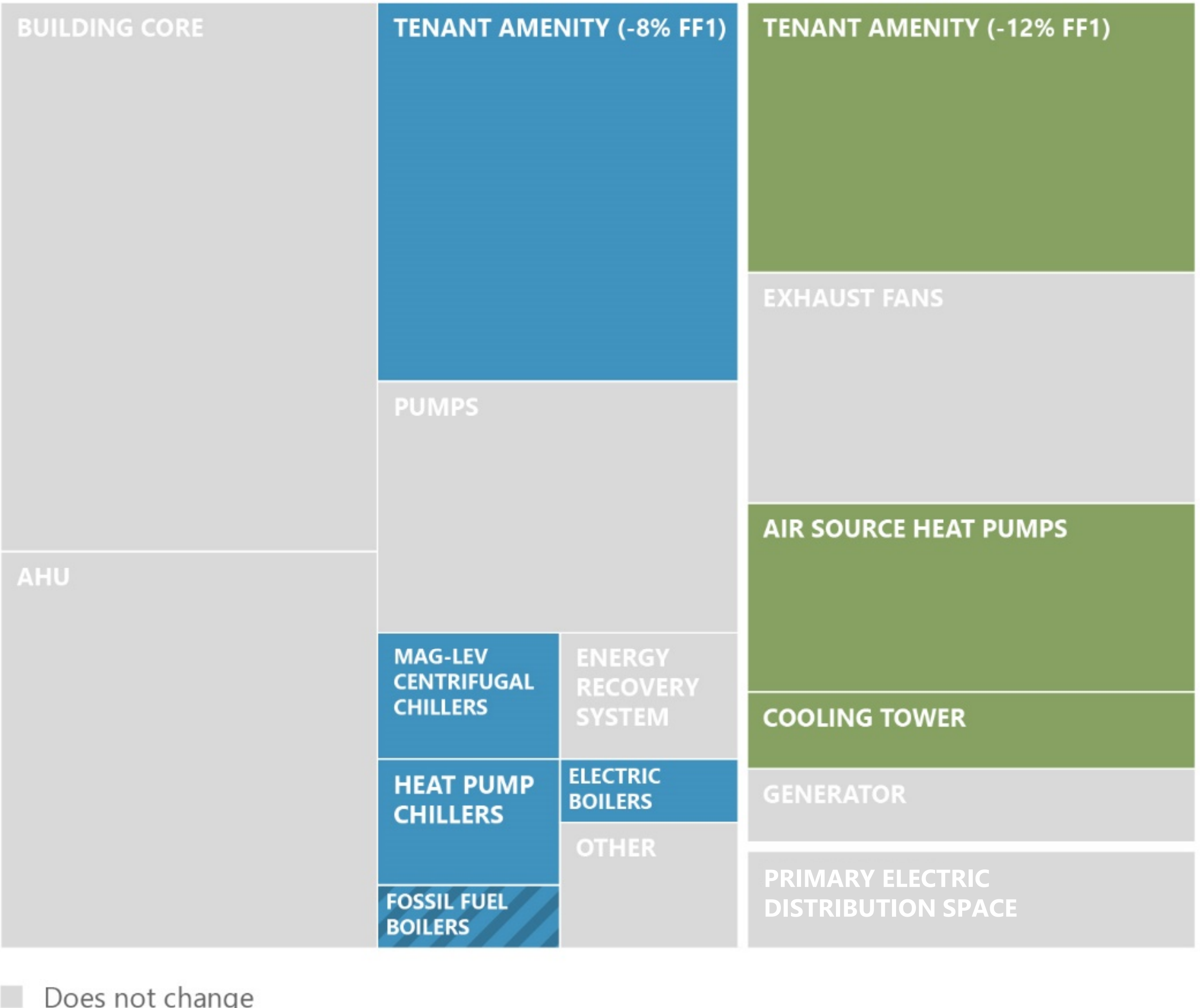
The sizing of an electrical service utility vault and associated electrical rooms will be based on location, building type, and GSF. There is a potential of the vault increase by 25%.

Space Planning: Boston Lab Example

FF1 | 47,000 ft²



EL1 | 47,000 ft²



The sizing of an electrical service utility vault and associated electrical rooms will be based on location, building type, and GSF. There is a potential of the vault increase by 25%.

