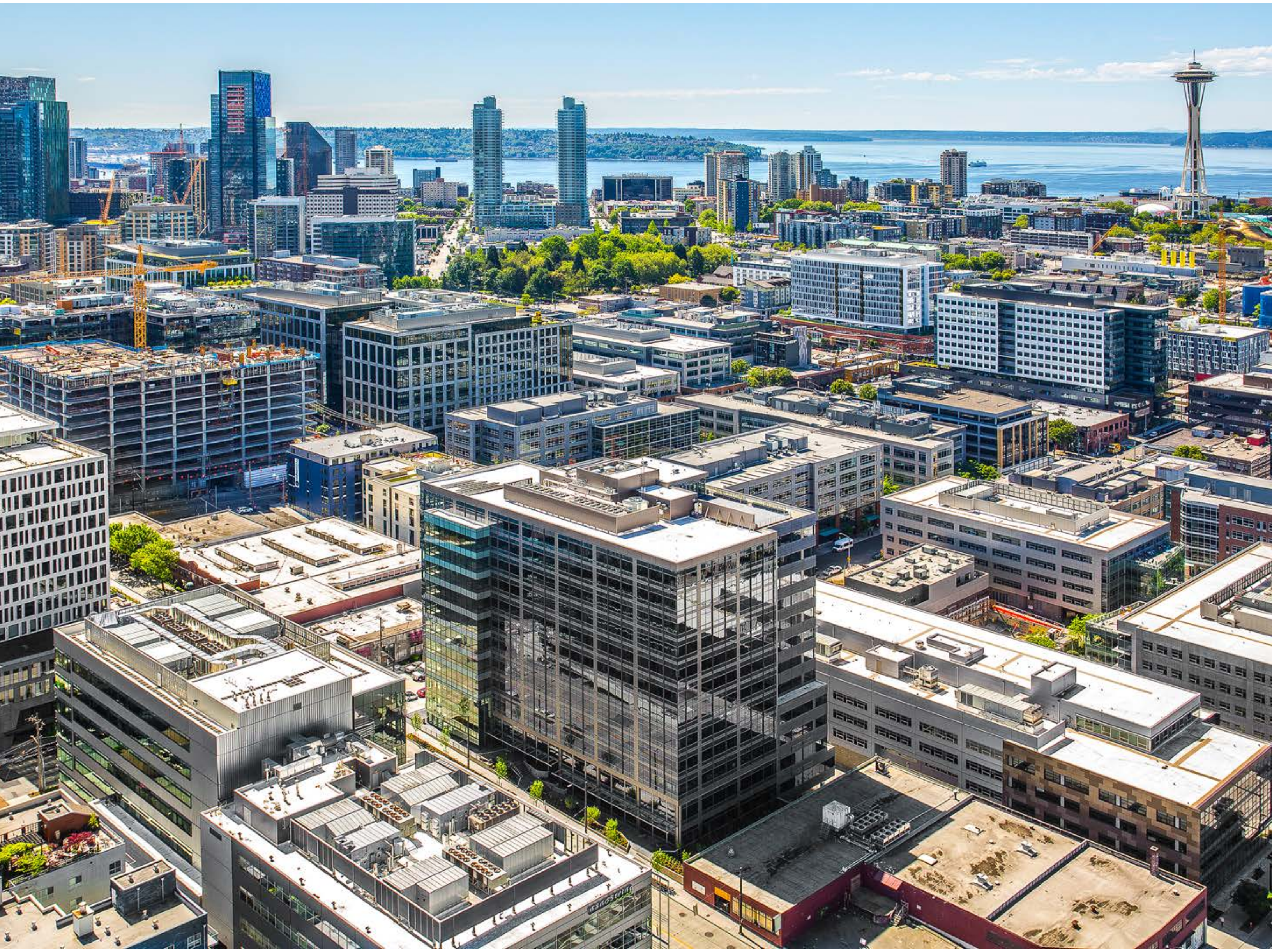
Seattle's 2015 Energy Code & Its Impacts on High-Rise Construction



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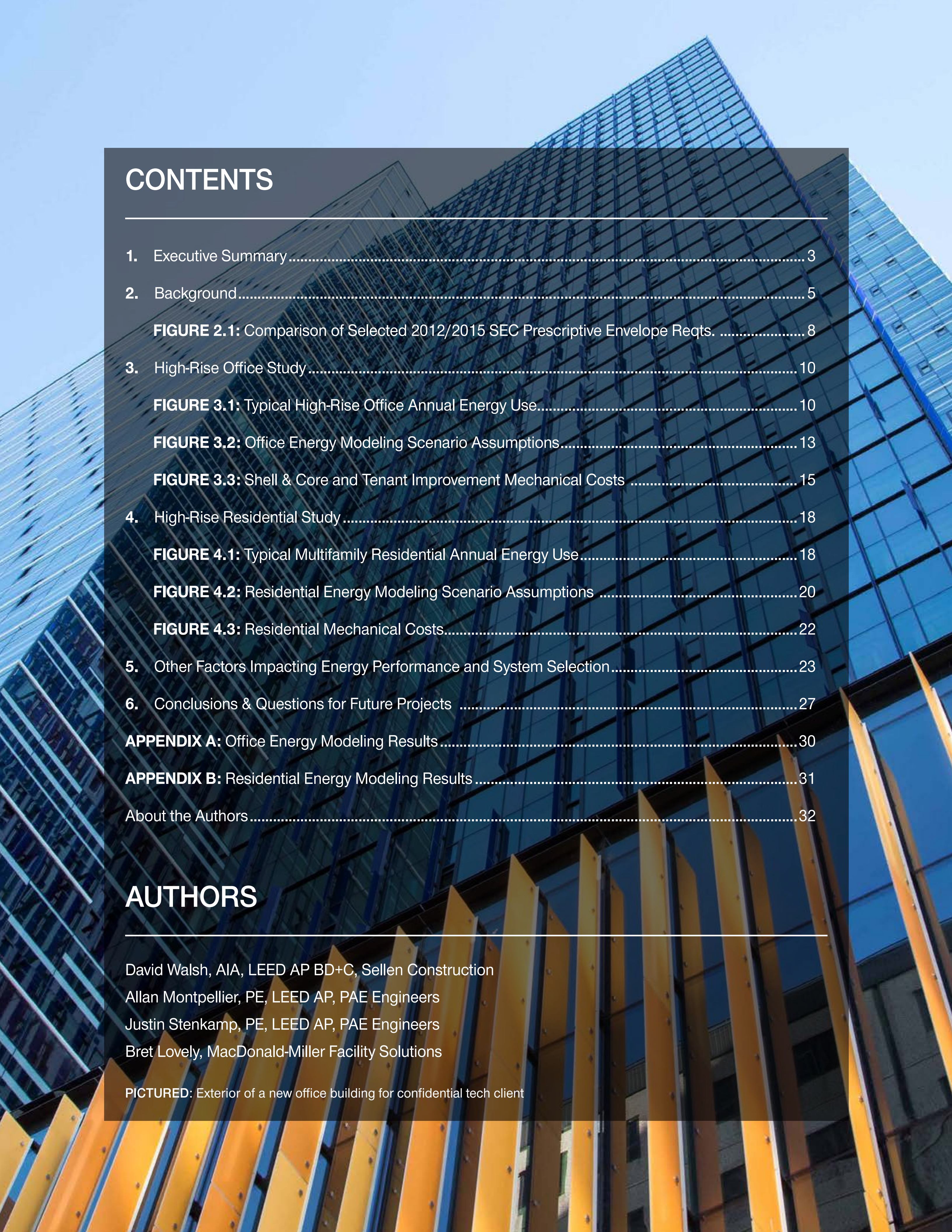

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PICTURED: Exterior of a new office building for confidential tech client

1. EXECUTIVE SUMMARY

Overall, this study found that increased glazing in high-rises is possible under the new code, but it comes with a cost.

Seattle officially adopted the new 2015 Seattle Energy Code on Jan. 1, 2017. Additional requirements came into effect in July, and further requirements will arrive in January 2018. These changes leave many in the design and construction communities questioning how this code will affect high-rise office and residential projects, especially those with increased glazing. Led by engineers and designers from Sellen Construction, PAE Engineers and MacDonald-Miller Facility Solutions, this study set out to answer those questions and provide results based on analysis of reference buildings.

The new energy code, referred to throughout this white paper as the 2015 SEC, ushers in stringent energy performance goals and new technical requirements, but these compliance changes are just one piece of the puzzle. The code's effects must be evaluated in concert with:

- the changing price points for mechanical systems;
- the inherent physical and zoning constraints of downtown sites; and
- the desire to maximize rentable area and glazing percentages to shape a project.

Overall, this study found that increased glazing in high-rises is possible under the new code, but it comes with a cost.

PROCESSES

The Sellen, PAE and MacMiller team used energy modeling to determine if the project Energy Use Intensity (EUI) calculation would meet the 2015 SEC when different mechanical systems and glazing percentages were applied. Focusing only on high-rise towers, multiple scenarios were studied for both office and residential projects. The scenarios were:

High-Rise Office

- **Baseline Case:** Actual mechanical costs (escalated to 2017 dollars) from a recently completed Seattle office building at the original glazing percentage
- **Scenario 1:** Costs for core and shell mechanical systems to be 2015 SEC compliant with no change to glazing percentages
- **Scenario 2:** Costs for core and shell mechanical systems to be 2015 SEC compliant while increasing glazing to 60%

- **Scenario 3:** Costs for tenant improvement mechanical systems to be 2015 SEC compliant with no change to glazing percentages
- **Scenario 4:** Costs for tenant improvement mechanical systems to be 2015 SEC compliant while increasing glazing to 60%

High-Rise Residential

- **Baseline Case:** Actual mechanical costs (escalated to 2017 dollars) from recently completed Seattle high-rise residential buildings at the actual glazing percentages
- **Scenario 5:** Costs for mechanical systems to be 2015 SEC compliant with no change to original glazing percentages
- **Scenario 6:** Costs for mechanical systems to be 2015 SEC compliant while increasing glazing to 60%

CONCLUSIONS

Perhaps the biggest impact of the 2015 SEC is its recalibration of the market, yielding a new set of questions to be asked, scenarios to be modeled, and new systems to be designed and installed.

