Building Performance Targets and Building Prototype Profiles for Boston

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and the City of Boston

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INTRODUCTION

Through the Zero Cities Project (ZCP), and with support from the Urban Sustainability Directors Network (USDN), New Buildings Institute (NBI) has provided guidance and technical analysis to the City of Boston (the City) in order to support the development of carbon neutral building zoning codes. This specific research effort and report is an offshoot of the ZCP, which sought to support both cities and their most impacted communities by co-developing and implementing actionable and equitable roadmaps and policy strategies to a zero-net-carbon (ZNC) building sector. Building on NBI's work for ZCP, which included developing advance code measures[1] and zero energy building targets[2], NBI has developed performance targets for buildings in Boston as well as well as design guidance for projects seeking to achieve the levels of performance set forth in this report.

To support the implementation of the performance targets identified in this report, NBI has included descriptions of some of the critical design and building strategies commonly utilized by zero energy (ZE) and high-performance buildings projects. To highlight the importance of some of these design strategies, six building profiles were developed that examined the potential impact of a selection of these strategies by comparing code baseline scenarios to several well documented ZE or high-performance building design approaches. These six profiles are meant to inform the process the City is undertaking in the development of a Carbon Neural zoning policy and should not be interpreted as a set of code or policy recommendations.

Zero Carbon Buildings

The City of Boston has adopted a policy goal to be carbon neutral by 2050 as outlined by the Carbon Free Boston initiative[3]. With regard to buildings, the initiative calls for a transition to zero-net carbon (ZNC) new construction and the development of carbon targets to improve existing building over time. Updating the City's zoning code has been identified as an opportunity to establish ZNC building standards for new construction and major renovations, representing a critical step towards achieving Boston's goal of carbon neutrality.

5 Foundations of Zero Carbon Building Policies

While Boston's goal of carbon neutrality established a clear policy goal for buildings, it provides little insight into the different ways that the construction and operation of buildings impact carbon emissions. As represented in **Error! Reference source not found.**, the following 5 Foundations of Zero Carbon Building Policies are presented as a way to consider the critical policies that must of developed and implemented in order to reduce and offset carbon emissions associated with buildings:

Foundation 1: Energy Efficiency
Energy efficiency still offers many of the least-cost actions to achieve carbon reductions in buildings. By ensuring that policies capture energy efficiency savings, each of the next three foundations becomes easier to meet.

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[1] 20% and 40% Stretch Code Provisions: https://newbuildings.org/code_policy/zero-cities/
[2] Kevin Carbonnier; *Zero Energy Commercial Building Targets;* NBI (2019)
[3] https://www.boston.gov/environment-and-energy/reducing-emissions

Foundation 2: Renewable Energy Resources
Promoting zero carbon and zero carbon-ready buildings requires the understanding that not all building types and locations will have access to enough onsite renewable energy to achieve an annual zero energy balance. Building owners will have to be able to purchase renewable energy from off-site locations as a way to meet their renewable energy requirements.

Foundation 3: Building-Grid Integration
Codes and policies that encourage buildings to generate enough energy to offset their entire annual energy consumption can actually create problems by putting extra burdens on the grid. This occurs when a building's demand for electricity during a day, week or year differs from the time when energy is being supplied by onsite or grid-supplied renewable energy, creating unaligned electricity demand load and generation curves. Codes and policies should encourage building designs that address the variable patterns of generation and consumption on the electricity.

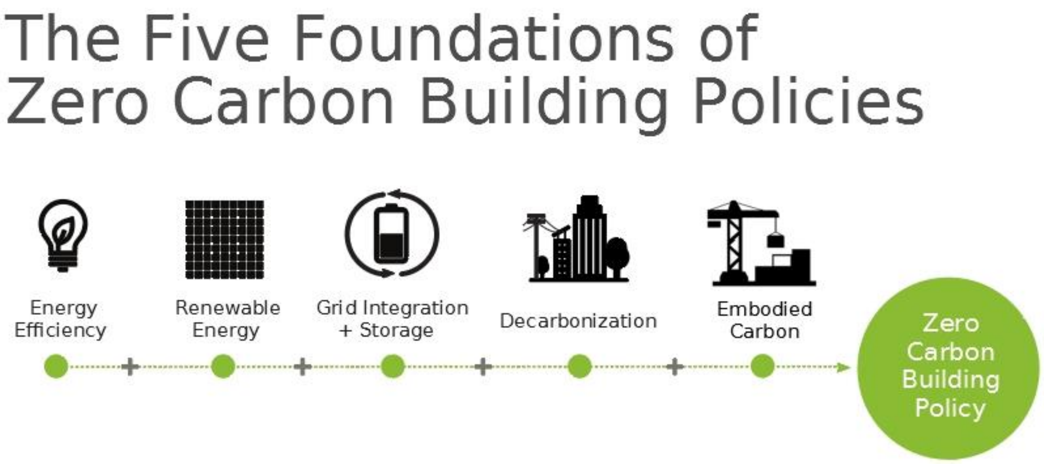

Figure 1: The Five Foundations of Zero Carbon Building Policies (Source: NBI)

Foundation 4: Decarbonization
Decarbonization, which implies the prohibition of onsite combustion, is not a necessary condition for a zero carbon code or policy. However, a growing number of jurisdictions have incorporated these decarbonization objectives in the shorter term. Best practice decarbonization policies should:

- address the transition away from onsite fossil fuel combustion as the electricity grid becomes cleaner,
- have strict standards for what qualifies as a renewable fuel for onsite combustion, and
- ensure that onsite combustion for buildings is not permitted to exacerbate local or indoor air quality problems.

Foundation 5: Embodied Carbon
Policymakers, designers and builders have typically focused on reducing the energy use and carbon emissions associated with building operations by focusing on building envelope, lighting, heating, ventilation, cooling, and equipment. However, as carbon emissions from building operations continue to decrease, embodied carbon will account for a larger and larger share of the emissions from new buildings. As the industry continues to develop standardized systems to track and disclose the carbon

embedded in construction materials, it will be important for jurisdictions to develop policies and incentives for low-carbon building materials.

ZNC Defined

Based on the City of Boston's research objectives and direction, a carbon neutral building, or zero net carbon (ZNC) building, is defined an extremely energy efficient building that is designed and operated to produce, or procure from offsite sources, as much renewable energy as it consumes over the course of a year. This definition aligns with NBI's definition of Zero Energy (ZE) buildings, which is the terminology that is used throughout this report, as it only includes the first two foundations described in the previous section. For this reason it should be considered as a technical resource that only provides insights on the energy efficiency and renewable energy aspects associated with zero carbon building policies and it is recommended that additional building policies that address grid integration and energy storage, decarbonization of fuels, and embodied carbon be developed and implemented as part of the City's approach to carbon neutral buildings.

Performance Targets in Codes and Policies

The use of energy targets is a critical step in the design and execution of zero energy and high performance buildings where the owner, architect, engineer, contractor and other team members use a common performance goal to guide the entire project delivery process. Numerous organizations and above-code building programs, including LEED, EnergyStar, Architecture 2030 and the Passive House building standards, have adopted this target setting approach as a critical strategy to delivering more efficient buildings. More recently, the use of performance targets have started to appear in energy codes such as the 2020 City of Boulder Energy Conservation Code, the 2015 Seattle Energy Code and the British Columbia Energy Step Code.

The inclusion of performance targets in energy codes and building policies represents a significant departure from the current approach applied by the model energy codes and standards as developed and published by the International Code Council (ICC) and ASHRAE. Leveraging building performance energy modeling, this approach shifts the focus from the complexity of prescribing component level efficiency to whole building performance. Most jurisdictions that have taken steps to incorporate performance targets into their local adopted energy codes have done so by developing a project submittal and verification methodology as an alternative compliance pathway.

While this report focuses on the identification of potential performance targets for buildings in Boston, it does not address some of the additional enforcement complexities associated with transitioning to a zoning code that uses predicted building performance targets as a basis for compliance. For an overview of these considerations and potential approaches, please refer to the "Energy Code Roadmap for Getting to Zero Outcomes" brief developed by NBI for the ZCP.

PERFORMANCE TARGETS

One of the primary tasks in this research is to establish ZE performance targets for the City of Boston. NBI developed these targets for six building types in Boston's climate zone. These ZE targets represent zero energy ready performance levels (not including adoption of renewable energy) demonstrated in modeling analyses and in existing buildings throughout North America.

In collaboration with the City of Boston, NBI sought to also compare ASHRAE 90.1-2016 to a level of building energy performance characterized as "maximum technical" potential. This maximum technical potential represents the limits of performance currently achievable with readily available technologies and design practices. The gap between the Massachusetts Energy Code, as represented by ASHRAE 90.1-2016, and the maximum technical potential serves to identify performance levels expected from the current approach to energy codes and helps inform the development of whole-building energy targets when a maximum technical potential approach is applied. This maximum technical potential is one interpretation of a ZE-ready target.

Development of Targets

NBI developed performance targets in line with zero energy ready performance levels for Boston's climate zone, 5A. The targets compare current code level (ASHRAE 90.1-2016) to high-performance building targets based on modeling analyses and measured data from NBI's getting to zero database. For the laboratory building type, NBI conducted a separate analysis as detailed below. These achievable levels of building performance can serve to inform policy decisions for the development of a ZE zoning code.

Building Types

The project team, as directed by the City of Boston, developed energy targets for a variety of buildings types. Except for the laboratory type, the building types match those analyzed by the Pacific Northwest National Laboratory (PNNL) as part of their code determination analysis. The City of Boston identified these buildings types as high priority. See the list of types below.