Capital Cost: Envelope

Higher performing envelopes tend to imply higher first costs.

For example: Upgrading from double to triple-pane glazing improves a building's thermal control, but the increase in material, weight, labor, etc. can result in increased costs.

While the cost of the envelope may increase, improved thermal control can result in downsized mechanical systems, removal of perimeter heating, and reduced monthly utility costs and maintenance.

Additional project examples are needed to illustrate a clear trend of cost impact.

Project (Estimate Year)	Glazing ft^2	Double Glazing $/$ft^2$	Triple Glazing $/$ft^2$	% Inc (Div. 08-41)
A (2019)	110,000 ft^2	$155	$171	+10.3%
B (2020)	100,000 ft^2	$178	$210	+17.9%
C (2021)	45,100 ft^2	Not available	$170	N/A

Capital Cost: Systems

HVAC and Electrical equipment for a small number of projects in the Boston region shows a ~1-5% increase for the M/E budget. The resulting whole-building increase is therefore much smaller.

The increase in cost is dependent on:

- Building program and size
- All-electric vs. all-electric ready
- Back-up power solution
- Climate and design day conditions

Importantly, the ‘additional cost’ examples shown here are compared to a specific baseline design. It is challenging to compare the additional cost when each project is likely comparing different systems.

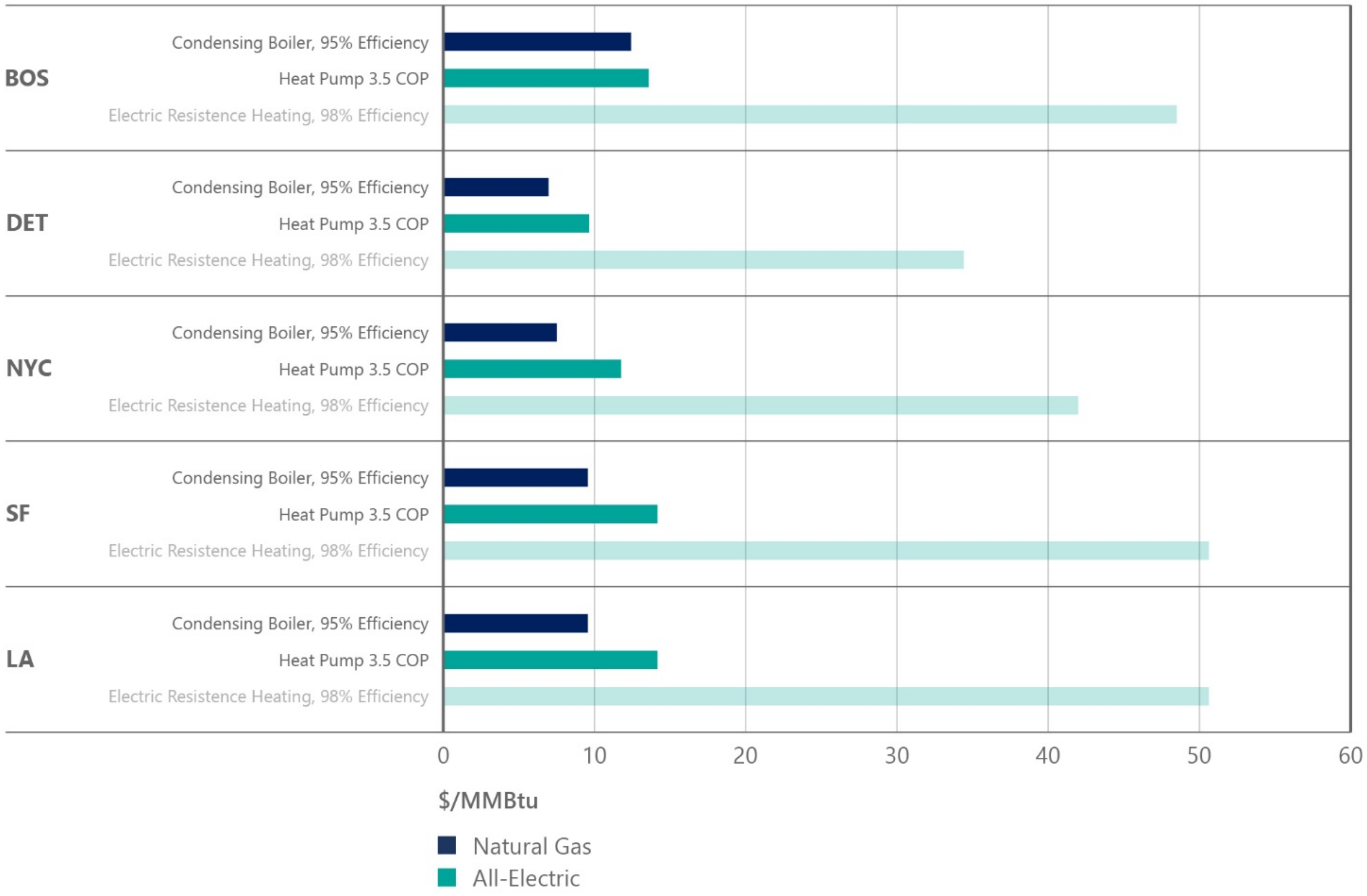
Project	Description	Additional Cost	
		\$/ft^{2}	% of Mech/Elec Systems (Div. 23 + 26)
1	All-Electric Ready – Lab Heat pump heating + supplemental combustion-based heating on an as-needed basis.	+\$1.61/ft^{2}	1.5%
2	All-Electric Ready – Lab Heat pump heating, ASHP heating support + combustion–based heating for periods when OAT <0°F	+\$2.20/ft^{2}	2.6%
3	100% All-Electric – Lab Heat Pump heating, ASHP heating support + electric resistance heating for periods when OAT <0°F. Combustion equipment for back-up only.	+\$5.11/ft^{2}	5.1%
4	100% All Electric – Lab Heat Pump heating, ASHP heating support + electric resistance heating for periods when OAT <0°F. Combustion equipment for back-up only.	+\$4.38/ft^{2}	5.2%
5	100% All-Electric – Office Heat Pump heating + electric resistance heating for periods when OAT <0°F. Combustion equipment for back-up only.	+0.92/ft^{2}	1.2%