For high-rise offices seeking glazing at 60%, the cost impacts for the core and shell's mechanical systems are relatively minor: it was a 9% cost increase to go from 42% glazing up to 60% glazing. To meet the thermal demand in tenant spaces and be compliant with the 2015 SEC, the tenant improvement mechanical systems will likely change from conventional variable air volume systems to ones that may be hydronic-based. This may require radiators and chilled beams in the spaces, which could mean tenant improvement mechanical costs increase by up to 96% in buildings with 60% glazing.

For the high-rise residential study, the jump to increase glazing to 60% was much higher: it was a 33% cost increase to go from 53% glazing up to 60% glazing. Providing a dedicated outdoor air system — going from a vertical heat pump in each unit to a four pipe fan coil system with an air-water heat pump, and then adding heat recovery — accounted for most of the 33% increase.

In conclusion, the study found that increased glazing at a rate of 60% or higher is possible under the 2015 SEC; however, it comes at a premium. The new 2015 SEC challenges developers, engineers and design teams to find a new sweet spot among increasing glazing, managing first and operational costs, as well as code compliance. Apart from energy savings and the associated reduction in greenhouse gases, perhaps the biggest impact of the 2015 SEC is its recalibration of the market, yielding a new set of questions to be asked, scenarios to be modeled, and new systems to be designed and installed.

2. BACKGROUND

Rather than prescribing a set of solutions based on code changes alone, this study also investigates the roles that of Energy Use Intensity (EUI), occupancy density and glazing targets can play when selecting mechanical systems.

Rather than prescribing a set of solutions based on code changes alone, this study also investigates the roles that of Energy Use Intensity (EUI), occupancy density and glazing targets can play when selecting mechanical systems.

Based on a combination of these selected targets, the Sellen, PAE and MacMiller team defined case scenarios for high-rise commercial office and high-rise residential buildings. Each scenario was tested with energy and cost modeling based on a prototypical building to understand its viability.

In short, this paper's intent is to help teams quickly understand what's within the realm of possibility regarding energy efficiency, code compliance, glazing and occupant load density when trying to achieve a given set of goals.

The intent of the study was to identify possible combinations of architectural and mechanical systems solutions, which are able to:

- Maximize glazing percentage to meet market demand, using 60% as target.
- Comply with the 2015 SEC energy use targets.
- Minimize first costs.

2.1 STUDY METHODOLOGY

This study focused on two building types: high-rise office and high-rise residential in the Seattle downtown core. Given the location, both of these building types are likely to have retail or restaurants/cafés in the podium base. These mixed uses can swing the range of modeled energy use considerably. Similarly, the amount of underground parking, if any, varies widely from one downtown site to another, also resulting in swings in assumed energy consumption.

To avoid these unpredictable energy swings, the team modeled only the typical office or residential floors, ignoring the mixed-use podium and any underground parking. While this results in a typical floor EUI that will be lower than the total building's EUI, it still represents most of the building's total gross area and is the primary driver of energy consumption.

The site dimensions, proportions and buildable zoning envelope are other key determinates of surface-to-area ratios and, thus, envelope thermal losses. Assuming that most developers will attempt the maximum buildable volume, the following assumptions were used to generate the model's form:

Downtown Office Prototype

- Assumed Zoning: DMC 240 (downtown mixed)
- Assumed Block Size: Typical half block in the Seattle urban core
- Assumed Tower Footprint above Setback: 220 feet by 110 feet (i.e. the modeled typical floor)
- Assumed Core Depth: 20 feet wide (leaving the core-to-façade distance of 50 feet)

Downtown Residential Prototype:

- Assumed Zoning: DMC 240/290-400
- Assumed Tower Footprint above Setback: 100 feet by 100 feet (i.e. the modeled typical floor)
- Assumed Core Depth: 50 feet by 50 feet wide (including corridor); core-to-façade distance of 25 feet

2.2 KEY IMPACTS OF THE 2015 SEC

Section C401 of the 2015 SEC provides three compliance paths:

1. Prescriptive;
2. Total building performance (energy model); and
3. A target performance path (performance demonstrated during operations phase).

While the focus of this paper is not a detailed itemization of changes from the 2012 SEC to the new version, three areas stand out as particularly impactful on architectural detailing, HVAC system design, and lighting/electrical design. They are:

- increased focus on thermal envelope, effective R-value, and leakage testing;
- mandatory selection of two additional efficiency options; and
- phased additional requirements.

While the focus of this paper is not a detailed itemization of changes from the 2012 SEC to the new version, three areas stand out as particularly impactful on architectural detailing, HVAC system design, and lighting/electrical design.

1. Increased Focus on Thermal Envelope, Effective R-Value and Leakage Testing

While a code compliant envelope may not seem like a difficult mark to achieve and the 2015 SEC does not have any significant variations (see Figure 2.1), the main difference is how the architectural details for various components will be evaluated for compliance.

For example, a detailed section of spandrel wall with R-21 insulation may not comply. This is due to thermal bridging, which, if detailed inadequately, may degrade the effective R-value to anywhere from R-9 to R-11.

The key takeaway is code officials will be looking for confirmation of the effective R-values for the assembly, which means detailing to minimize thermal bridging is a critical envelope performance component.

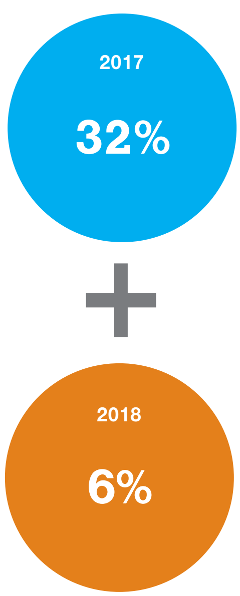
In addition to thermal bridging, air leakage is responsible for significant energy loss — up to 40% of the building's heat loss — and a contributing factor to condensation with envelope assemblies. To verify the integrity of the envelope, all buildings will be tested for leakage; refer to Figure 2.1 for the revised maximum allowed air leakage rate.

2. Mandatory Selection of Two Additional Efficiency Options

Projects pursuing the prescriptive option are required to comply with at least two additional efficiency package options, per Section C406. This is in addition to meeting the prescriptive envelope requirements. Additional efficiency package options are:

- Increased HVAC performance per C406.2
- Reduced lighting power per C406.3
- Enhanced lighting controls per C406.4
- On-site renewable energy per C406.5
- Dedicated Outdoor Air System per C406.6
- High-Efficiency Service Water Heating per C406.7
- Enhanced Envelope Performance per 406.8 (beyond Tables in C402)
- Reduced Air Infiltration per C406.9 (beyond 402.5.1.2)

MULTI-FAMILY LPD REDUCTION



3. Phased Additional Requirements

As of July 1, 2017, the 2015 SEC requires including a Dedicated Outdoor Air System, or DOAS, as part of the baseline energy model. This raises the performance bar of the baseline system and necessitates deeper efficiencies and additional strategies to meet minimum energy code compliance.

Jan. 1, 2018, will introduce new requirements, including increased performance of glazing and lighting power, as well as defining heat pumps as the baseline heating source. For projects submitting for permit review on or after Jan. 1, 2018, these new requirements will necessitate evaluating additional energy conservation strategies, such as higher performing glazing, shading strategies, and highly efficient lighting.

Compared to the 2013 energy code, the Lighting Power Density (LPD) allowances have been reduced by up to 32% (multi-family). After January 2018, LPDs are further reduced up to an additional 6% (as compared to the 2013 baseline). Although the falling cost of LED fixtures have led to widespread installation in many building types, especially offices, these new requirements will further LED installations.

FIGURE 2.1: Comparison of Selected 2012/2015 SEC Prescriptive Envelope Requirements

Note: Deviations from the U or R values below may be permitted if in accordance with the UA Tradeoff Method, per C402.1.5 of the 2015 SEC.

ENVELOPE COMPONENT	2012 SEC PRESCRIPTIVE OPTION REQUIREMENTS	2015 SEC PRESCRIPTIVE OPTION REQUIREMENTS	2015 SEC REMARKS
Opaque Thermal Envelope Insulation: (Table C402.1.3)			
Roof (all insulation above deck)	• R-38 c.i.	• R-38 c.i.	• Where "ci" is indicated, continuous insulation is required (typical). • No changes from 2012 SEC.
Mass Walls	• Insulation at Exterior: R-16 c.i. AND • Insulation at Interior: R-13 between metal studs + R-10 ci.	• Insulation at Exterior: R-16 c.i. AND • Insulation at Interior: R-13 between metal studs + R-10 ci.	• Applies to above-grade walls. • No changes from 2012 SEC.
Steel-Framed Opaque Walls	• For all occupancies except "R": R-13 + R-10 c.i. • For Group "R": R-19 + R-8.5 c.i.	• For all occupancies except "R": R-13 + R-10 c.i. • For Group "R": R-19 + R-8.5 c.i.	• Applies to above grade walls. • No changes from 2012 SEC.
Below Grade Walls	• Insulation at Exterior: R-10 c.i. AND • R-13 between metal studs + R-6 c.i.	• Insulation at Exterior: R-10 c.i. AND • R-13 between metal studs + R-6 c.i.	• No changes from 2012 SEC.
Slab-on-Grade Floors (unheated slab)	• R-10 for 24" below	• R-10 for 24" below	• No changes from 2012 SEC.
Opaque Door Performance: (Table C402.1.3)			
Swinging Doors	• U = 0.37	• U = 0.37	• No changes from 2012 SEC.
Vertical Fenestration Performance: (Table C402.3 in 2012 SEC; Table C402.4 in 2015 SEC)			
Non-Metal Framing (all)	• U = 0.30	• U = 0.26	• For 2015 SEC, U value assumes project meets the criteria of Column A in Table C402.4
Metal Framing (fixed windows)	• U = 0.38	• U = 0.31	• Ditto
Metal Framing (operable windows)	• U = 0.40	• U = 0.38	• Ditto
Metal framing (entrance doors)	• U = 0.60	• U = 0.60	• No change from SEC 2012