Table 1: Building Types included in this report

20-story High-Rise Apartment
Secondary School
Medium Office
Large Office
Large Hotel
Laboratory

Baseline Performance

The newly adopted Massachusetts energy code references IECC 2018 and ASHRAE 90.1-2016. This performance level serves as the baseline condition for the analysis. For laboratories, an analysis of existing labs in Cambridge serve as the baseline in lieu of standard laboratory prototype energy models. This baseline condition is the starting point from which potential savings up to the zero energy performance target levels are established.

Zero Energy Performance

To represent the endpoint for the potential savings analysis and establish energy targets, NBI has identified zero energy ready performance levels for each building type and Boston's climate zone. The zero energy ready performance levels are based on research conducted by NBI within the Zero Cities Project, and pull together a mix of modeled analyses and measured performance data for existing zero energy buildings in North America. The full report on zero energy performance targets – titled *Zero Energy Commercial Building Targets* - is available online[4]. These whole-building energy performance levels, measured in kBtu/ft², are achievable with currently available technology and advanced design practices. Design guidance for reaching low energy consumption levels in various building types are available in NBI's zero energy resources hub[5]. For laboratories, NBI based the zero energy levels of performance on exemplary laboratories representing real-world examples of high-performance laboratories.

Results

The energy performance targets developed for Zero Cities for the Boston climate zone are included below and customized by building type. These energy targets represent a starting point that policymakers may adjust, taking into account weather conditions and specific characteristics of individual building designs that may merit an increase or decrease in the energy target.

Whole Building Performance

NBI developed whole-building performance targets by combining multiple energy modeling studies and measured data from zero energy buildings throughout North America. More detail on the methodology of the target development are available in a separate deliverable for Zero Cities[4]. The targets presented herein are based on climate zone 5A - Boston's climate. In brief, the performance targets combine an average of various maximum technical potential studies and median EUI values for existing zero energy projects. We weighted measured data from existing buildings more heavily than modeling studies, combining the two sets for each buildings type after normalizing the data by climate zone.

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[4] https://newbuildings.org/resource/zero-energy-commercial-building-targets/

[5] https://gettingtozeroforum.org/technical-resources/

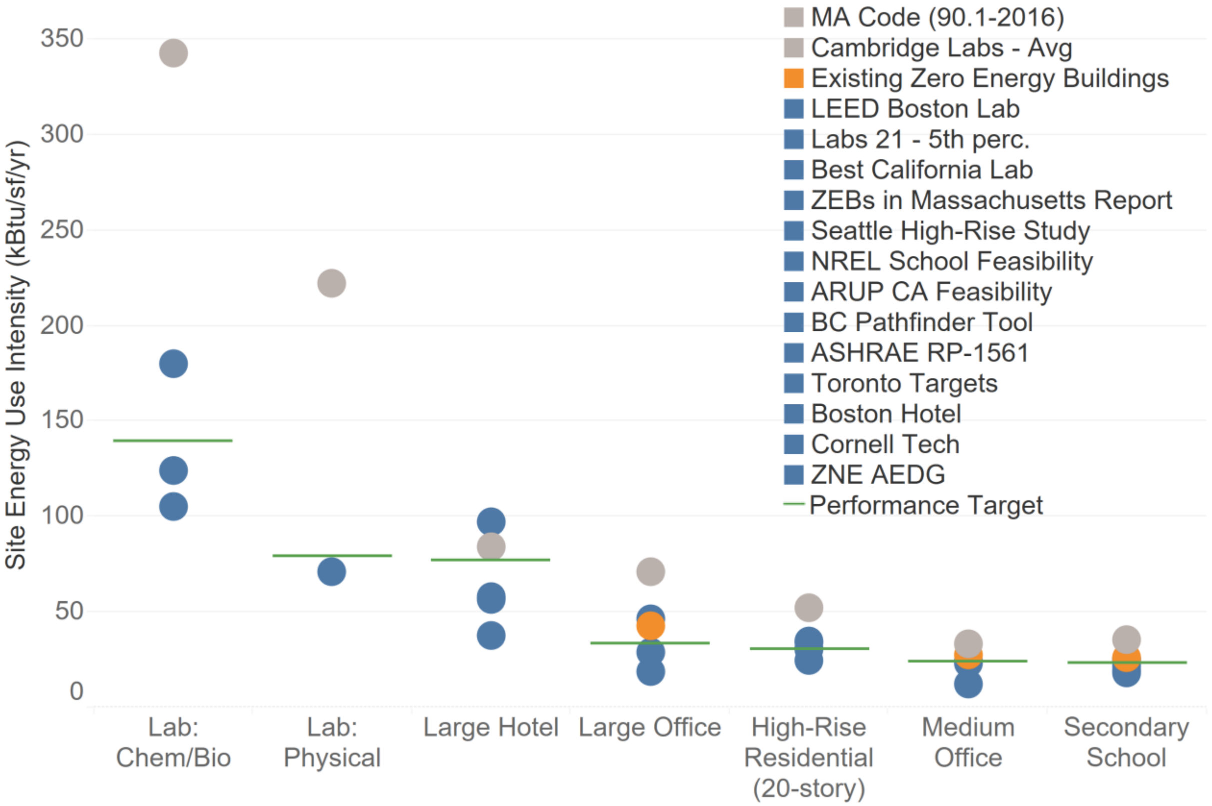

Figure 2: Energy performance comparison of MA Energy Code, modeling analyses, measured data, and recommended energy performance targets by building type. All energy use intensities are normalized to Boston's climate zone (5A).

Figure 2 above plots each of the modeling analyses representing zero energy performance levels as blue circles. The Massachusetts Energy Code (ASHRAE 90.1-2016) modeled performance levels are included as grey circles for context. The measured energy data for existing buildings are included as orange circles, where available. Finally, the recommended targets are shown as green bars in the figure above and identified by EUI in Table 2, below.

Table 2: Recommended whole-building Zero Energy Ready performance targets for Boston

Building Type	MA Code Performance [kBtu/sf/yr]	Performance Target [kBtu/sf/yr]	Percent energy reduction to target
20-story High-Rise Apartment	52	31	40%
Secondary School	35	24	31%
Medium Office	33	25	24%
Large Office[6]	70	34	51%

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[6] The large office prototype includes a data center, which significantly increases the predicted energy use.

Large Hotel	84	78	7%
Physical Laboratory	-	80	-
Chem/Bio Laboratory	-	140	-

Performance Variability

A range of factors can impact the energy performance of commercial buildings in ways that can be difficult to predict. While the use of performance targets can be a valuable tool for designers and policy makers looking to improve the performance of buildings, it is also important to allow for actual building performance to be recalibrated, not only when compared to its design (modeled) performance, but also from year to year.

In order to introduce this topic, the following variables were identified by referring to those considered by Portfolio Manager and a modeling exercise conducted by Ecotope and NBI[7]. These two analyses point to a common set of variables for policymakers to keep in mind when adjusting energy performance targets for buildings. We recommend further studies to determine to what degree each of these variables would influence energy use in buildings built to current and future iterations of the code in Boston's climate for each of the building types the city prioritized in this project. Table 3 lists the top recommended variables for further study across all building types.

Table 3: Summary of impactful variables to consider for energy target adjustments

Category	Variable	Estimated Impact Level
Climate-driven	Heating degree days	Low
	Cooling degree days	Low
Occupant-driven	Occupants/Workers per area	Medium to High
	Number of computers/equipment per area	Medium to High
Building-driven	Operating hours and seasonal use	Medium
	Percent of building heated	Low to Medium
	Percent of building cooled	Low
	Space use type	High
	Data Center or process loads present	Medium to High

Building Type Prioritization

Certain building types make good candidates for the use of predicted performance targets while other building types can be more challenging. This results from the fact that some building types are more

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[7] https://newbuildings.org/resource/sensitivity-analysis-comparing-impact-design-operation-and-tenant-behavior-building-energy-performan/

challenging than others to characterize and that more predictable building types represent the easiest place to start on the performance path. Based on our analysis, the following building types make good candidates for building performance targets:

- 10-story High-Rise Apartment
- 20-story High-Rise Apartment
- Secondary School
- Large Office (although the presence of a data server can cause some variability)
- Warehouse

ZE BUILDING STRATEGIES

For the purposes of this report and the definition of carbon neutral articulated by the City of Boston, the following section describes some of the building strategies that are common to zero energy buildings that should be prioritized in order to achieve the performance targets described in the previous section of this report. The order in which the strategies are presented, starting with energy efficiency and followed by on-site renewable generation and offsite renewable energy procurement, represents the loading order in which these strategies should considered.

Energy Efficiency

Buildings that have achieved zero energy levels of performance have demonstrated that prioritizing energy efficiency is the most cost-effective way to achieve the levels of performance described in this report. This is achieved by leveraging the synergies between different energy efficiency measures, which can help optimize performance while keeping costs down.

Envelope

The thermal envelope of a building is comprised of many different elements that can be combined into a wide variety of assembly types. When considering assembly types, decision represents an opportunity to improve the thermal performance of the envelope and impact the energy outcome of the building. From the earliest stages of design, the team must consider building components and configurations that take advantage of climate conditions and reduce thermal, solar and internal loads. To achieve a high-performance thermal envelope typical of ZE buildings, the following strategies must be prioritized:

Low Window-to-Wall Ratio (WWR)

Designers of ZE building have demonstrated that a WWR of 30% is a good balance between achieving the level of thermal performance needed from the envelope without compromising daylighting opportunities and view glazing for building occupants.

Energy Code Context: Both prescriptive paths of IECC-2018 and ASHRAE 90.1-2016 have a 40% WWR limit. Projects complying with the prescriptive path of IECC-2018 that fall between 30% and 40% WWR must meet additional daylighting requirements. Projects that exceed 40% WWR must follow the performance path and use energy modeling to demonstrate code equivalency.

Reducing Thermal Bridging

Thermal bridging occurs when thermally conductive materials break the continuity of the insulation layer of an assembly and create a bridge between the exterior and interior thermal environments. Metal window frames, uninsulated parapet walls, slab edges, and metal or concrete structural extrusions often used to support balconies can create thermal bridges.