Operational Cost: Utilities

Comparison between condensing boilers and heat pumps shows an incremental increase across regions.

Findings:

- Electric resistance heating is not an efficient or cost-effective solution for electrification.
- Heat pump heating for this study is in the range of a 5-10% utility cost premium based on today's electricity and gas costs.
- The impact of a shift to all-electric buildings on electricity and gas prices is currently unknown; theories range from gas becoming cheaper to gas becoming much more expensive.



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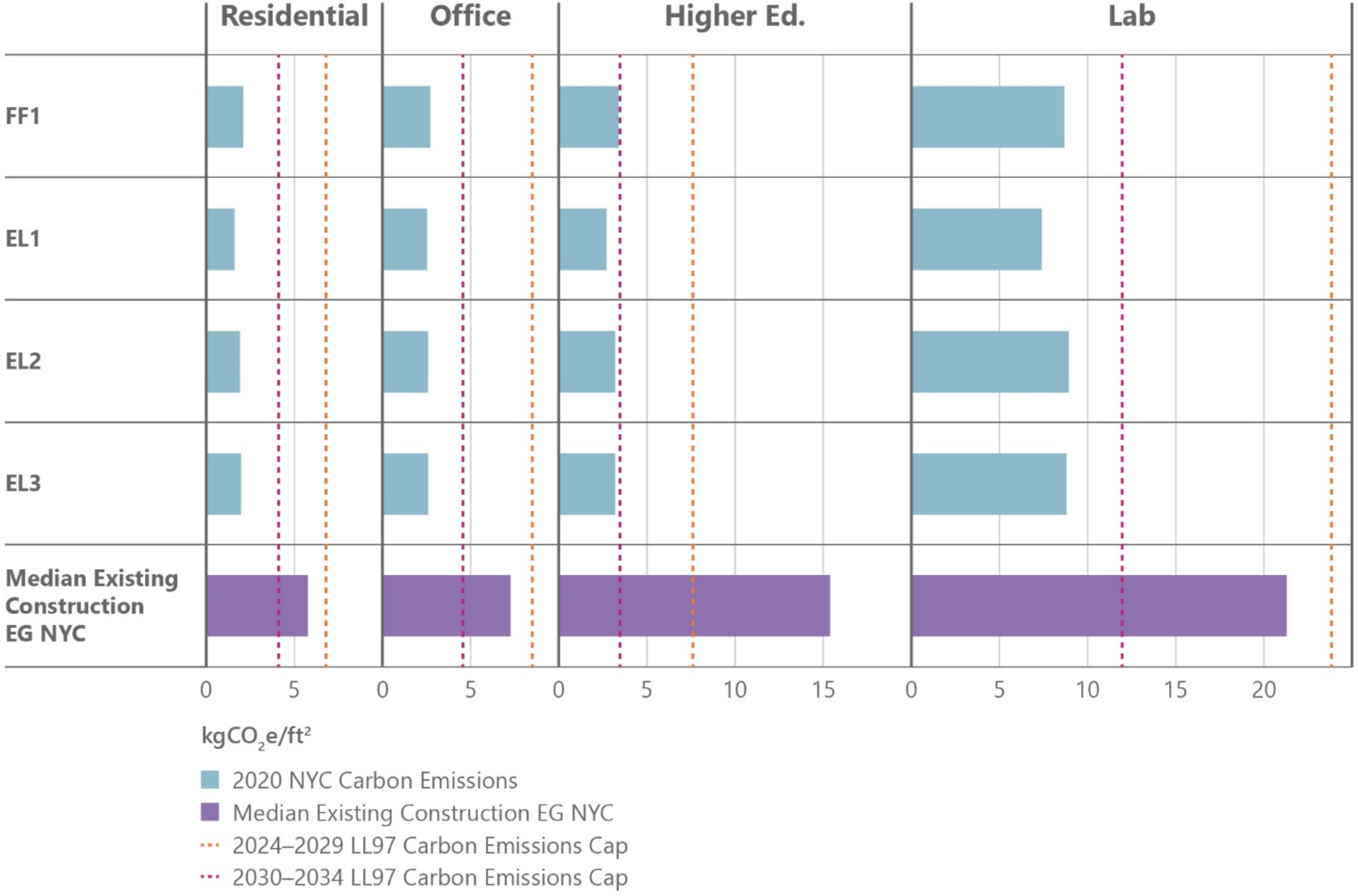
Incentives & Penalties: NYC LL97 Example

New York City's Local Law 97 has introduced carbon emissions thresholds that reduce over time.