(continued on next page)

ENVELOPE COMPONENT	2012 SEC PRESCRIPTIVE OPTION REQUIREMENTS	2015 SEC PRESCRIPTIVE OPTION REQUIREMENTS	2015 SEC REMARKS
Solar Heating Glazing Coefficient (SHGC) Projection Factor (PF) < 0.20	• SHGC = 0.35 (in all orientations)	• S, E or W orientation: SHGC = 0.35 • N orientation: SHGC = 0.53	• For N orientation only, no change in SHGC.
0.20 < PF <0.5		• S, E or W orientation: SHGC = 0.45 • N orientation: SHGC = 0.58	• For N orientation only, no change in SHGC
PF >= 0.5		• S, E or W orientation: SHGC = 0.60 • N orientation: SHGC = 0.64	• For N orientation only, no change in SHGC
Glazing Area Maximums			
Glazing Percentage Maximums (except street-level glazing as required by land use code)	• 40% maximum (bonus with higher performance fenestration)	• 40% maximum	For the 40%, The 2015 SEC also requires: • 25% of net floor area is within daylight zone; • visible transmittance (VT) is greater than or equal to 1.1 times SHGC (see C402.1.1.1); or • provide high performance glazing (see C402.4.1.3)
Street-level glazing as required by land use code	• 75% maximum	• 75% maximum	• See C402.4.1 Exception section for details.
Skylights			
	• U = 0.45 • SHGC = 0.32	• U = 0.45 • SHGC = 0.32	• See C402.4.2 for min. skylight area. No U- and SHGC-value changes from 2012 SEC
Air Leakage at Thermal Envelope (402.5.1.2)			
	• Leakage test performance: No greater than 0.40 cfm/sf	• Leakage test performance: No greater than 0.30 cfm/sf	• Tested at a pressure differential of 0.3 inches water gauge

3. HIGH-RISE OFFICE STUDY

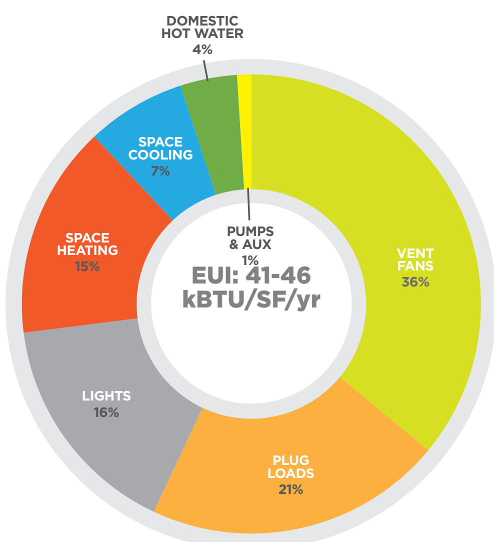
It is more important than ever for developers to understand which combination of building systems help their buildings achieve, or possibly surpass, the 2015 SEC requirements while minimizing costs.

The market is demanding large glazing percentages of 50% to 60%, high-occupancy densities, increased occupant comfort (thermal and visual), and connections to the outdoors. The 2015 SEC has a requirement of an EUI of 40 kBtu/SF/year*. In light of this, it is more important than ever for developers to understand which combination of building systems help their buildings achieve, or possibly surpass, the 2015 SEC requirements while minimizing costs.

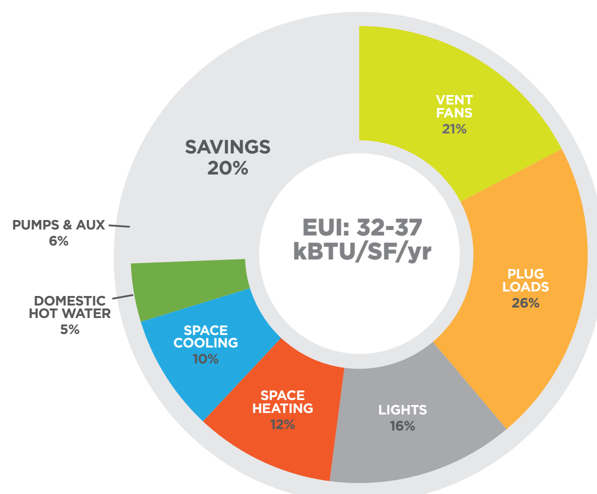
This is where architects, engineers and general contractors can help evaluate the many systems options and work with the owner to find an integrated solution that meets market demand while also achieving the energy code and realizing the project proforma.

Before exploring systems options, it is critical to identify the major energy uses in an office building. The major energy users are the HVAC system, lighting, and plug loads (see Figure 3.1), all adding up to an EUI of 41 to 46. Note that plug loads become more dominant as the building systems become more efficient and at higher occupancy densities.

FIGURE 3.1: Typical High-Rise Office Annual Energy Use



Typical High-Rise Office Annual Energy Use with High Efficiency VAV System (Typical 2012 SEC Solution)



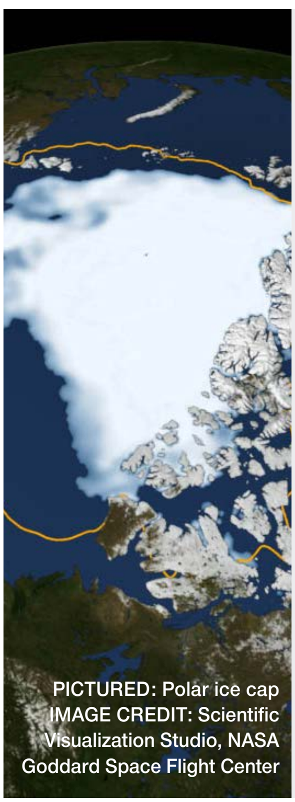
Typical High-Rise Office Annual Energy Use with Heat Pump and DOAS System (Potential 2015 SEC Solution)

**The 40 kBTU/SF/year is for the prescriptive path, assuming 40% glazing for Group B office.*

Glazing systems are much less energy efficient than a wall assembly since they typically have more outside air infiltration, release more heat in the winter, and allow more conductive and solar heat gain in the summer.

The challenge is that the high-rise office building market has an expectation for higher percentages of glazing, which puts pressure primarily on mechanical systems to help overcome the reduced performance of the envelope due to more glazing. Glazing systems (i.e. the glass plus the mullions) are much less energy efficient than a wall assembly since they typically have more outside air infiltration, release more heat in the winter, and allow more conductive and solar heat gain in the summer. Since HVAC system energy use is mostly dependent on the performance of the building envelope, there is a need to find mechanical systems that have improved performance over the prescriptive solutions offered by the 2015 SEC.

This white paper evaluates possible strategies for meeting and exceeding the 2015 SEC energy consumption requirements, while still accommodating the market demand for high glazing percentages. The Sellen, PAE and MacMiller team evaluated building energy comparisons at 40% glazing and 60% glazing, the range within which most office building envelopes fall. As expected, there is no “silver bullet” solution that allows a 60% glazed building to achieve the 2015 SEC target of 40 EUI. A combination of a good-performing envelope (i.e. 2015 SEC compliant with prescriptive requirements), high-efficiency building, and air-to-air heat recovery are all key contributors to achieving the desired energy performance goal.



PICTURED: Polar ice cap
IMAGE CREDIT: Scientific Visualization Studio, NASA Goddard Space Flight Center

Refrigerants and Risk

Many buildings are evaluating variable refrigerant flow (VRF) solutions, which are a great mechanical systems option as they leverage heat pump technology and also move energy around the building before rejecting/extracting heat to/from the outside air. The challenge with this system is refrigerant is distributed throughout the building instead of contained in one location, as with traditional chillers. Since refrigerant escapes as a gas when there is a leak, it is often difficult to find and fix leaks in the system.

VRF systems use R410A or R134a refrigerant, which are being phased out around 2021 under the newly signed Kigali Agreement, an amendment to the Montreal Protocol. Current replacement refrigerants are flammable under certain conditions, which poses additional risks for systems with refrigerant piping running through the building.

As identified in *The New York Times* bestseller, “Drawdown,” man-made chemical refrigerants are the major contributing factor to global warming, and our biggest opportunity to slow and reverse this trend. The volumes of refrigerants being used in VRF systems and the associated leakage is a negative environmental impact we need to keep in mind when evaluating these systems.

3.1 OFFICE HVAC DESIGN CONSIDERATIONS

Heating and Cooling

When it comes to HVAC system energy savings, heat pump technology is fast becoming one of the go-to system options. Along the Pacific coast (west of the Cascades where winter conditions are mild compared to eastern Washington and Oregon) air source heat pumps are economically viable and provide significant contributions to energy savings. The ability to move energy from an area that needs cooling to another area that needs heating is very energy efficient.

In heat rejection mode, air source heat pumps are not as efficient as water cooled versions; however, with a mild summer climate, the energy penalty is minimal. The biggest benefit can be found in heating mode, when the air source heat pump is extracting heat from the air and delivering it to the building. In this mode, the heat pump can operate at a Coefficient of Performance (COP) ranging from 2 to 3-plus depending on the outside air conditions while even the most efficient condensing boiler is only operating at a COP of 0.97.

PICTURED: Facility used as the office baseline case. A 2012 SEC-compliant, 12-story office building.