The first step to reducing thermal bridges is to account for them when designing building envelopes. The energy code allows three methods to comply with opaque envelope requirements—the R-value method, the U-factor method and the Component Performance Alternative—and all three allow projects to largely ignore the thermal bridges between envelope components and between the envelope and the structure. Using the specifications for an assembly that composes only the “field” part of the assembly to meet code requirements neglects envelope and structural interfaces. Use the area-weighted average for the opaque envelope to account for thermal bridging. Structural elements that comprise a direct, uninsulated path to the building exterior and have a combined surface area that exceeds 0.5% of area of the envelope component of which they are part (roof, wall, etc.) should be included as discrete building areas in the area weighted average calculation of envelope thermal performance.

Area Weighted U-Factor (UA) for Vertical Assemblies and Glazing Systems

An area weighted U-factor considers both the U-factor of vertical opaque assemblies, the U-factor of vertical glazing systems and the impact of thermal bridges to provide a good indication of the overall performance of a buildings envelope. As the insulated, opaque portions of the envelope provide higher levels of thermal performance when compared to glazing systems, the relative area of each of these components can dramatically impact the overall UA number.

Reducing Infiltration

The use of a continuous air barrier in building enclosures aims to reduce uncontrolled airflow through the assembly, which cuts back on heat loss and can improve occupant health and envelope durability by limiting water and vapor infiltration. Ensuring performance of the air barrier starts with careful design and appropriate detailing. Include an air barrier continuity plan in construction documents that includes a schedule of details showing typical joints between air-barrier materials, assemblies and fenestration.

During construction, use envelope commissioning and whole-building blower door testing to verify the continuity and quality of the installed air barrier. Blower door testing should target an air leakage rate of 0.25 cfm/ft^2 of enclosure area, in accordance with ASTM E779 at pressure differential of 0.3-inch water gauge (75 Pa). Projects where a whole-building blower door test is not feasible should consider either a floor isolation blower door test or compartmentalization testing.

Efficient Heating, Cooling and Ventilation Systems

The type and configuration of a building's HVAC systems will greatly impact its performance outcomes. ZE buildings often feature HVAC systems that leverage passive design principles by taking a whole-system approach to space conditioning and ventilation. Taken together, these active and passive systems must respond to a variety of factors, including internal loads from occupants and equipment as well as external factors such as climate and solar exposure. All specified mechanical equipment should be appropriately sized to the load it is meeting and should never be oversized as a rule.

Low Annual Thermal Energy Demand Intensity (TEDI)

TEDI provides a measure of the amount of energy a building requires to maintain an indoor temperature that is comfortable for occupants per square foot of conditioned floor area per year. It considers both passive gains (solar radiation and internal gains from appliances and lights) and losses (from thermal transmittance) as well as the energy used for the purposes of space and ventilation conditioning. This includes all central systems as well as terminal equipment regardless of fuel type. TEDI is a useful metric for calculating energy consumption associated with heating and cooling loads as a function of the envelope design. TEDI can be calculated with modelling software and is the amount of heating and cooling energy delivered to the project that is outputted from any and all types of space conditioning equipment, per unit of gross floor area.

Specify High-Performance Heating and Cooling Equipment

The most efficient heating and cooling equipment commercially available today leverages heat pump technology to move heat from inside to outside the building during the cooling season and from outside to inside during the heating season. There are three primary types of heat pumps that vary based on the source of the heat being utilized: air-to-air, water source, and ground source (or geothermal). While this technology can be characterized by a high coefficient of performance (COP), a wide range of variables can impact the efficiency of these systems making it critical to consider the temperature range of the heat source as well as the annual and peak heating and cooling loads.

An additional efficiency benefit of specifying heat pump-based technologies is that they pair well with ductless or radiant/hydronic distribution approaches. Air has a very low capacity to carry heat, making it a poor medium for delivering and removing heat from spaces. Generally, this means that a larger mass of air is required to heat and cool a building with an air-based distribution system when compared to a system that uses water or refrigerant. Additionally, the fan power associated with moving large amounts of air can result in a less efficient system when compared to hydronic or refrigerant based distribution systems.

Efficiently Ventilate with a Dedicated Outdoor Air System (DOAS)

Meeting the ventilation requirements of a building can be most efficiently achieved by “decoupling” it from the heating and cooling systems. Known as a dedicated outdoor air system (DOAS), this system is designed to meet 100% of the code ventilation requirements for all indoor spaces. These systems can be highly tailored to leverage efficient strategies such as demand controlled ventilation (DCV) and energy recovery ventilation (ERV). When outside air does not require tempering, a DOAS can serve as an economizer, efficiently meeting the building’s space-conditioning needs during these conditions.

Efficient Hot Water Systems

The energy use associated with heating and distributing hot water can be one of the largest end-uses in some commercial building types, such as multifamily residential, hotels and restaurants making it an essential load to reduce for projects seeking to achieve the performance targets described in this report. There are three primary components that need to be addressed to improve the performance of water heating systems: the efficiency of the water heating equipment, water conservation at the point of use, and the distribution system. High performance water heating requires careful consideration of all three of these components in the system design as well as leveraging opportunities for heat recovery whenever possible.

Specify High Efficiency (Electric) Equipment

Rapid advancements in heat pump technologies are driving performance levels in hot water heating equipment that exceed minimum code requirements. Targeting a Coefficient of Performance (COP) above 1 will help guarantee the deployment of heat pump water heating technologies.

Efficient Interior Lighting and Controls

The wide proliferation of solid-state lighting combined with deep and ongoing improvements in the efficacy of LED lighting technology has resulted in very low-power lighting installations that often exceed the values in even the most efficient energy codes.

Specify High Efficacy Luminaires

Luminaire efficacy differs from the lighting power density (LPD) approach used in most energy codes, which regulates total connected lighting load. Luminaire efficacy describes the efficiency of the entire luminaire in converting energy to delivered light (in lumens/watt). It accounts for the entire luminaire, including the light source, ballast and luminaire losses. When specifying high efficacy luminaires, consider products from the DesignLights Consortium's Qualified Products List[8].

Networked Lighting Controls (NLC)

Advanced lighting control strategies are capable of individual space control when provided by an NLC system or a fixture-level control approach as provided by a luminaire level lighting control (LLLC) system. These systems can reduce lighting levels based on ambient light needs, occupancy, schedule, or use patterns. When specifying an NLC system, consider products from the DesignLights Consortium's Qualified Products List[9].

Reducing Plug Loads

Implementing strategies and building features that reduce plug and process loads (PPLs) is a critical component of improving whole building energy performance, especially as these loads continue to increase relative to the other primary building loads. PPLs are typically defined as electric loads that result from electric devices that are not responsible for space heating, cooling, water heating or lighting. Plug loads are generated by hard-wired and plug-in devices such as computers, monitors, printers, projectors, kitchen equipment, data center servers and, elevators, as well as other portable equipment such as space heaters and fans. Critical PPL reduction strategies include automatic controls, the specification of efficient appliances, and providing the capability to monitor and manage them overtime.

Specify Automatic PPL Controls

Specifying building controls that are capable of turning off PPL equipment when they are not in use or when the building is not occupied is the most effective approach to managing and reducing PPLs. This can be accomplished by providing automatic receptacle control that powers off those circuits based on a timer, programmed schedule or an automated signal from an occupant sensor or a building energy management system (BEMS).

Specify Efficient Appliances and Equipment

All appliances and equipment should comply with the equivalent criteria required to achieve the ENERGY STAR® label. This applies to, but is not limited to, the following equipment and/or appliance types:

- Electronics
- Office equipment
- Commercial food service
- Heating and cooling
- Lighting
- Water heating

Permanently submeter PPLs

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[8] https://www.designlights.org/solid-state-lighting/

[9] https://www.designlights.org/lighting-controls/search/

Aggregate all PPLs on a dedicated electrical circuit that is labeled at the electrical panel and organized by tenant or floor. Include information about dedicated PPL circuits and metering in the final construction documents. This will help ensure there is adequate space in the panel for the installation of the metering equipment, and that the electrical contractor is aware of the circuiting requirement.

Onsite Renewable Energy Generation

After minimizing building energy loads through passive systems and efficiency, projects should evaluate options to produce energy on-site from renewable energy systems. Solar PV is almost always the most cost-effective way to create energy on-site, usually followed by solar thermal systems. The following strategies can help optimize onsite solar PV production.

Evaluate Solar Access

Shade cast from surrounding trees and buildings can reduce solar access, minimizing available on-site energy production potential from photovoltaics. Use bioclimatic analysis to select the best array location, keeping in mind that new and future buildings or design elements such as awnings, cooling towers, and other architectural and mechanical elements that could hinder the future production of energy. When siting options are limited, or an existing building shades the roof area, ground or vertically mounted PV arrays may be the best opportunity before researching to off-site generation.

Maximize Roof Area

Maximize the roof area available for solar panels by consolidating and minimizing rooftop equipment. Be sure that the structure can support the 2-6 lbs/ft2 that solar PV and thermal panels add.

Offsite Renewable Energy Procurement

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ZE BUILDING PROFILES

The following section takes the six building types for which the performance targets were generated in the **Error! Reference source not found.** section of this report and focuses on four building strategies from the previous section that can be considered critical to the achieving those targets. Table 4 indicates which energy measures were explored in each building type profiled.

Table 4: Energy Efficiency Strategies Explored by Building Type

Building Type	Envelope Strategies	HVAC Strategies	Hot Water System Strategies	Plug Load Reduction Strategies
Large Office	X	X		X
Medium Office	X	X		X
Secondary School	X	X		X
Large Hotel	X	X	X	
High-Rise Residential	X	X	X	
Laboratory		X		X

While a wide range of energy efficiency measures should be explored and evaluated as part of the design process for a ZE building, these four measures have been selected to be explored for these building types as they represent a significant opportunity to go beyond energy code in order to significantly reduce primary building loads.

