

Facade Tectonics

High-Performance Façades: Barriers to widespread adoption in non- residential and multi-family buildings and strategies to overcome them

16th August 2024



Photo by [David Smooke](#) on [Unsplash](#)

This report has been prepared by the Façade Tectonics Institute (FTI) for the U.S. Department of Energy under subcontract from Lawrence Berkeley National Laboratory (LBNL), No. 7702007.

The Façade Tectonics Institute is a 501(c)3 non-profit member organization, whose primary mission is to advance the art, science, and technology of the building skin through research, practice, and education, including:

- Expanding recognition and understanding of the integral role the facade system plays in resilience, sustainability, energy efficiency, durability, health and productivity in buildings and urban habitat.
- Building a collaborative, facade-based action-oriented dialogue bridging industry silos and filling key knowledge gaps.
- Accelerating innovation and tangible improvements in buildings and urban habitat through strategic facade-based initiatives.
- Providing the industry-leading platform for building facade knowledge-sharing, communication and collaboration.

The principal researchers who conducted this research on behalf of FTI were FTI fellows, Helen Sanders (Technoform North America) and Stephen Selkowitz (LBNL affiliate) with assistance from Valerie Block (Façade Tectonics Institute) who organized the roundtables and provided essential contract administration.

Acknowledgements

FTI would like to thank Skidmore, Owings & Merrill and WSP Canada for their generosity in hosting the in-person roundtables at their offices in Los Angeles, Chicago, New York, and Toronto. Thank you also to the National Glass Association who accommodated our first roundtable focused on the glazing contractor and fabricator community in Las Vegas during their Building Envelope Contractors conference in March 2023. We are also grateful for the support of Technoform North America which provided support and resources to facilitate completion of this project.

We are extremely grateful for the time and expertise of more than 100 members of the FTI community and beyond, who gave us the benefit of their valuable insights and experiences and connected us with a broader network of contributors. The depth and diversity of views from all parts of the design and construction value chain made it possible to develop such a comprehensive view of the challenges faced in transforming façade performance. Participants in this study care deeply about delivering higher performance facades. This research, analysis and solution development could not have been completed without their passionate input and collaboration.

Contents

Acknowledgements	2
Executive Summary	5
The barriers	5
Where market transformation is happening faster	6
A blueprint for change.....	7
Next step recommendations.....	8
Introduction and context.....	9
Why façades matter	9
Market dynamics.....	12
Current challenge.....	13
Study description	14
Participants	15
Barriers to adoption of high-performance fenestration and façades	18
Barrier 1: There is a significant increase in first cost over business-as-usual (BAU):	21
Barrier 2: There is insufficient return on investment (ROI) or payback on the initial first cost increase of using high-performance solutions:	25
Barrier 3: Design and product selection decisions are driven to the status quo to manage risk	26
Barrier 4: Standard project delivery methods drive to lowest cost and status quo solution selection..	27
Barrier 5: Project design is HVAC drive	28
Barrier 6: Code compliance is lax.....	29
Barrier 7: There is insufficient capacity at most architect / façade consultant firms to design high-performance façades	30
Additional barriers to the retrofitting of façades	33
Unknown existing conditions:.....	34
“You touch it, you own it”:	34
Set back issues.....	34
High disruption causing lost revenue and incurred costs	35
Window / façade replacements do not provide fast enough payback on energy cost savings	35
Curtain wall systems are not designed to be easily upgraded or maintained	35
Resulting impact	35
Where and why market transformation is happening: Case studies - translating theory into action	36
Case Study #1: British Columbia and the City of Vancouver	36
Case Study #2. Massachusetts	40
Case Study #3: Seattle, WA.....	49

Case Study #4: London, UK	52
Case Study #5: Certified Passive House Deployment	54
Case Study #6: The world's first for-profit Living Building Challenge commercial office	55
Recommendations to address key barriers.....	58
Concept 1: Develop an above code certification program for high-performance façades that can be referenced by incentive programs to drive market deployment.....	59
Concept 2: Create tools and programs that improve the ability to communicate the overall economic value of high-performance façades to owners.....	63
Concept 3: Make windows the next “marble countertop” – a must have for owners and tenants alike65	
Concept 4: Ensure there is sufficient selection of high-performance curtain wall and window wall systems and trained installers available for a competitive market.....	66
Concept 5: Create and/or identify certification programs for practitioners to verify competence, build capacity and improve facade simulation, design and execution.	68
Concept 6: Increase façade knowledge and education across the full value chain	69
Concept 7: Create façade incentive programs.....	72
Concept 8: Deploy code related recommendations.....	78
Concept 9: Implement strategies to solve the retrofit challenge.....	86
Concept 10: Enhance domestic supply chain competitiveness.....	89
Conclusions and recommendations	91
Appendix A: Data generation methodology.....	93
Appendix B: Glossary	95
Appendix C: Detailed list of solution ideas.....	97

Executive Summary

The U.S. has aggressive goals to reduce energy use and carbon emissions that cannot be achieved without addressing the challenge of delivering high-performance façades to every new building and in an existing building stock of poorly performing buildings. However, today façade performance in non-residential and multi-family residential buildings rarely achieves best practice performance and falls even further short of what is needed to reach emerging societal net zero energy building goals.