FIGURE 3.2: Office Energy Modeling Scenario Assumptions

The energy modeling assumptions for the office baseline 2015 SEC minimally compliant scenario and the 60% glazing scenario are as follows:

MODELING ASSUMPTION OFFICE SCENARIOS	2015 SEC MINIMALLY COMPLIANT SCENARIO	2015 SEC OPTIMIZED FOR 60% GLAZING RATIO
System Description	• High Efficiency Variable Air Volume (HE VAV) system	• Air to Water Heat Pump with DOAS
Cooling Source/Distribution	• Chiller	• Multi-module air to water heat pump provides chilled water to chilled beam, radiant panels (installed by tenant)
Heating Source/Distribution	• Boiler	• Multi-module air to water heat pump provides heated water to chilled beam, radiant panels (installed by tenant)
Ventilation	• Rooftop Air Handling Unit connected to overhead air supply	• Dedicated Outdoor Air System (DOAS). Distribution through medium pressure overhead air supply
Economizer	• Airside economizer	
Heat Recovery	• None	• Exhaust is ducted to outside via heat recovery air handler
Load	• Occupancy: 200 SF/Person LPD*: 0.66 watts/SF • EPD**: 0.75 watts/SF	• Occupancy: 200 SF/Person LPD*: 0.66 watts/SF • EPD**: 0.75 watts/SF
Ventilation	0.25 CFM/SF	• 0.25 CFM/SF
Unit Efficiency	• Code minimum boiler or code minimum depending on the model scenario	• Air-to-Water Heat Pump Cooling EER: 10.6 • Heating COP: 2.1
Envelope Performance	• Code minimum requirements	• Roof Insulation: Entirely above deck; R-38 ci, Max. U: 0.026 • Walls: Spandrel; Min. Insulation: R-18; Max. U: 0.125 • Vertical Glazing: Assumed metal framed, fixed windows; U-value with fossil fuel: 0.31; SHGC: 0.35

** LPD: Lighting Power Density. Allowed LPD will drop to 0.59 W/SF on Jan. 1, 2018*

*** Energy Power Density*

3.2 OFFICE SYSTEMS COST PREMIUMS FOR 2015 SEC AND INCREASED GLAZING

Although it is common to divide the mechanical costs into core and shell and tenant improvement packages, the increased financial impact of the 2015 SEC for tenant improvements may result in revisiting this traditional cost split.

To understand the cost impact of the 2015 SEC, as well as the additional impact of increasing the glazing percentage to a 60% Window-to-Wall Ratio (WWR), the Sellen, PAE and MacMiller team researched the following scenarios:

- **Office Baseline Case:** 2012 SEC-compliant office building with 42.3% glazing
- **Scenario 1:** Costs for core and shell mechanical systems to be 2015 SEC compliant with no change to glazing percentages
- **Scenario 2:** Costs for core and shell mechanical systems to be 2015 SEC compliant while increasing glazing to 60%
- **Scenario 3:** Costs for tenant improvement mechanical systems to be 2015 SEC compliant with no change to glazing percentages
- **Scenario 4:** Costs for tenant improvement mechanical systems to be 2015 SEC compliant while increasing glazing to 60%

Office Baseline Case: 2012 SEC with 42% Glazing

The baseline case was a 2012 SEC-compliant, 315,000-square-foot (half block) office building with retail (restaurants) at the ground floor and 12 stories. It was constructed in 2014. Baseline costs have been escalated to 2017 dollars and costs premiums are based on 2017 dollars. The original glazing was 42.3%. Under the original 2012 SEC-compliant design, the mechanical system was a Direct Expansion (DX) rooftop unit with Variable Air Volume (VAV) distribution to the office floors. The original building did not have a Dedicated Outdoor Air System (DOAS) for ventilation, but it did have a central exhaust with heat recovery.

Scenario 1: 2015 SEC with 42% Glazing (Shell/Core)

For this baseline building's shell and core mechanical systems to comply with the current 2015 SEC with the same percentage of glazing, a rooftop DOAS unit and DOAS riser was added. This resulted in a small downsizing of the rooftop DX unit. The new DOAS riser resulted in a slight loss of leasable area. Air was distributed via the overhead VAV units, and there was no change to the exhaust or the heat recovery. For this scenario, the result was an increase in the core and shell mechanical costs up to 7.3% compared to the baseline case.

Scenario 2: 2015 SEC with 60% Glazing (Shell/Core)

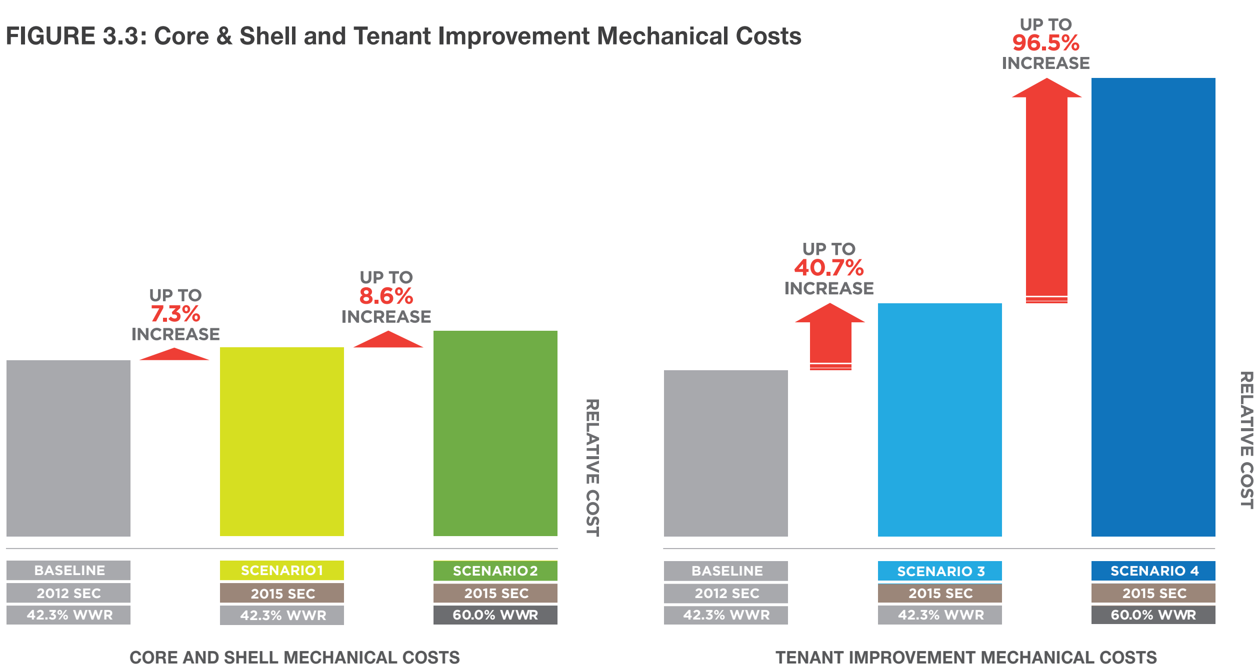
Increasing the glazing to 60% glazing and complying with the current 2015 SEC necessitated replacing the Scenario 1 core and shell mechanical system with an air-to-water heat pump with hot and cold water risers stubbed to the office floors. As in Scenario 1, there was a DOAS for ventilation and a central exhaust with heat recovery. For this scenario, the result was an increase in the core and shell mechanical costs up to 8.6% compared to Scenario 1.

Scenario 3: 2015 SEC with 42% Glazing (Tenant Improvement)
Looking at only the tenant improvement mechanical systems with no increase of glazing, the air distribution could remain an HE-VAV system and still comply with the 2015 SEC. For this scenario, the result was an increase in the tenant improvement mechanical costs of up to 40.73% compared to the baseline case.

Scenario 4: 2015 SEC with 60% Glazing (Tenant Improvement)
Increasing the glazing to 60% glazing and complying with the current 2015 SEC necessitated replacing the Scenario 1 tenant improvement mechanical system with chilled beams/chilled sails and radiators connected to the hot and cold water risers to/from the building's air-to-water heat pumps. For this scenario, the result was an increase in the tenant improvement mechanical costs up to 96.5% compared to Scenario 3.

Although it is common to divide the mechanical costs into core and shell and tenant improvement packages, the increased financial impact of the 2015 SEC for tenant improvements may result in revisiting this traditional cost split. As a new generation of core and shell projects with tenant improvements are permitted under the 2015 SEC and the financial impacts become apparent, market forces may blur this financial line, potentially impacting development costs for core and shell developers.

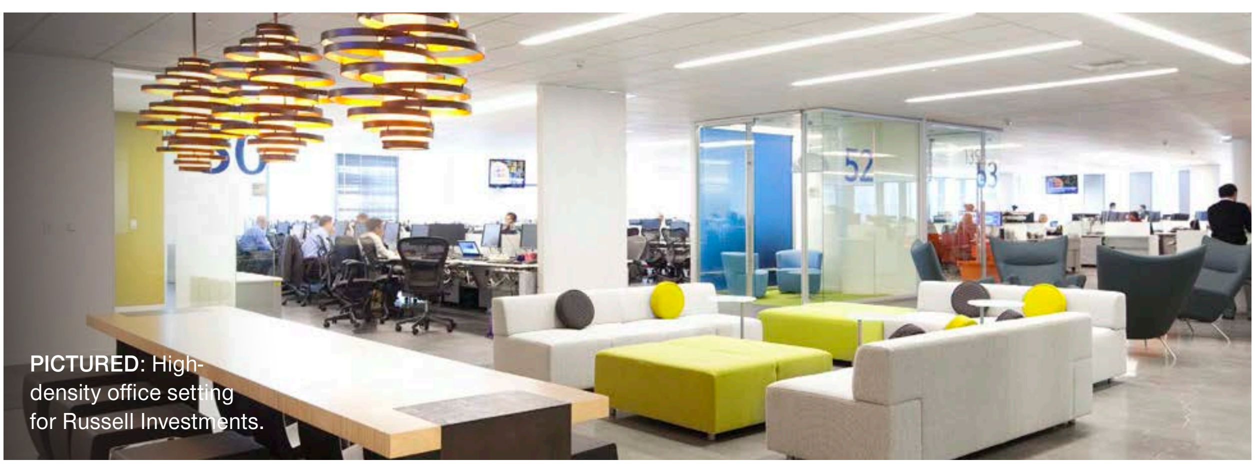
FIGURE 3.3: Core & Shell and Tenant Improvement Mechanical Costs



3.3 KEY FINDINGS: HIGH-RISE OFFICE

Based on our study sample, the following was observed for a high-rise commercial office building in downtown Seattle that complies with the modeled performance path of the 2015 SEC:

- High-Efficiency Variable Air Volume (HE-VAV) systems do not approach the energy efficiency of High-Efficiency Heat Pump (HE-HP) Systems with DOAS for ventilation.
  The HE-HP/DOAS system was more energy efficient than HE-VAV in all cases.
- While buildings with 60% glazing did have a higher EUI than comparable buildings with 40% glazing, the difference was not significant when HE-HP/DOAS systems were used.
- One of the most important factors affecting the EUI was the occupancy density relative to the default occupancy density factors in the Seattle Mechanical Code (SMC). Since a high-rise office building may have either (or both) conventional occupancy densities per the SMC (such as a professional service firm of attorneys), and a high-density occupancy loading (such as some technology companies), the EUI will vary by 25 to 40% depending on this loading.
- In Seattle's climate, with the high performance systems modeled, triple pane glazing resulted in less than a 5% reduction in building energy use.
- An increase in building glazing from 40% to 60% results in an increase of energy use by approximately 5% and an increase in building peak load of approximately 15%. The resulting load on the south and west façades increases peak load by over 22%. This increase in load restricts the viability of common technologies used with DOAS systems (such as radiant sails and chilled beams). External shading will likely be required for buildings using these technologies if glazing percentages higher than 40% are desired.