Each building profile includes a summary description of the prototype building[10] evaluated and the ZE performance targets in terms of site EUI. The strategies section includes a set of design targets associated with each strategy that can be considered as a good threshold for reducing primary building loads and optimizing performance. In order to put these design targets into context, each strategy concludes with a section where the design target is compared to other reference points, including the code baseline assumption, a high-performance/ZE building or resource, and in the case of the envelope strategies, assemblies representative of Passive House levels of performance.

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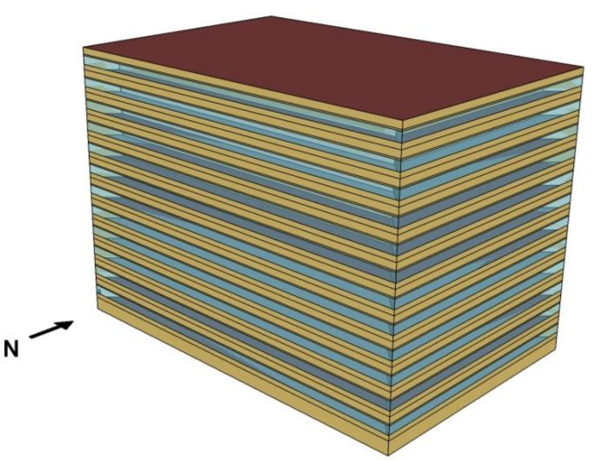
[10] https://www.energycodes.gov/development/commercial/prototype_models

Large Office

Large Office Prototype Building	
498,600 Sq. Ft.	
240’ X 160’ Floor Plate	
11 Stories	
13’-00” Floor-to-Floor Height	
40% WWR	

Performance Target

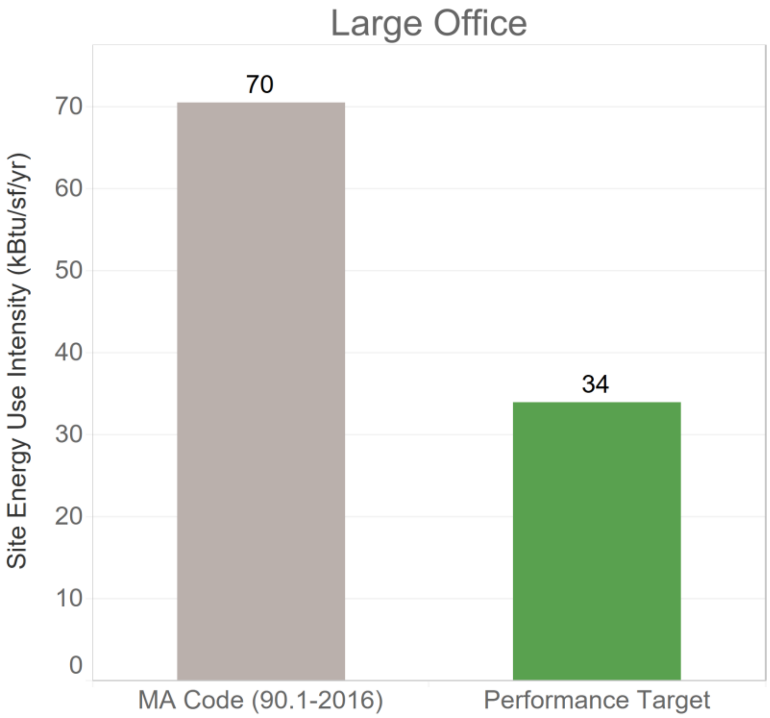


Figure 3: Large Office ZE Target

Strategies

To reach the high-performance levels in the performance targets set in this report, the following design strategies should be prioritized:

1. Improve envelope to reduce heating, cooling and infiltration loads
2. Specify efficient heating, cooling and ventilation systems
3. Reduce and manage plug loads

1. Envelope Strategies

Strategy	**Target**
Low Window-to-Wall Ratio (WWR)	30% - 40%
Area Weighted U-Factor (UA) for Vertical Assemblies and Glazing Systems	≤ 0.15
Reducing Thermal Bridging	Account for structural elements that comprise a direct, uninsulated path to the building exterior as part of UA calculation
Reducing Infiltration	Infiltration rate: ≤ 0.25 cfm/ft2 at 75 Pa

Area-weighted Average U-Factor (UA) Reference Points

	Code (2018 IECC)	ZE Building (USGBC-MA Study)[11]	Passive House Equivalent
Opaque Wall Assembly	0.064	0.044	0.028
Window U-Factor	0.38	0.3	0.19
WWR	40%		
Area Weighted Average U-factor	**0.19**	**0.15**	**0.09**

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[11] https://usgbcma.org/wp-content/uploads/2019/09/ZeroEnergyBldgMA2019.pdf

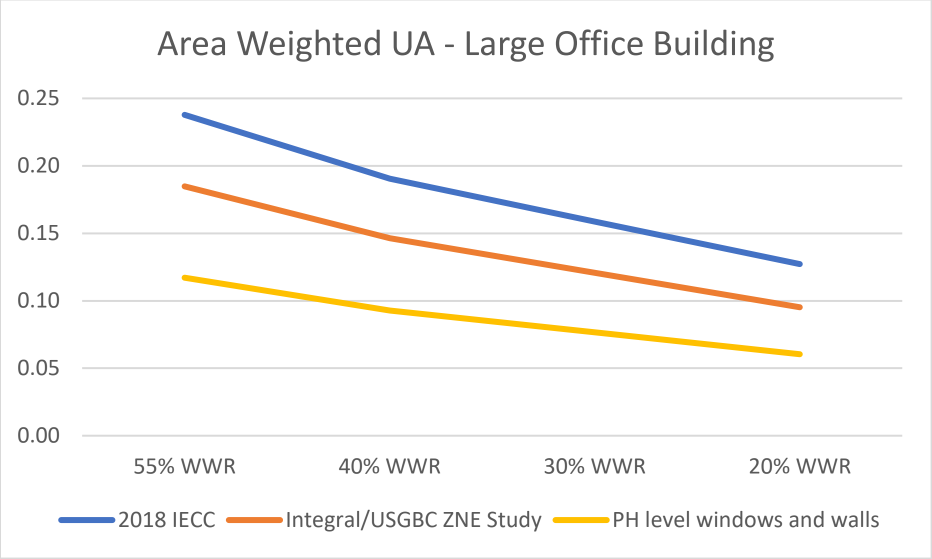


Figure 4: Large Office UA Comparison

2. HVAC Strategies

Strategy	**Target**
Specify High-Performance Heating and Cooling Equipment	Air-to-air, water source, and ground source (or geothermal) Heat Pump Technologies
Efficiently Ventilate with a Dedicated Outdoor Air System (DOAS)	DOAS plus ERV

Low Annual Heating and Cooling Demand Intensity (Thermal Energy Demand Intensity) Reference Points

Code Equivalent TEDI (2018 IECC)	ZE Equivalent TEDI (USGBC – MA Study)
20.14	6.3

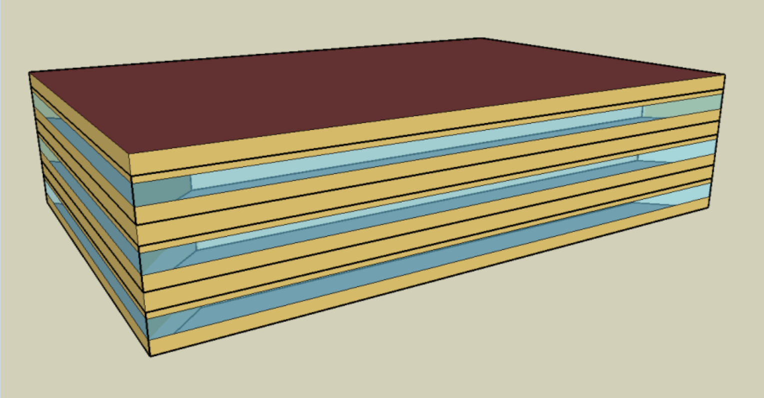
3. Plug Load Strategies

Strategy	**Target**
Specify Automatic PPL Controls	50% of receptacles controlled by automatic control device
Specify Efficiency Appliances and Equipment	Construction Documents call out ENERGY STAR® labeled equipment and appliances
Permanently submeter PPLs	Construction Documents call for all PPLs to be on a dedicated electrical circuit that is labeled at the electrical panel and organized by tenant or floor

Average Equipment Power Density (modeled) Reference Points

Equipment Power Density – Code Baseline	Equipment Power Density – ZE Equivalent (USGBC – MA Study)
46.4 kBtu/ft2/yr	11.9 kBtu/ft2/yr

Medium Office

Medium Office Prototype Building	
53,600 Sq. Ft.	
164’ X 109’ Floor Plate	
3 Stories	
13’-00” Floor-to-Floor Height	
33% WWR	