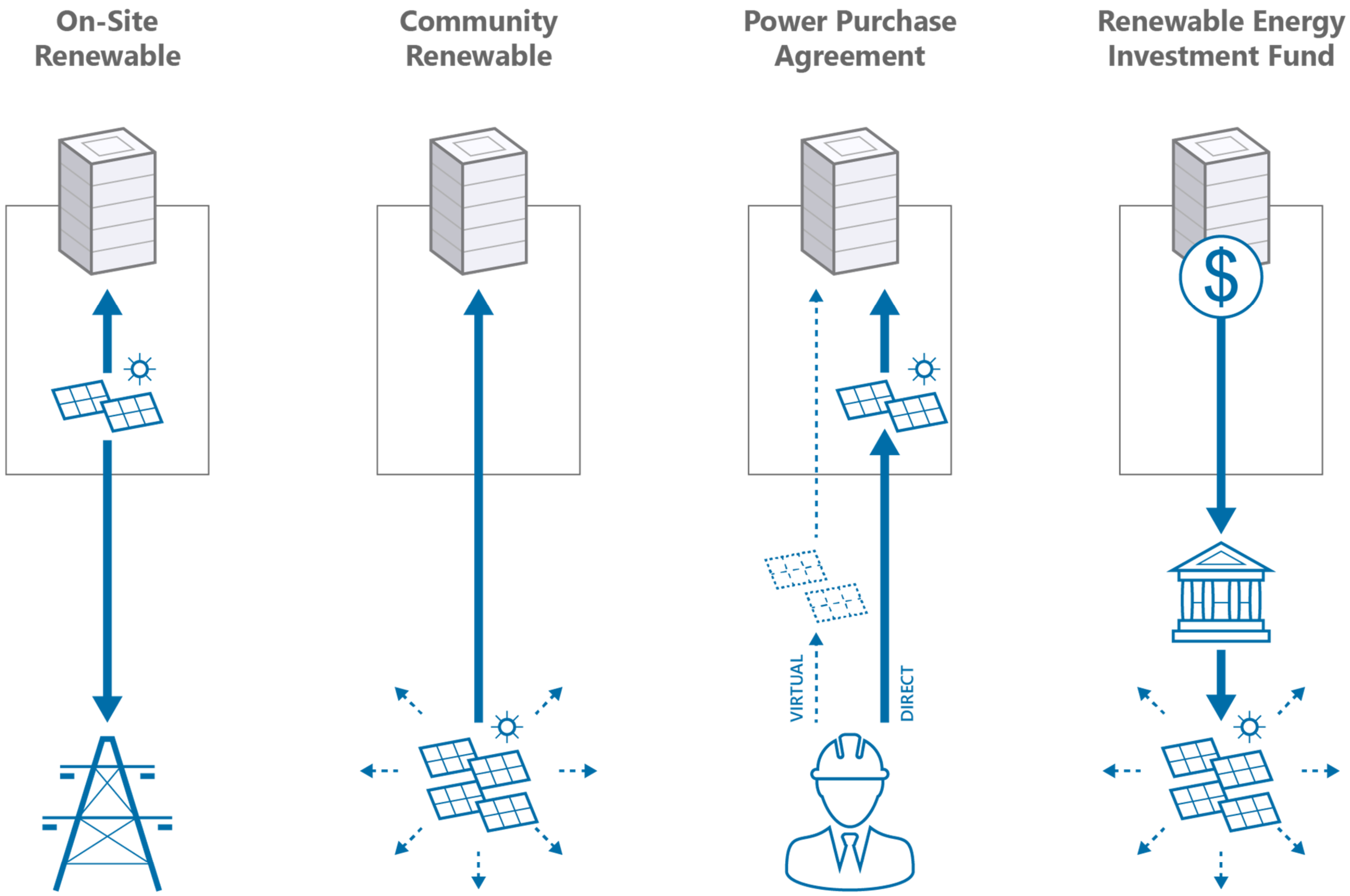
- NYC (LL97) and Boston (BERDO 2.0) are among the first US cities to set emissions limits with clear timelines and penalties.
- A high-performance new construction project in both NYC and Boston is typically well below the near-term emissions requirements.
- The median existing buildings shown for NYC are all exceeding the 3034 emissions cap.
- Building owners now have a clear mandate to reduce emissions.



Market Engagement: Energy Procurement

On-site renewable energy is an excellent strategy, but not always feasible.

- The definition of “zero” is shifting from requiring on-site renewable production to allowing a variety of high-quality offset options, both on- and off-site.
- Power purchase agreements may also allow for known energy costs and related portfolio management.
- Architecture 2030’s ZERO Code has a technical support document for off-site procurement of renewable energy that describes these and other options in more detail.



On-Site Renewable

Community Renewable

Power Purchase Agreement

Renewable Energy Investment Fund

A preliminary study, in summary:

What is the feasibility of all-electric buildings across climate zones and sectors?

A Feasibility Checklist for All-Electric Buildings

GHG Emissions

- ☐ Reduce energy use intensity (EUI)
  - ☐ Design high-performance envelopes to reduce heating loads
  - ☐ Select efficient, all-electric/ready systems
- ☐ Evaluate local grid carbon factors and lifetime GHG emissions

Grid Resiliency

- ☐ Manage and reduce peak loads, particularly heating in cold climates
- ☐ Reduce heating loads below cooling load requirements to optimize connected load
- ☐ Prioritize reliability by developing a grid-interactive building (e.g. demand management strategies)

Technology

- ☐ Maximize use of heat pumps to limit or omit use of electric resistance
- ☐ Rely on fossil-fuel generators where necessary for resiliency, and evaluate opportunities for battery back-up
- ☐ Eliminate on-site combustion

Cost

- ☐ Implement cost-competitive fully-electric systems, such as heat pumps
- ☐ Utilize financial hedging strategies such as PPAs to secure operational costs
- ☐ Study life-cycle costs, including carbon, capex and opex, for a holistic cost analysis

Closing

This is version 01 of a feasibility study that represents some of our work to date and aims to contribute to a dialogue in the industry on decarbonizing the built environment. There are many items to be introduced, challenged and/or developed for the next version, including but not limited to:

- Additional locations
- A list of key resources
- City-scale all-electric studies
- Existing building evaluations
- Other topics mentioned in our climate action agenda (e.g. embodied carbon and social equity)

We look forward to sharing our future work!

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