PICTURED: High-density office setting for Russell Investments.

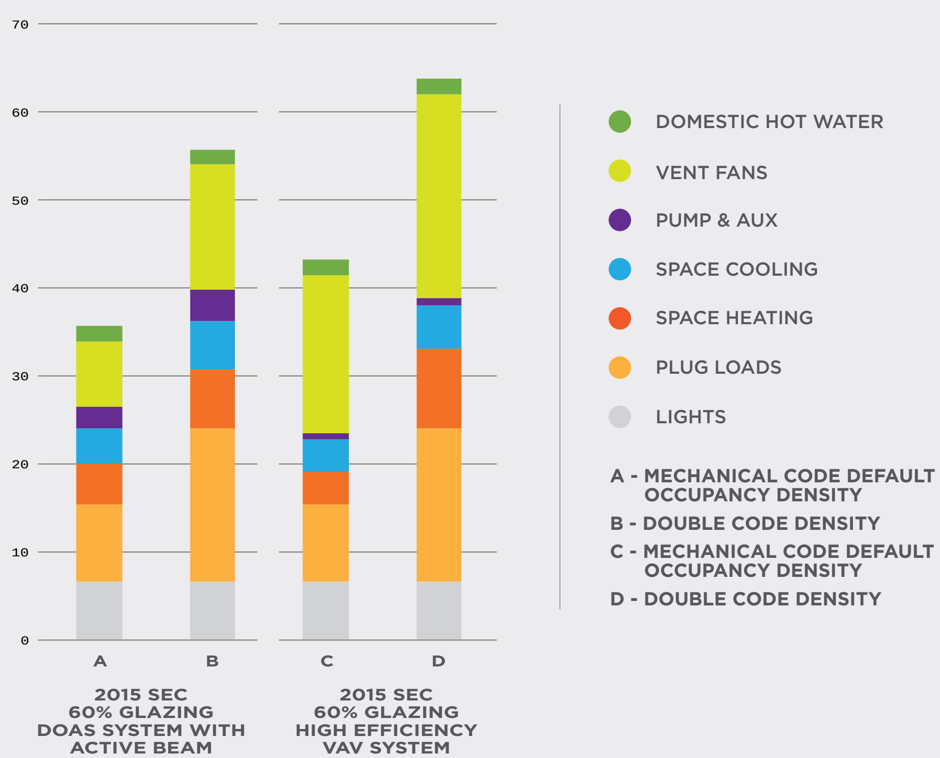
Impact of Internal Loads

As designers continue to improve the performance of the building envelope, increase daylighting, reduce lighting power densities, and increase the HVAC system performance for office buildings, the energy use of plug loads (i.e. computers and monitors) is becoming the major driver for a building's EUI.

Is this a bad thing? Not necessarily. An increasing density of occupants ultimately leads to building less office space, which helps reduce environmental impact. Still, the heating gain from the internal heat gains (i.e. people, lights and equipment) can be better leveraged through the use of heat pump technology by transferring heat from interior zones to perimeter zones.

From an SEC and LEED perspective, where the proposed building is compared with a baseline, increased occupants and plug loads in a densely packed office scenario can pose a major challenge to the team. Twenty years ago, an office building's energy comprised one-third lighting use, one-third HVAC system use, and one-third plug loads. This equal load distribution provided teams with ample opportunities to focus on lighting and HVAC system energy use reductions for an overall building energy use reduction between 20% to 30% or more. Now, in high-performing buildings, up to 50% to 70% of an office building's energy is used for plug loads, over which design, engineering and construction teams have minimal influence.

While the computing and display monitor industry continues to move to more efficient systems, the building community needs to play a part in educating owners on the growing dominance of plug loads on a building's EUI performance.



4. HIGH-RISE RESIDENTIAL STUDY

In multifamily residential buildings, the market demand for a large percentage of glazing (50% to 60%) plus full air conditioning, conflicts with the 2015 SEC prescriptive path at 30% glazing, or an Energy Use Intensity (EUI) of 35 kBtu/SF/year.

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Before starting a project, developers must understand which combination of building systems will ensure that their buildings achieve or exceed the 2015 SEC requirements while minimizing costs.

Bringing architects, engineers and contractors on early in the evaluation process can help developers explore the multiple solutions available that will meet the market demand for high glazing percentages while also achieving the energy code and realizing the project proforma.

Before exploring system options, it is critical to identify the major energy uses in a multifamily residential building. Historically, the major energy users have been the HVAC system and domestic hot water system, followed by plug loads and lighting, adding up to an EUI of approximately 50 (see Figure 4.1).

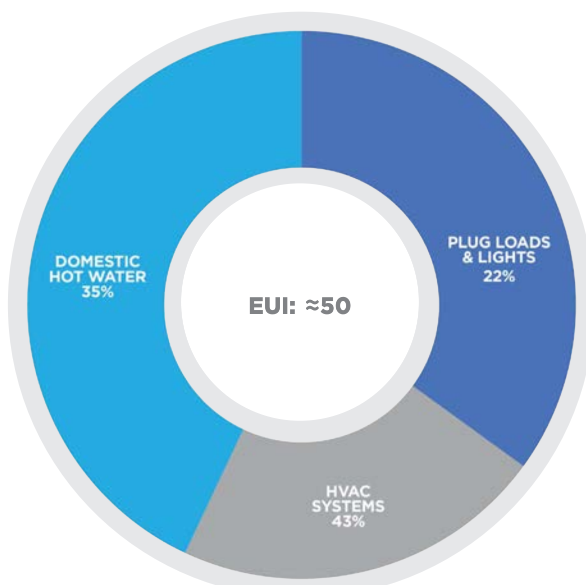


FIGURE 4.1: Typical Multifamily Residential Annual Energy Use

4.1 RESIDENTIAL HVAC DESIGN CONSIDERATIONS

Air source heat pumps are economically viable and provide significant contributions to energy savings.

Heating and Cooling

As with office buildings, to maximize HVAC system energy savings, heat pump technology is fast becoming one of the leading systems options. Along the Pacific coast (west of the Cascades where winter conditions are mild compared to eastern Washington and Oregon) air source heat pumps are economically viable and provide significant contributions to energy savings. The ability to move energy from an area that needs cooling to another area that needs heating is very energy efficient.

In heat rejection mode, air source heat pumps are not as efficient as water cooled versions; however, with a mild summer climate, the energy penalty is very minimal. The biggest benefit is in heating mode when the air source heat pump is extracting heat from the air and delivering it to the building. In this mode of operation, the heat pump can operate at a Coefficient of Performance (COP) ranging from 2 to 3-plus, depending on the outside air conditions when even the most efficient condensing boiler is only operating at a COP of 0.97.

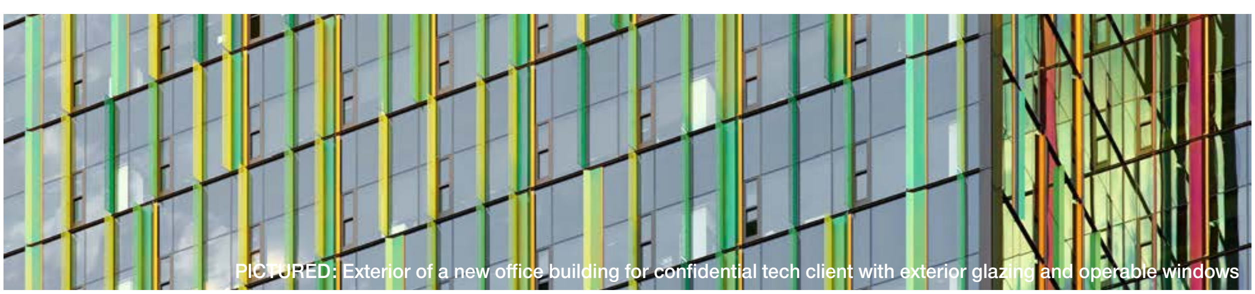
Residential Domestic Hot Water

Air source heat pump technology is also being applied to domestic hot water systems with significant improvements in energy efficiency. Solar thermal is a renewable energy that can also be leveraged and has a good return on investment, often paying back in less than five years.

Residential Ventilation Air Heat Recovery

Residences require exhaust for bathrooms, kitchens and laundry. With envelopes moving toward construction standards that minimize infiltration, the use of trickle vents has been a go-to solution. However, unconditioned air trickling in through a vent has negative impacts on both comfort and energy use.

Air-to-air heat recovery solutions, in either a centralized or decentralized configuration, are an important contributor to conserving energy and are becoming an industry standard for most high-rise residential buildings.