Performance Target

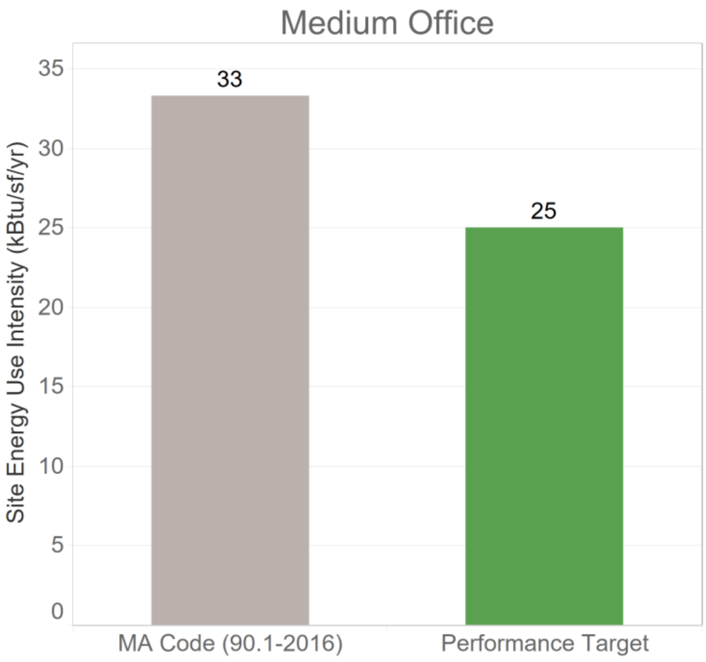


Figure 5: Medium Office ZE Target

Strategies

To reach the high-performance levels in the performance targets set in this report, the following design strategies should be prioritized:

1. Improve envelope to reduce heating, cooling and infiltration loads
2. Specify efficient heating, cooling and ventilation systems
3. Reduce and manage plug loads

1. Envelope Strategies

Strategy	**Target**
Low Window-to-Wall Ratio (WWR)	30% - 35%
Area Weighted U-Factor (UA) for Vertical Assemblies and Glazing Systems	≤ 0.15
Reducing Thermal Bridging	Account for structural elements that comprise a direct, uninsulated path to the building exterior as part of UA calculation
Reducing Infiltration	Infiltration rate: ≤ 0.25 cfm/ft2 at 75 Pa

Area-weighted Average U-Factor (UA) Reference Points

	Code (2018 IECC)	ZE Building (ASHRAE AEDG – Zero Energy)[12]	Passive House Equivalent
Opaque Wall Assembly	0.064	0.052	0.028
Window U-Factor	0.38	0.34	0.19
WWR	33%		
Area Weighted Average U-factor	**0.17**	**0.15**	**0.08**

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[12] https://www.ashrae.org/technical-resources/aedgs/zero-energy-aedg-free-download

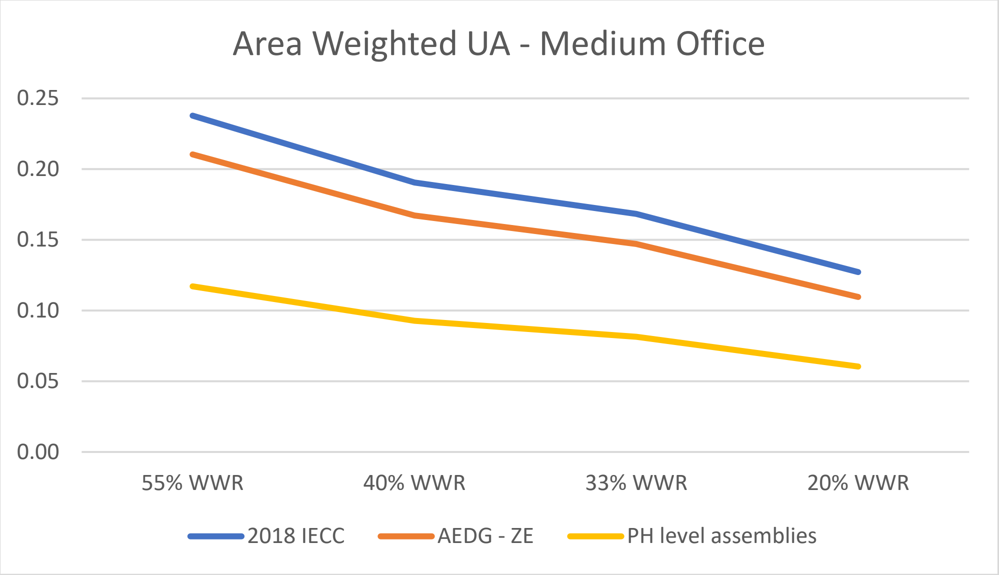

Figure 6: Medium Office UA Comparison

2. HVAC Strategies

Strategy	**Target**
Specify High-Performance Heating and Cooling Equipment	Air-to-air, water source, and ground source (or geothermal) Heat Pump Technologies
Efficiently Ventilate with a Dedicated Outdoor Air System (DOAS)	DOAS plus ERV

Low Annual Heating and Cooling Demand Intensity (Thermal Energy Demand Intensity) Reference Points

Code Equivalent TEDI (2018 IECC)	ZE Equivalent TEDI (Bullitt Center[13])
12.06	2.93

3. Plug Load Strategies

Strategy	**Target**
Specify Automatic PPL Controls	50% of receptacles controlled by automatic control device
Specify Efficiency Appliances and Equipment	Construction Documents call out ENERGY STAR® labeled equipment and appliances

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[13] https://www.wbdg.org/additional-resources/case-studies/bullitt-center

Permanently submeter PPLs	Construction Documents call for all PPLs to be on a dedicated electrical circuit that is labeled at the electrical panel and organized by tenant or floor

Average Equipment Power Density (modeled) Reference Points

Equipment Power Density – Code Baseline	Equipment Power Density – ZE Equivalent (RMI Boulder Commons[14])
13.3 kBtu/ft2/yr	7 kBtu/ft2/yr

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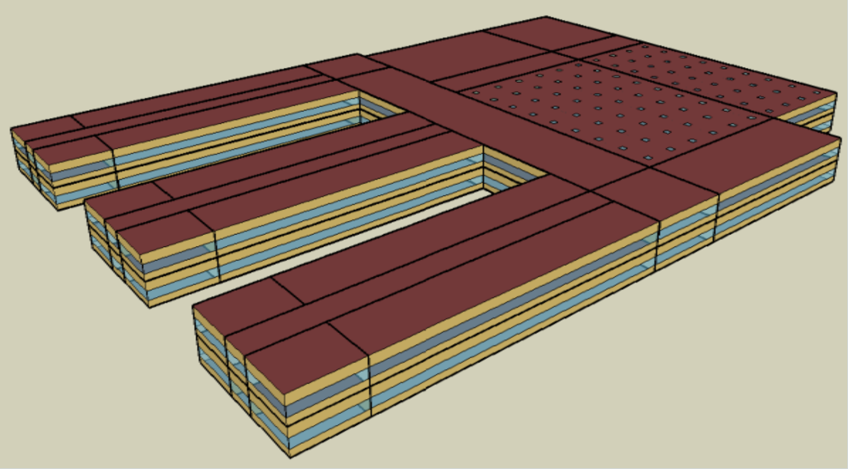
[14] https://d231jw5ce53gcq.cloudfront.net/wp-content/uploads/2018/01/BoulderCommons_casestudy_digital-1.pdf

Secondary School

Secondary School Prototype Building	
210,900 Sq. Ft.	
340’ X 460’ Floor Plate	
2 Stories	
13’-00” Floor-to-Floor Height	
35% WWR	

Performance Target

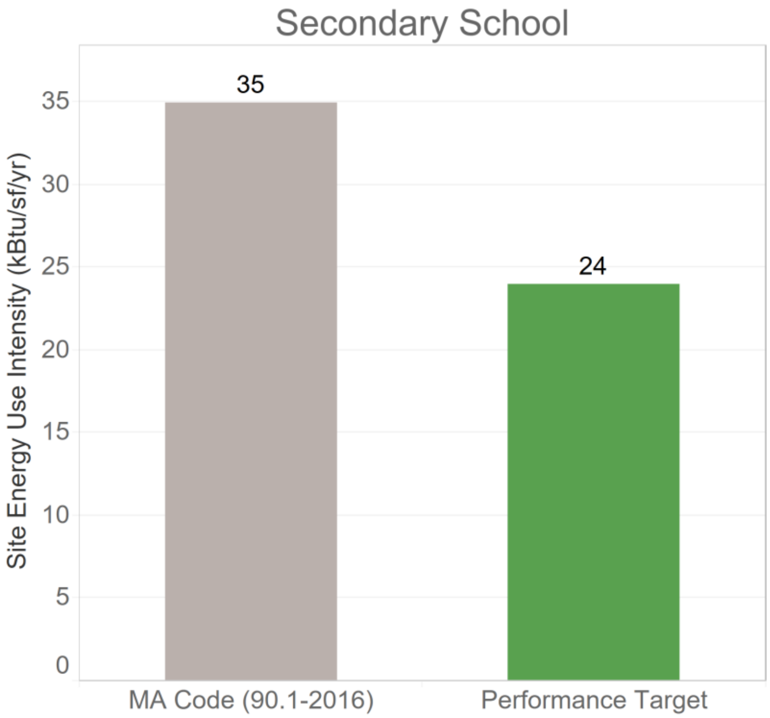


Figure 7: Secondary School ZE Target

Strategies

To reach the high-performance levels in the performance targets set in this report, the following design strategies should be prioritized:

1. Improve envelope to reduce heating, cooling and infiltration loads
2. Specify efficient heating, cooling and ventilation systems
3. Reduce and manage plug loads

1. Envelope Strategies

Strategy	**Target**
Low Window-to-Wall Ratio (WWR)	30% - 35%
Area Weighted U-Factor (UA) for Vertical Assemblies and Glazing Systems	≤ 0.14
Reducing Thermal Bridging	Account for structural elements that comprise a direct, uninsulated path to the building exterior as part of UA calculation
Reducing Infiltration	Infiltration rate: ≤ 0.25 cfm/ft2 at 75 Pa

Area-weighted Average U-Factor (UA) Reference Points

	Code (2018 IECC)	ZE Building (USGBC-MA Study) [15]	Passive House Equivalent
Opaque Wall Assembly	0.064	0.044	0.028
Window U-Factor (Area Weighted[16])	0.40	0.32	0.20
WWR	35%		
Area Weighted Average U-factor	**0.18**	**0.14**	**0.09**

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[15] https://usgbcma.org/wp-content/uploads/2019/09/ZeroEnergyBldgMA2019.pdf

[16] 35% of windows are operable, which have a different U-factor requirement

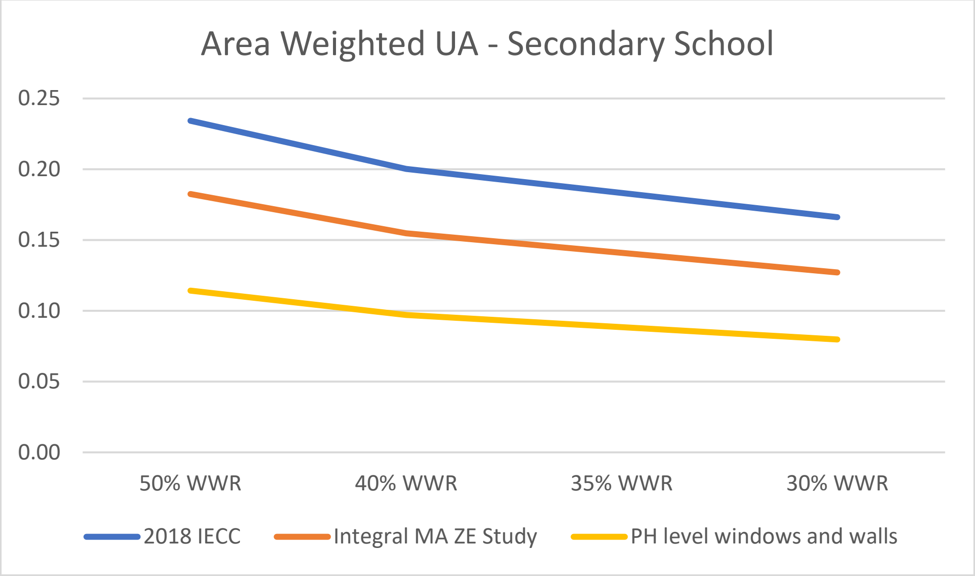


Figure 8: Secondary School UA Comparison

2. HVAC Strategies

Strategy	Target
Specify High-Performance Heating and Cooling Equipment	Air-to-air, water source, and ground source (or geothermal) Heat Pump Technologies
Efficiently Ventilate with a Dedicated Outdoor Air System (DOAS)	DOAS plus ERV

Low Annual Heating and Cooling Demand Intensity (Thermal Energy Demand Intensity) Reference Points

Code Equivalent TEDI (2018 IECC)	ZE Equivalent TEDI (USGBC – MA Study)
12.27	6.16

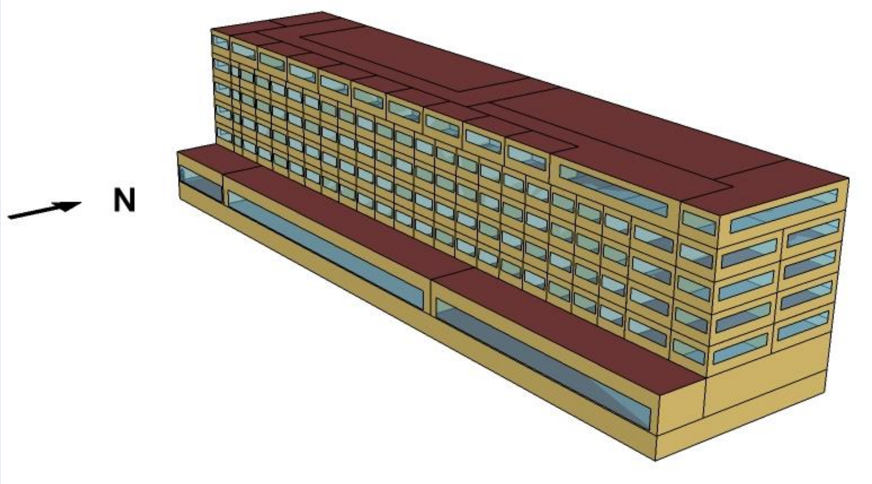
3. Plug Load Strategies

Strategy	Target
Specify Automatic PPL Controls	50% of receptacles controlled by automatic control device
Specify Efficiency Appliances and Equipment	Construction Documents call out ENERGY STAR® labeled equipment and appliances
Permanently submeter PPLs	Construction Documents call for all PPLs to be on a dedicated electrical circuit that is labeled at the electrical panel and organized by tenant or floor

Average Equipment Power Density (modeled) Reference Points

Equipment Power Density – Code Baseline	Equipment Power Density – ZE Equivalent (USGBC – MA Study)
14.8 kBtu/ft2/yr	8.4 kBtu/ft2/yr

Large Hotel

Large Hotel Prototype Building	
122,132 Sq. Ft.	
284’ X 75’ Floor Plate (ground floor) 284’ X 56’ (all other floors)	
6 Stories	
Floor-to-Floor Height 13’-00” (ground floor) 10’ – 00” (all other floors)	
30% WWR	

Performance Target

Figure 9: Large Hotel ZE Target

Strategies

To reach the high-performance levels in the performance targets set in this report, the following design strategies should be prioritized:

1. Improve envelope to reduce heating, cooling and infiltration loads
2. Specify Efficient heating, cooling and ventilation systems
3. Specify efficient hot water systems

1. Envelope Strategies

Strategy	**Target**
Low Window-to-Wall Ratio (WWR)	30% - 40%
Area Weighted U-Factor (UA) for Vertical Assemblies and Glazing Systems	≤ 0.16
Reducing Thermal Bridging	Account for structural elements that comprise a direct, uninsulated path to the building exterior as part of UA calculation
Reducing Infiltration	Infiltration rate: ≤ 0.25 cfm/ft2 at 75 Pa

Area-weighted Average U-Factor (UA) Reference Points

	Code (2018 IECC)	ZE Building (ASHRAE HPB Case Study)	Passive House Equivalent
Opaque Wall Assembly	0.064	0.038	0.028
Window U-Factor (Area Weighted[17])	0.39	0.35	0.20
WWR	30%		
Area Weighted Average U-factor	**0.16**	**0.13**	**0.08**

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[17] 22% of windows are operable, which have a different U-factor requirement

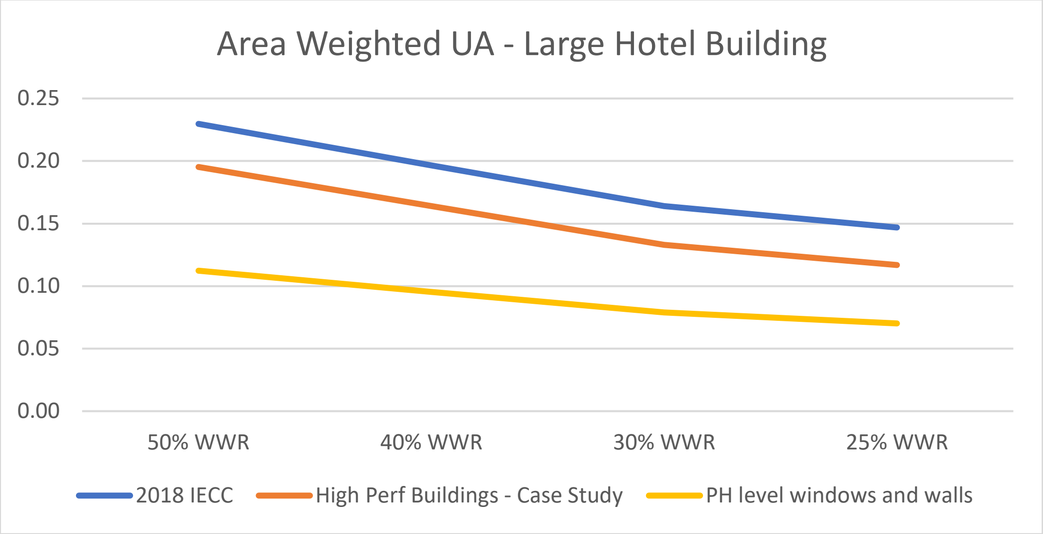


Figure 10: Large Hotel UA Comparison

2. HVAC Strategies

Strategy	**Target**
Specify High-Performance Heating and Cooling Equipment	Air-to-air, water source, and ground source (or geothermal) Heat Pump Technologies
Efficiently Ventilate with a Dedicated Outdoor Air System (DOAS)	DOAS plus ERV

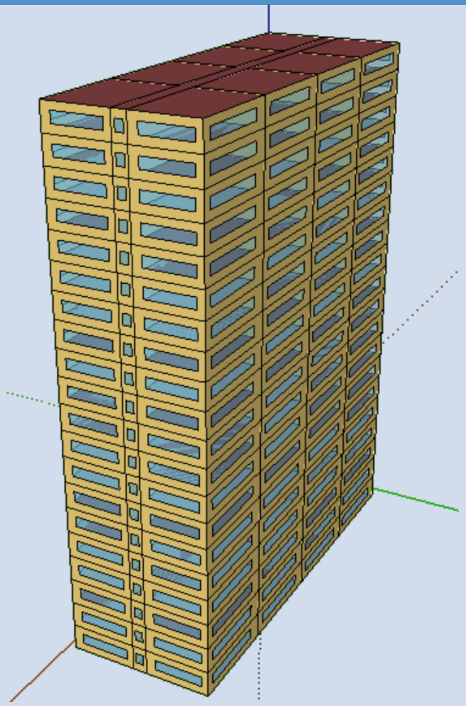
Low Annual Heating and Cooling Demand Intensity (Thermal Energy Demand Intensity) Reference Points

Code Equivalent TEDI (2018 IECC)	ZE Equivalent TEDI (Max Tech Study)
21.81	9.60

3. Specify Efficient Hot Water Systems

Strategy	**Target**
Specify High Efficiency (Electric) Equipment	Minimum Energy Factor of 0.95.
Specify Efficient Dishwashers and Fixtures	ENERGY STAR® (EPA, 2016) labeled dishwashers and WaterSense (EPA) labeled lavatory faucets and showerheads.