PICTURED: Exterior of a new office building for confidential tech client with exterior glazing and operable windows

FIGURE 4.2: Residential Energy Modeling Scenario Assumptions

The energy modeling assumptions for the office baseline 2015 SEC minimally compliant scenario, and the 60% glazing scenario are as follows:

MODELING ASSUMPTION RESIDENTIAL SCENARIOS	2015 SEC MINIMALLY COMPLIANT SCENARIO	2015 SEC OPTIMIZED FOR 60% GLAZING RATIO
Cooling Source	Chiller	Multi-module air to water heat pump
Heating Source	Boiler	Multi-module air to water heat pump
Distribution	Rooftop Air Handling Unit connected to overhead air supply	Cooling and heating distribution will be provided by four pipe fan coil units
Ventilation		Dedicated Outdoor Air System (DOAS)
Economizer	Airside economizer	
Heat Recovery	None	Exhaust is ducted to outside via heat recovery air handler
Load	Occupancy: 500 SF/Person LPD*: 0.41 watts/SF EPD**: 9.0 watts/SF	Occupancy: 500 SF/Person LPD*: 0.41 watts/SF EPD**: 9.0 watts/SF
Ventilation	0.06 CFM/SF	0.06 CFM/SF
Unit Efficiency		Air-to-Water Heat Pump Cooling EER: 9.6 Heating COP: 2.1

** LPD: Lighting Power Density. Allowed LPD will drop to 0.59 W/SF on Jan. 1, 2018*

*** Energy Power Density*

Passive House Principles

What is Passive House? Passive house is a philosophy that can be applied to almost any building type and size. It is not just for single family residences. The overarching goal is to save energy. It employs the following design principles:

- Continuous insulation, no thermal bridges
- Air tight construction
- Optimized window performance and solar gain
- Heat and moisture recovery ventilation
- Minimized mechanical systems

Applying these principles will not only achieve a highly energy efficient and comfortable building, but the ability to reduce and eliminate mechanical systems can also offset increased costs for the envelope.

4.2 RESIDENTIAL COST PREMIUMS FOR 2015 SEC AND INCREASED GLAZING

To understand the cost impact of the 2015 SEC and the additional impact of increasing the glazing percentage to a 60% window-to-wall ratio (WWR), the Sellen, PAE and MacMiller team researched the following scenarios:

- **Baseline Case:** 2009 SEC-compliant office building with 53% glazing
- **Scenario 5:** Costs for mechanical systems to be 2015 SEC compliant with no change to original glazing percentages
- **Scenario 6:** Costs for mechanical systems to be 2015 SEC compliant while increasing glazing to 60%

Residential Baseline Case: 2009 SEC with 53% Glazing

The baseline case was a 2009 SEC-compliant, 422,800-square-foot, 39-story residential high-rise constructed in 2014. As in the office scenarios, the baseline costs have been escalated to 2017 dollars and cost premiums are based on 2017 dollars.

The original glazing was 53%. Under the original 2009 SEC-compliant design, the mechanical system consisted of a condensing boiler and chiller connected to vertical fan coil units in each of the residential units. The original building did not have a Dedicated Outdoor Air System (DOAS) for ventilation. Exhaust was directly from the unit to exterior curtainwall without any heat recovery.

Scenario 5: 2015 SEC with 53% Glazing

For this baseline building to comply with the 2015 SEC at the same level of 53% glazing, the system employs vertical heat pumps with fluid coolers and condensing boilers. A DOAS unit is added and a dedicated heat pump pre-tempers outside air delivered to each unit's heat pump. As with the baseline case, exhaust air is relieved directly from the unit to exterior curtainwall without any heat recovery. For this scenario, the result was an increase in the mechanical costs up to 13.9% compared to the baseline case. It's important to note that the 13.9% cost increase represents the impact of two code cycles since the baseline in this case was the 2009 SEC.

Scenario 6: 2015 SEC with 60% Glazing

Increasing the glazing to 60% glazing and complying with the 2015 SEC necessitated replacing the Scenario 5 mechanical system with an air-to-water heat pump with hot and cold water risers connected to four-pipe fan coil units in each apartment. As in Scenario 5, a DOAS provided ventilation and a central exhaust with heat recovery. For this scenario, the result was an dramatic increase in mechanical costs, up to 32.7%.

Future residential projects permitted under the 2015 SEC should weigh the costs of external shading and/or improved glazing performance with the cost of mechanical systems to find the most cost-effective balance of strategies.

4.3 RESIDENTIAL KEY FINDINGS

For high-rise residential buildings in downtown Seattle complying with the modeled performance path of the 2015 SEC, we observed the following:

- The application of heat pump technology is a key driver for reducing the heating energy use for both the heating ventilation and air conditioning (HVAC) and domestic hot water systems.
- For HVAC systems, the heat pump technology selected must also be capable of transferring energy within the building before using the atmosphere as a heat sink or source.
- With tight envelope construction required as part of the 2015 SEC, using trickle vents may not be viable when considering glazing percentages higher than 50%. Using central or distributed air-to-air heat recovery systems may be required.
- A 60% glazed residential building should be able to meet the 2015 SEC (i.e. an EUI of 35 or lower) by using heat pumps and possibly solar thermal to produce domestic hot water, high-efficiency heat pump systems for cooling and heating the building, air-to-air heat recovery, along with a code compliant envelope.
- The cost premium for going from 53% glazing to 60% glazing was substantial; in this example it was an increase of almost 33% in mechanical costs. Future residential projects permitted under the 2015 SEC should weigh the costs of external shading and/or improved glazing performance with the cost of mechanical systems to find the most cost-effective balance of strategies.
- Applying passive house standards can further reduce building energy use down to EUI levels ranging from 20 to 25, as well as avoid the cost of full cooling systems, which have now become an industry standard for high-rise residential units in Seattle.

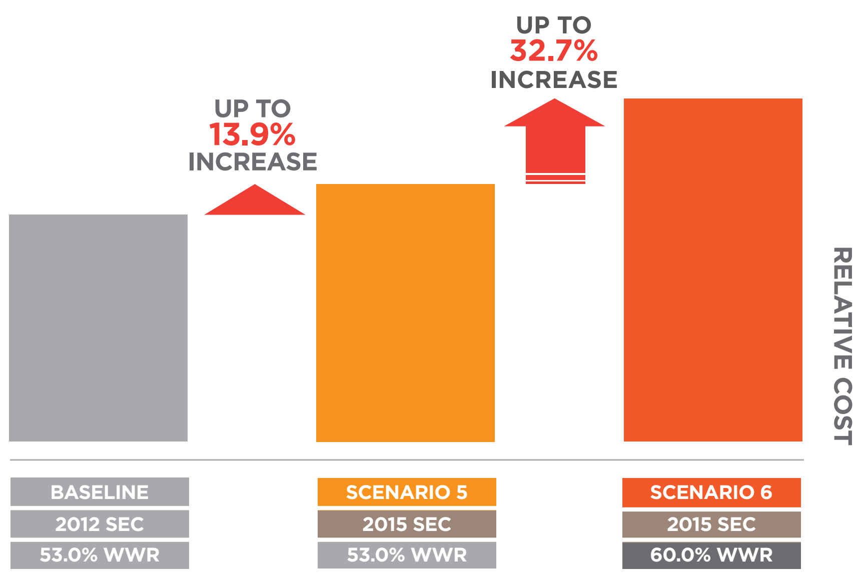


FIGURE 4.3: Residential Mechanical Costs

5. OTHER FACTORS IMPACTING ENERGY PERFORMANCE AND SYSTEM SELECTION

The new code will redefine the inflection points at what height a particular system makes good energy and fiscal sense.

5.1 SITE IMPACTS ON ENERGY CONSUMPTION

As available properties in the Seattle urban core become scarce, the impact of site givens — solar exposure, the availability or lack of daylighting, the feasibility of natural ventilation, and the available building footprint and resulting massing — have an increased role in energy consumption.

Site and Daylighting

Sites with a large buildable zoning envelope that maximizes building depth in both dimensions offer a large rentable floorplate, but reduce the percentage of available floorplate within the daylight zone.

The 2015 SEC recognizes (in C402.4.1.1) the balance between increasing vertical glazing to 40% window-to-wall ratio (WWR) in order to admit energy-saving daylighting and maximize the percentage of floorplate with access to daylighting. When buildings move away from a square footprint to more elongated rectangles with narrower skin to core depths, the percentage of floorplate in the daylight zone grows, as does the ratio of exterior skin to rentable area. Teams are increasingly aware of the interplay of increasing daylight zones through narrower buildings and reducing operational energy costs, while also managing the exterior skin's first costs.

Zoning, Building Height and Residential Systems

For tall residential buildings in the downtown core, Belltown and the Denny Triangle (DOC1, DOC2, DMC), the zoning step-back above the podium limits the available average floorplate to 10,700-13,800 square feet, depending on the specific zone (SMC 23.49.058, Table B). In order for projects to be financially feasible, this relatively small allowable floorplate pushes residential projects as high as 500 feet, with many projects maximizing their height through Section 23.49.015 by voluntarily providing low- and moderate-income housing.

While several mechanical systems are possible for high-rise residential, Variable Refrigerant Flow (VRF) systems are often used due to their lower initial costs. Under the previous SEC, a building height of 240 feet was often the assumed maximum height that air-cooled VRF systems could work efficiently; above that height, water-cooled VRF units would be needed. The new code will redefine these inflection points at what height a particular system makes good energy and fiscal sense.

Through "thermal matchmaking," design teams and planners have an opportunity to connect buildings that have a simultaneous need to reject heat from one building and use it in another.

One potential solution is using the all-electric Variable Refrigerant Packaged Heat Pumps (VRP-HP) in each unit, avoiding heating and ventilation equipment on the roof, while reducing HVAC/unit first costs. Architecturally, these VRP-HPs require a large louver at each unit, which will need architectural/mechanical coordination to accommodate the free air requirements, while fitting into the overall façade design concept.

Impact of Thermostatic Zones

To reduce wasted energy, adjacent zones with connected openings of more than 10 percent of the floor area of either zone may not simultaneously heat and cool the adjacent zones (C403.2.4.1). This will not only impact the mechanical distribution, but it may also inform where functions are located within a building.