High Rise Residential (20-Story)

High Rise Residential Prototype Building	
168,720 Sq. Ft.	
152' X 55.5' Floor Plate	
20 Stories	
Floor-to-Floor Height 10'-00"	
45% WWR	

Performance Target

Figure 11: High Rise Residential ZE Target

Strategies

To reach the high-performance levels in the performance targets set in this report, the following design strategies should be prioritized:

1. Improve envelope to reduce heating, cooling and infiltration loads
2. Specify Efficient heating, cooling and ventilation systems
3. Specify efficient hot water systems

1. ZE Envelope Strategies

Strategy	**Target**
Low Window-to-Wall Ratio (WWR)	35% - 45%
Area Weighted U-Factor (UA) for Vertical Assemblies and Glazing Systems	≤ 0.09
Reducing Thermal Bridging	Account for structural elements that comprise a direct, uninsulated path to the building exterior as part of UA calculation
Reducing Infiltration	Infiltration rate: ≤ 0.25 cfm/ft2 at 75 Pa

Area-weighted Average U-Factor (UA) Reference Points

	Code (2018 IECC)	ZE Building (ASHRAE AEDG – Zero Energy[18]	Passive House Equivalent
Opaque Wall Assembly	0.064	0.022	0.028
Window U-Factor	0.38	0.17	0.14
WWR	45%		
Area Weighted Average U-factor	**0.21**	**0.09**	**0.08**

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[18] ASHRAE Advanced Energy Design Guide For Multifamily Buildings – Achieving Zero Energy (2019)

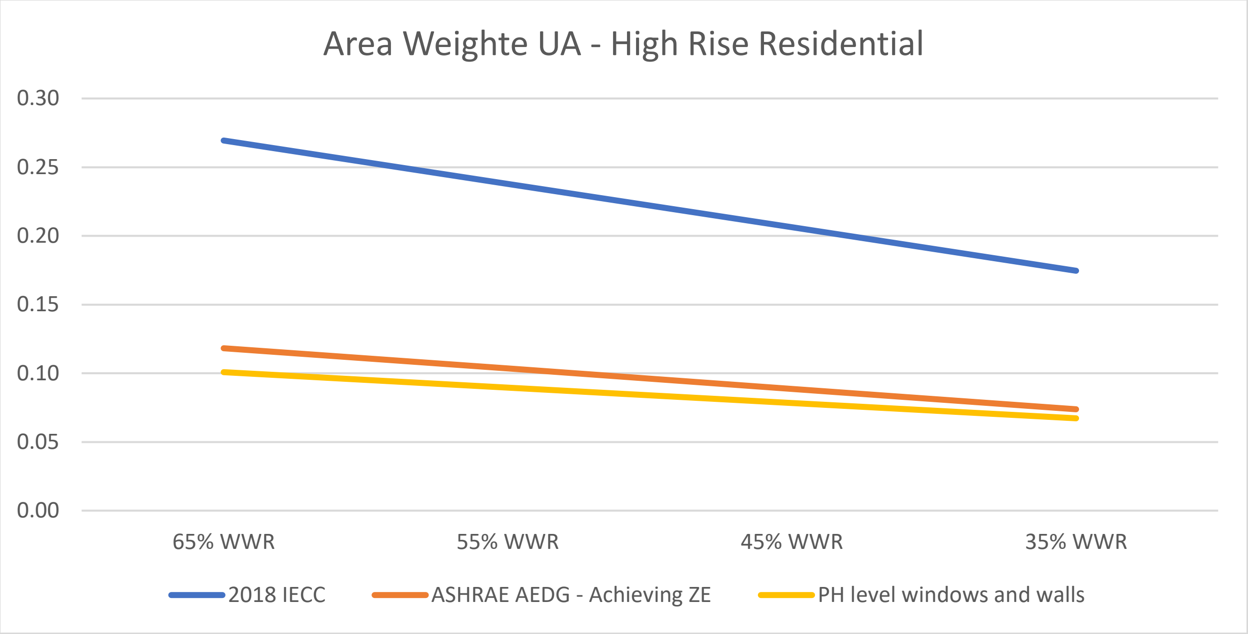

Figure 12: High Rise Residential UA Comparison

2. HVAC Strategies

Strategy	**Target**
Specify High-Performance Heating and Cooling Equipment	Air-to-air, water source, and ground source (or geothermal) Heat Pump Technologies
Efficiently Ventilate with a Dedicated Outdoor Air System (DOAS)	DOAS plus ERV

Low Annual Heating and Cooling Demand Intensity (Thermal Energy Demand Intensity) Reference Points

Code Equivalent TEDI (2018 IECC)	ZE Equivalent TEDI (Max Tech Study)
16.91	4.09

3. Specify Efficient Hot Water Systems

Strategy	**Target**
Specify High Efficiency (Electric) Equipment	Minimum Energy Factor of 0.95.
Specify Efficient Dishwashers and Fixtures	ENERGY STAR® (EPA, 2016) labeled dishwashers and WaterSense (EPA) labeled lavatory faucets and showerheads.

Laboratory Prototype

The laboratory building type is not standardized in the energy code evaluation analysis like offices, schools, or other common building types. For this report, we assembled benchmarking data using the best available sources to set aggressive yet attainable energy performance targets for laboratories. We broadly group laboratories into dry[19] vs. wet[20], or physical vs. biological/chemical. "Wet" laboratories tend to use more energy due to increased ventilation requirements as well as additional equipment needed to work with chemicals, biological material, and other potentially hazardous substances. To safely work with these substances, wet laboratories tend to have more fume hoods, piped services, and other equipment that drive up energy needs as compared to "dry" laboratories. Dry laboratories tend to focus more on physical testing and electronics, which do not require constant ventilation for safety.

Although laboratories are traditionally energy intensive, modern designers are able to optimize the building to achieve significant savings compared to median labs.

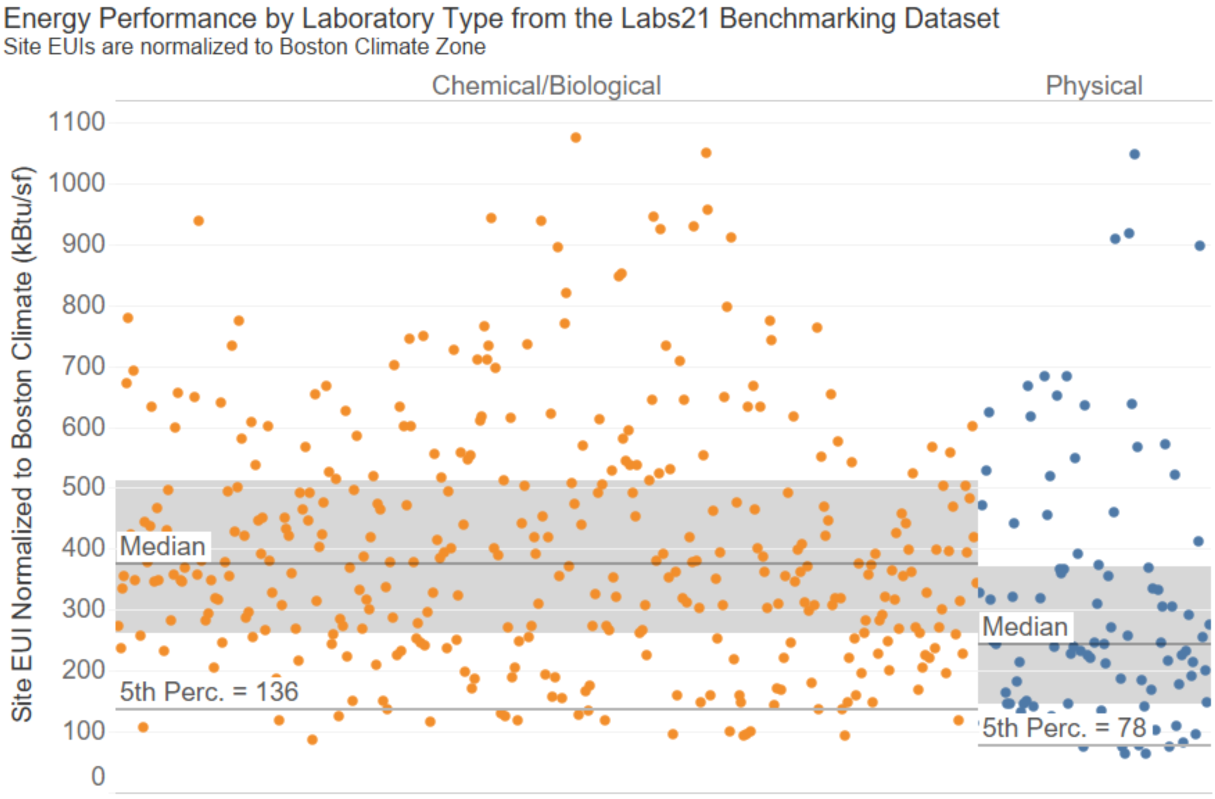

Figure 13: Laboratory performance benchmarking data

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[19] https://www.wbdg.org/space-types/laboratory-dry

[20] https://www.wbdg.org/space-types/laboratory-wet

ZE Performance Target

Taking into account Boston's climate zone, benchmarking data for existing laboratories, and best-in-class laboratory performance, we set energy targets for laboratories based on their type, outlined below. These targets represent performance levels demonstrated or exceeded in existing laboratories[21].