Grouping functions with similar cooling or heating needs together, as well as segregating areas with dissimilar thermal needs, helps prevent simultaneous heating and cooling within a zone. Other architectural decisions, such as the amount of glazing allocated to different façades with varying degrees of thermal exposure, will also inform the extent of thermostatic zones and mechanical system distribution. Buildings with simultaneous heating and cooling needs are good candidates for hydronic systems or other systems that can move thermal energy around the building instead of rejecting it in some areas and creating it for others (see Section 5.2 on the following page).

Carbon Neutrality by 2050

The City of Seattle's Climate Action Plan, formally adopted in 2013, charts a course for the city to achieve carbon neutrality by 2050. One of the commercial building strategies identified in the report is switching from fossil fuel use for heating and domestic hot water, to using electric heat pumps and district energy. Future code initiatives will likely incentivize project teams to use high-performance heat pump systems that use Seattle City Light's carbon neutral electric power, in lieu of conventional systems that use natural gas.

District energy systems using waste thermal energy, such as the new district energy system in Denny Triangle that moves waste heat from a server facility to a corporate office campus, is another pathway toward carbon neutrality. Through "thermal matchmaking," design teams and planners have an opportunity to connect buildings that have a simultaneous need to reject heat from one building and use it in another.

5.2 RECURRING THEMES

In researching the various scenarios, multiple recurring themes appeared, both expected and unexpected. They include the following.

Move Heat Before Creating It

Maximizing energy efficiency depends in part on a mechanical system that can move thermal energy within the building from areas rejecting heat to areas demanding heat. Owners can no longer afford to create heat in one building zone while simultaneously cooling in another zone.

Systems, such as conventional Variable Air Volume (VAV) with electric reheat, are the antithesis of moving heat within buildings; these systems are not able to meet both the current code and the desire for increased glazing. Heat pumps and VRF provide simultaneous heating and cooling for buildings with dramatic swings in solar gain throughout the day. The investment in these systems provide not only savings in operational energy, but they are also an important key to increasing glazing percentages to 60% and beyond.

Build a Better Highway

The efficiency with which heat is transferred depends on the medium; water has a specific heat capacity that is four times higher and a volumetric heat capacity that is 3,000 times higher than air. Similar to the analogy of rail versus highway infrastructure and the relative real estate required for transportation, the space savings and energy efficiency bonus of hydronic systems are considerable.

This efficiency of space and thermal transfer comes at price. For an office project, including both the core and shell and tenant mechanical system, a four-pipe fan coil with DOAS systems can cost up to 23-25% more than a high-efficiency VAV system. While upfront costs are substantial, hydronic systems provide the greatest flexibility to change out components at either end of the "highway" — the chillers, boilers, heat pumps or fan coil units — as they reach the end of their productive life. Compared to replacing an entire air distribution system, component upgrades connected to an existing hydronic system reduce disturbances to tenants and allow for greater jumps in efficiency.

Invest in Long Lifespan Elements

For long-term holds, invest in building elements and strategies that have a long lifespan and are unlikely to be upgraded, such as glazing systems and the exterior opaque envelope. If a new building offsets the lower performance of a long-lifespan building element with higher-performing, shorter-term elements, such as lighting, the lower-performing element will become a long-term energy liability, dragging down the best possible performance in future upgrades.

Seattle requires energy consumption disclosure at the time of sale, making an investment in a higher performing system at the time of construction an investment in a potential higher resale value.

Indoor Environment Quality as an HR Strategy

Beyond the basics of the statistical comfort defined by standards like ASHRAE 55 and 62.1, creating and maintaining a high-quality indoor environment is an important productivity, staff retention and talent attraction strategy. A Dedicated Outdoor Air System (DOAS) can not only reduce electric energy consumption up to 42%, as compared to conventional VAV systems, but they also offer superior air quality since no air is recirculated. Contaminates from one area of the building are not blended with incoming outside air and spread throughout the building.

After decades of fixed windows and relying solely on mechanical ventilation, office projects for technology companies and state government are once again providing operable windows to increase occupant satisfaction.

As demonstrated in an ASHRAE study conducted by the University of California Center for the Built Environment, occupants that could control their thermal comfort (through direct access and adjustment of operable windows) reported increased satisfaction despite temperature variations. Through strategies such as DOAS, HEPA filters or natural ventilation, improved Indoor Environment Quality (IEQ) is an important key to improving occupant satisfaction, reducing occupant turnover, and minimizing absenteeism that directly affect the bottom line.

Alternatives to New Development and Missed Opportunities

Despite the unprecedented amount of new construction projects in the Seattle urban core with tenant improvements designed and built to recent energy codes, many older buildings are also attracting new tenant improvements. Depending on the scope and whether the tenant improvement is considered a substantial alteration, a building-wide upgrade may not be triggered, leaving many mid-century buildings with poorly performing core and shell mechanical systems intact.

While some early 19th century buildings come with the “good bones” of high floor-to-floor heights and good daylighting opportunities, thermal performance and air infiltration often does not match current performance levels. In other cases, tenants may choose to avoid the costly Seattle market altogether, opting for for an office location near suburbs. Both scenarios limit the full implementation of the new energy code and the full level of energy efficiency.

Mitigate the Risk of Future Code Requirements

Although Seattle’s energy code is widely viewed as one of the most stringent codes in the country, California’s energy code, the 2030 Challenge, and Passive House standards define even higher levels of efficiency that will likely shape future code requirements. Seattle requires energy consumption disclosure at the time of sale, making an investment in a higher performing system at the time of construction an investment in a potential higher resale value.

6. CONCLUSIONS AND QUESTIONS FOR FUTURE PROJECTS

When charting a path for 2015 SEC compliance, it's essential that the occupancy density is known early. It will not only drive the system selection, but it also may necessitate additional non-mechanical strategies affecting the budget and design.

While the increasing stringency of the 2015 SEC and the market's desire for increased glazing in both office and residential projects are seemingly in conflict, technical and architectural solutions exist, but at a cost.

In studying the multiple energy modeling scenarios, glazing percentages above 40% in office and residential high-rises will likely require either heat pump or variable refrigerant flow solutions that work in conjunction with Dedicated Outdoor Air System (DOAS) and heat recovery. As glazing percentages rise even higher, additional strategies will be needed to reduce thermal gain or supplement grid-supplied energy with on-site renewable energy.

6.1 HIGH-RISE OFFICE CONCLUSIONS

Based on the limited high-rise office scenarios studied, the team found that a High-Performance Variable Air Volume (HE-VAV) could meet the new 2015 SEC EUI office target of 40 kBTU/Hr/SF, but only if glazing was limited to 40% and it was triple glazed. In order to comply with the 2015 SEC and meet the higher 60% glazing target, a High-Efficiency Heat Pump (HE-HP) was required for the tested scenarios. In all cases, the HE-HP/DOAS system was more energy efficient than the HE-VAV.

The modeled office scenarios used the default occupancy densities in the mechanical code, but the team also tested options that had twice the code's default densities — similar to the densities found in recent open office configurations. Doubling the occupancy had a significant impact on increasing EUI — far more than any other factor.

When charting a path for 2015 SEC compliance, it's essential that the occupancy density is known early. It will not only drive the system selection, but it also may necessitate additional non-mechanical strategies affecting the budget and design. These strategies could include additional insulation, high performance glazing (above code minimums), and external shading devices.

The cost impacts to office core and shell mechanical systems for going from a 2012 SEC-compliant to a 2015 SEC-compliant solution while still maintaining conventional amounts of glazing (42%) were modest. The team calculated a core and shell mechanical cost premium of up to 7.3% to build the same project under the new code. The newly required DOAS and inflation accounted for most of this premium.

To increase the glazing percentage up to a 60% window-to-wall ratio, the core and shell mechanical premium was up by an 8.6% increase over the 40% glazing scenario.

In contrast to the core and shell, the cost premium for the office tenant improvement mechanical systems is substantial. Without any increase in glazing percentages, the cost premium to go from the 2012 SEC to the 2015 SEC was up to 40.7%. In many cases, compliance with the current code means a hydronic system with the tenant mechanical package incurring the costs of hydronic distribution to chilled beams and radiators. Increasing the glazing to 60% increases thermal load, the need for additional distribution, and cost. The tenant mechanical premium for 60% glazing resulted in cost increases up to 96.5%. These costs assume a higher occupancy density commonly found in the open office spaces of technology companies.

Ultimately the market will find the sweet spot of acceptable mechanical costs and the desire (and willingness to pay) for more glazing. This will challenge developers in budget planning and setting tenant improvement allowances, as well as design teams in identifying mechanical systems and façade performance that capitalize on views without over burdening the energy performance.

6.2 HIGH-RISE RESIDENTIAL CONCLUSIONS

For the high-rise residential study, the baseline project was originally permitted under the 2009 SEC (two previous code cycles) and had 53% glazing. To bring this building up to the current code with no increase in glazing, the cost premium was up to 13.9%. The jump to increase glazing to a 60% window-to-wall ratio incurred a 32.7% price increase — a significant increase considering that the amount of glazing rose only by 7%. Providing a DOAS system, going from a vertical heat pump in each unit to a four-pipe fan coil system with an air-water heat pump, and adding heat recovery, accounted for most of the 32.7% increase.

The code also points both residential and office projects toward some important energy and health advancements. These include improved energy conservation and air quality through DOAS, the importance of moving energy within the building instead of recreating it, and all-electric mechanical systems that could conceivably be powered without contributing to climate change. Added emphasis on reducing air infiltration and avoiding thermal bridges will necessitate a new set of architectural details, as well as revisiting how cantilevered decks can comply.

6.3 QUESTIONS FOR FUTURE PROJECTS

There is no one-size-fits-all solution to the 2015 SEC, and this study is only the beginning of the conversation. Questions to begin the modeling and system selection efforts on future projects may include:

Since the financial burden for increased glazing falls overwhelmingly on the tenant improvement mechanical systems, will future office tenants ask for larger tenant improvement allowances to meet the code in buildings with 60% or higher glazing percentages?

- For office projects, is the increased marketability of raising glazing to 60% worth the substantial increase in tenant improvement mechanical costs, up to 96.5%? If not, what level of glazing is acceptable in new Class A offices in Seattle's urban core?

- Since the financial burden for increased glazing falls overwhelmingly on the tenant improvement mechanical systems, will future office tenants ask for larger tenant improvement allowances to meet the code in buildings with 60% or higher glazing percentages?

- To what extent can architectural and envelope strategies — such as exterior shading, electrochromic glazing, high-performing glazing above prescriptive values, and superinsulation — drive downsizing of the mechanical system? Do the first cost savings from mechanical downsizing exceed the additional costs required for these architectural and envelope strategies?

- For new office projects that wish to stay with conventional HE-VAV systems, how significantly does this limit the percentage of glazing? Will these buildings, likely with 40% or less glazing, be competitive with other buildings with higher glazing but more expensive mechanical solutions?

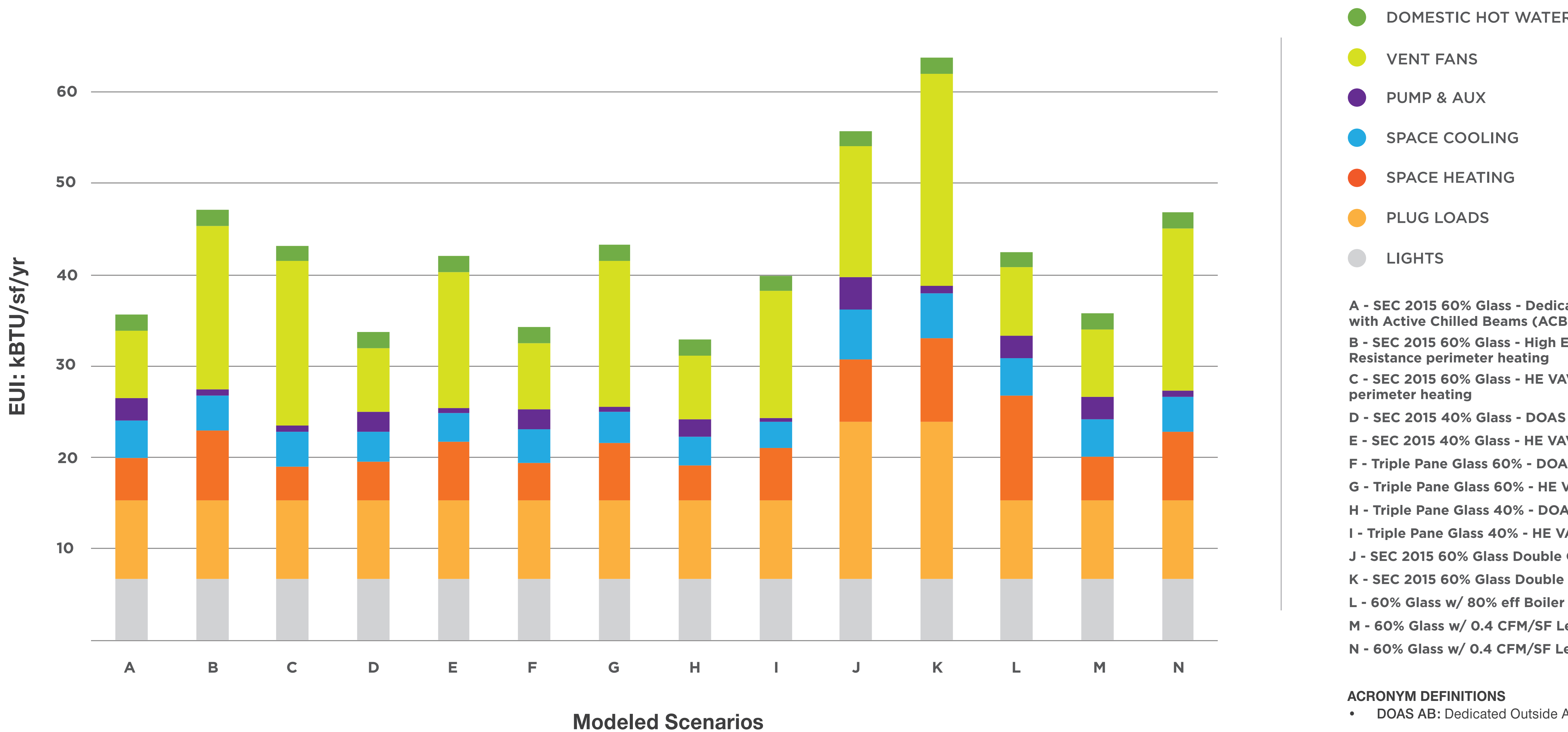
- Is an all-electric solution — one that could conceivably be from non-fossil fuels such as wind or hydro — an important driver? How do these solutions support Seattle's carbon-free goal of 2050? Is the possibility for a greenhouse gas-free mechanical system, such as electric heat pumps for both HVAC and domestic hot water, a compelling story for developers and cost effective to operate for buyers?

- What is the health risk for occupants, as well as the global warming and ozone depletion risk for the environment, if refrigerant leaks within occupied spaces? Which systems isolate toxic refrigerants in mechanical rooms and penthouses, and which systems circulate these refrigerants throughout the walls in offices and residences?

- What is the impact of various mechanical systems on usable square footage, as well as the façade? What is the space premium for DOAS systems? How can VRF systems be integrated into the façade design with maintaining air circulation for thermal transfer?

- What is the time horizon for owning the building and the need to be able to upgrade mechanical components to maintain the highest level of efficiency? How should first-cost dollars be allocated between high-performing, long-term building components — such as fenestration, building skin and thermal distribution — and shorter-term mechanical components?

APPENDIX A: OFFICE ENERGY MODELING RESULTS



A - SEC 2015 60% Glass - Dedicated Outside Air System (DOAS) with Active Chilled Beams (ACB)

B - SEC 2015 60% Glass - High Efficiency (HE) VAV Electric Resistance perimeter heating

C - SEC 2015 60% Glass - HE VAV Heat Pump hydronic perimeter heating

D - SEC 2015 40% Glass - DOAS ACB

E - SEC 2015 40% Glass - HE VAV

F - Triple Pane Glass 60% - DOAS ACB

G - Triple Pane Glass 60% - HE VAV

H - Triple Pane Glass 40% - DOAS ACB

I - Triple Pane Glass 40% - HE VAV

J - SEC 2015 60% Glass Double Occupancy - DOAS ACB

K - SEC 2015 60% Glass Double Occupancy - HE VAV

L - 60% Glass w/ 80% eff Boiler - DOAS ACB

M - 60% Glass w/ 0.4 CFM/SF Leakage - DOAS ACB

N - 60% Glass w/ 0.4 CFM/SF Leakage - HE VAV

ACRONYM DEFINITIONS

- **DOAS AB:** Dedicated Outside Air System with Active Chilled Beams
- **HE VAV Elec Resis:** High Efficiency VAV with Electric Resistance Perimeter Heating
- **HE VAV Heat Pump:** High Efficiency VAV with Heat Pump Hydronic Perimeter Heating

APPENDIX B: RESIDENTIAL ENERGY MODELING RESULTS

A - SEC Residential 60% Glass
B - SEC Residential 60% Glass W/O Heat Recovery (HR)
C - SEC Residential 40% Glass
D - SEC Residential 40% Glass W/O HR
E - 60% Glass W/ Boiler @ 80%
F - 60% Glass W/ Boiler @ 80% W/O HR
G - 60% Glass W/ Lighting @ 0.8 watts/sf
H - 60% Glass W/ Lighting @ 0.8 watts/sf W/O HR
I - Glass W/ Gas Water Heater
J - Glass W/ Gas Water Heater W/O HR
K - Glass W/ Passive House Standards
L - 40% Glass W/ Passive House Standards
M - 60% Glass W/ Passive House Standards
N - Sample 2012 SEC Real Building Model

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ABOUT THE FIRMS

SELLEN CONSTRUCTION

Sellen Construction is a locally owned and operated commercial builder. Founded in 1944 and headquartered in the South Lake Union neighborhood of Seattle, Sellen builds iconic projects for the region's tech, science, arts, healthcare and hospitality leaders. We believe in building community by creating unique spaces where significant things happen, and in giving back to non-profit organizations that make our community a great place in which to live and work.

Sellen operates primarily in the Pacific Northwest and offers a wide range of services from preconstruction support, cost estimating and constructability services, to Virtual Design and Construction (VDC), integrated project delivery and sustainability services. Sellen has a Special Projects group that regularly performs renovations and tenant improvements in existing buildings for a variety of office and health care clients. Sellen's notable projects include the Bill & Melinda Gates Foundation Campus, Seattle Children's Hospital Building Hope Expansion, the Museum of History and Industry at South Lake Union, King Street Station Restoration, and the new Amazon office towers in Seattle's Denny Triangle neighborhood.

PAE ENGINEERS

PAE is a leader in sustainable engineering design. Founded in Portland in 1967, PAE provides mechanical, plumbing, electrical, and technology consulting and engineering-design services for projects ranging from greenfield buildings to retrofits to historic renovations. We also offer related services such as commissioning, comfort analysis, envelope optimization, carbon-footprint and water-cycle analysis, and energy modeling. In everything we do, we prioritize quality and work responsibly—keeping a close eye on cost and sustainability. Our high-performing buildings work because our people listen – to our clients, to each other, and to the natural world around us.

MACDONALD-MILLER FACILITY SOLUTIONS

MacDonald-Miller is a full-service design-build mechanical contractor in the Pacific Northwest. With over 1,000 talented professionals, 10 locations and our own prefabrication shop, no project is too big or too small. We've helped shape the local landscape for over half a century with buildings that operate in the most efficient manner possible. We like to think we're saving the planet one building at a time. Facility managers, owners and tenants can all rest assured that our experience as industry leaders lends itself well to tackling the complexities of their industries–healthcare, biotech/labs, industrial, marine construction, commercial office buildings, and residential projects.

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