Building Type	Target Site EUI (kBtu/sf/yr)
Lab: Chem/Bio	140
Lab: Physical	80

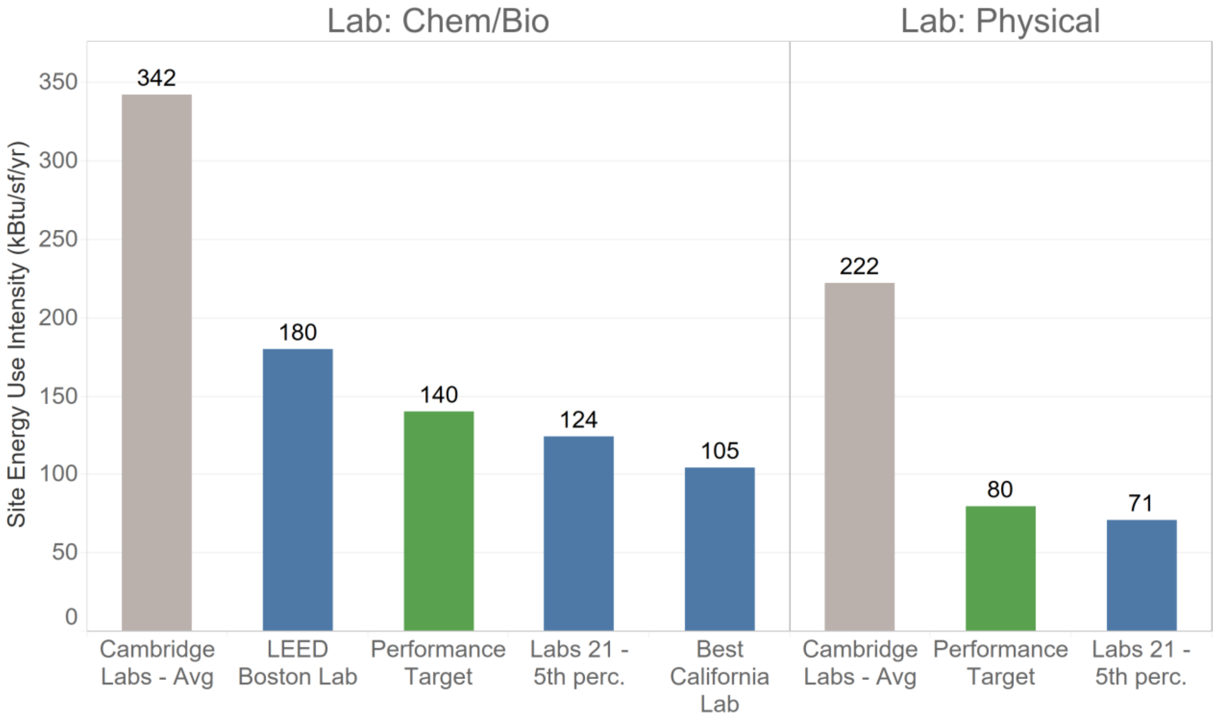

Figure 14: Laboratory performance benchmarks by type

ZE Strategies

To reach the high-performance levels in the performance targets set in this report, designers will need to consider several key strategies:

1. Set appropriate ventilation rates by space type

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[21] A detailed case study on the Craig Venter laboratory in California is available here: https://www.pge.com/pge_global/common/pdfs/save-energy-money/savings-programs/zero-net-energy-program/ZNE-Case-Study-Buildings-Vol3.pdf

2. Manage energy impacts of ventilation
3. Specify high-efficiency equipment

The Sbrega Health and Science Building in Fall River, MA is a great example of a high performance laboratory. The designers considered an extensive list of efficiency measures, including ventilation and plug loads[22].

Ventilation Overview

For laboratories, ventilation rates are a key driver of overall energy consumption. Taking in unconditioned outside air and bringing it to supply temperature requires considerable energy, particularly during cold winter months. While energy recovery can greatly reduce the energy required to condition that outside air, contamination concerns, particularly in wet labs, may preclude energy recovery as a viable efficiency strategy. Aside from recovering the energy from air exiting the building space to precondition outside air, reducing excess outside air coming into the building can similarly reduce energy consumption. Laboratories are particularly sensitive to ventilation needs, particularly when hazardous materials are stored and handled in the laboratory. Equipment such as fume hoods also drive up ventilation requirements and should be addressed specifically to minimize any excess ventilation.

Ventilation Rates

Laboratories are made up of a mix of space types, including office, storage, laboratory, and other types. Considering the following strategies can optimize performance:

- **Combine zones with similar ventilation requirements** to avoid over-ventilating spaces that do not require the same, high levels of outside air as the laboratory spaces.
- Within laboratory spaces, careful consideration of equipment requirements and design criteria are paramount to **avoid using conservative, rule-of-thumb air change per hour requirements** that can lead to greatly increased energy consumption.
- Fume hoods are traditionally a large driver of ventilation requirements. In some cases, **filtration-based fume hoods** that do not exhaust air via ductwork to the HVAC system can meet laboratory requirements without the additional ventilation needs.

Ventilation Energy Impact

With ventilation rates set to appropriate levels based on space and equipment requirements, mitigating the energy cost of that ventilation is the next priority.

- Where possible, **energy recovery** is the best option to reduce energy needs to maintain comfort conditions. Energy recovery may only be possible in non-laboratory spaces that are separately zoned due to contamination, corrosion, or other concerns. Grouping these spaces in order to maximize their heat recovery potential is one option to improve the potential energy performance of the building.
- **Properly controlling outside air rates** with variable speed fans and economizers. Setting back ventilation rates based on occupancy, equipment status, CO2, or other drivers can greatly reduce HVAC energy demands both in laboratory and non-laboratory spaces.

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[22] Sbrega Building case study including a detailed list of efficiency measures: http://www.hpbmagazine.org/John-J-Sbrega-Health-and-Science-Building-Fall-River-Mass/

- Ventilation control at major equipment such as fume hoods in some instances can greatly impact HVAC sizing due to pressure drops across fume hood sashes. **Low energy control technologies**, such as pressure-independent valves with digital airflow measurements avoid the need for high-pressures to maintain safe ventilation rates into fume hoods. Low-pressure drop systems reduce HVAC size requirements, potentially leading to significant energy and cost savings.

Equipment Efficiency

Laboratories have significantly higher miscellaneous electrical loads compared to offices, schools, and other common building types. Refrigeration, electrical equipment, and other specialized equipment can make up 50% of more of a laboratory's energy consumption over the course of a year.

- Where possible, **specify EnergyStar rated equipment**, particularly for refrigeration. Other equipment standards that apply to laboratories exist, including the ACT Label[23]. These standards offer a simple way for designers to reduce the total equipment load in the space.
- For fume hoods in particular, specifications regarding **occupancy sensing capabilities and low-pressure sash control** are good options to address ventilation rates and electricity consumption from the equipment itself.

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[23] https://act.mygreenlab.org/equipment.html

DISUCSSION OF FINDINGS

As Boston considers what role predicted energy performance plays in meeting its climate goals through the implementation of energy codes, this analysis has served to highlight a number of critical factors.

Carbon Reduction Opportunities

Based on the end-use analysis of these buildings, and the steps being taken by the State to clean the grid, reducing natural gas combustion across the building stock can have significant impact on carbon emissions. Key opportunities include:

- Greatly reduce building thermal energy demands by taking steps to require more efficient envelop design. This needs to include strategies to reduce thermal bridging and infiltration.
- Eliminate on-site combustion of natural gas by switching to efficient, heat pump based Technologies for space conditioning and hot water heating
- Incorporate a GHGI target for new construction that is aligned with the existing building policies

Building Type Prioritization

Certain building types make good candidates for the use of predicted energy use targets while other building types can be more challenging. This results from the fact that some building types are more challenging than other to characterize and that more predictable building types represent the easiest place to start on the performance path. Based on our analysis, the following building types make good candidates for energy performance targets:

- 20-story High-Rise Apartment
- Secondary School
- Large Office (although the presence of a data server can cause some variability)
- Medium Office

Linking Predicted Performance to Energy Outcomes

Energy modeling will continue to be an essential tool for not only reducing energy loads in buildings but also for determining energy code compliance. As these tools continue to advance and be leveraged by designers and building departments it is essential that there is feedback and accountability in this process. The simple act of going back to update and understand energy modeling accuracy closes an important feedback loop for the design community and pushes the industry toward more accountability on predictive modeling. Over time with this enhanced feedback loop, the discrepancy between predicted performance and outcome performance will lessen and accuracy of models will improve.

APPENDIX A: ADDITIONAL RESOURCES

Secondary School

- Advanced Energy Design Guide for K-12 School Buildings – Achieving Zero Energy: https://www.ashrae.org/technical-resources/aedgs/zero-energy-aedg-free-download

High-Rise Residential Resources

- Multifamily Building Guide: https://newbuildings.org/product/multifamily-guide/
- Pursuing High-Rise Multifamily Energy Efficiency in Seattle: https://rushingco.com/pursuing-high-rise-multifamily-energy-efficiency-in-seattle/
  The World's Tallest and Largest Residential Passive House: https://www.burohappold.com/wp-content/uploads/2016/05/bhe-cornell-tech-casestudy-web.pdf
- A Zero Emissions All-Electric Multifamily Construction Guide: https://fossilfreebuildings.org/ElectricMFGuide.pdf

Laboratory Resources

- Market Assessment of Energy Efficiency Opportunities in Laboratories: https://www.etcc-ca.com/reports/market-assessment-energy-efficiency-opportunities-laboratories

- Energy use and savings potential for laboratory fume hoods
  https://hightech.lbl.gov/sites/default/files/documents/fh_energy_lbnl%20%281%29.pdf

- Laboratory benchmarking tool
  https://lbt.i2sl.org/

- Smart Labs Accelerator. Includes more resources, case studies, guidance, etc.
  https://betterbuildingssolutioncenter.energy.gov/accelerators/smart-labs