Yet there are high-performance façade and fenestration products available, built examples and measured data that demonstrates the technical feasibility of achieving much higher performance levels from the façade as part of the larger whole building context. Why then are high-performance façades not business-as-usual in U.S. non-residential and multi-family construction?

This report summarizes the results of a research project funded by the U.S. Department of Energy and carried out by the Façade Tectonics Institute (FTI) that explores the reason for this apparent deployment gap. It also explores what steps might be taken to rapidly move to a new normal where most of our new buildings and much of our existing building stock can achieve dramatically better performance than today's "business-as-usual" solutions.

To explore this deployment gap, FTI engaged with over 100 façade industry professionals in a series of roundtables and one-on-one discussions to better understand the underlying market context that drives façade design today. While the research is largely qualitative, with subjective responses from participants, cross-validation with additional stakeholder review has provided confidence in the summary outputs. As expected, different stakeholders will attach different priorities to the conclusions and recommendations that follow.

The barriers

Seven overarching barriers to effective deployment of high-performance façades have been identified through this research, each with multiple underlying, often interlinked causes:

- There is a **significant increase in first cost** over business-as-usual (BAU)
- There is **insufficient return on investment (ROI)** or payback on the initial first cost increase
- Design and product selection **decisions are driven to the status quo** to manage risk
- Standard **project delivery methods drive to lowest cost** and status quo
- Project design is **HVAC driven**
- **Code compliance is lax**
- There is **insufficient capacity** at architects, engineers, façade consultants **to design better façades**

Finding the primary root cause(s) that drive the more obvious barriers is critical to understanding how to reduce or eliminate them. Full descriptions of the extensive series of barriers and root causes beneath these higher-level barriers are provided in the body of this report.

As an example, the complexity of the first barrier was such that it breaks down into four additional sub-barriers each of which have yet more root causes and which link to some of the other high-level barriers:

- **Codes set the baseline cost and don't require any better**
- **The risk premium on new/different solutions**
- **Insufficient competitive solutions**
- **Insufficient resources for R&D in architecture firms**

Additional barriers were also identified for retrofitting / renovating existing façades related to **high cost, high risk, high complexity**, and occupant **disruption**:

- **Unknown existing conditions** which substantially increase the risk and cost
- **“You touch it, you own it”** challenges where any change to a façade triggers a requirement to bring it up to seismic code or take on structural responsibility or additional hardening requirements.
- **Set back issues** that prevent implementing thicker more thermally efficient façades
- **High disruption causing lost revenue and incurred costs**
- **Window / façade replacements do not provide fast enough payback on energy cost savings**
- **Curtainwall systems are not designed to be easily upgraded or maintained**

These additional challenges to retrofitting existing building façades underscore why the façade retrofit remains at 0.5% or less a year – far from the rate needed to meet national decarbonization targets.

The multitude of barriers identified reinforced that the challenges are mainly those of market deployment. However, the need for improved curtain wall and window wall systems were identified, as well as a need to achieve the needed economies of scale to reduce the cost of high-performance systems to the level seen in more developed markets like Europe.

Where market transformation is happening faster

Facade design and performance varies widely across North American and global markets. This provides an opportunity to explore those differences and the underlying market drivers. Six case studies are explored where façade performance is changing much faster than elsewhere. They have been used to identify deployment strategies that are working and lessons that can be learned. Four case studies feature jurisdictions which have used regulation in combination with other supporting strategies to drive performance: Vancouver, BC; Massachusetts; Seattle, WA; and London, UK. It is interesting that some of the most innovative and promising new programs are occurring at the local city and state level.

There are a few key themes that were found as common denominators for the most successful programs:

- Political will and support
- Financial support for code development and validation
- Flexible cost-effectiveness criteria that do not rely on simplistic energy cost payback
- Market support and training for capacity building

The fifth case study reviews the dynamics of certified Passive House deployment and aligned performance, the penetration of which has been increasing, driven by several jurisdictions including British Columbia and Massachusetts. The Passive House Network has distilled policies that are driving Passive House Standards into the following categories:

- Approved alternative high-performance code compliance pathways
- A framework of incentives and policies that activate those alternative pathways
- Setting clear performance targets which are measurable along with appropriate tools
- Tiered code adoption programs (like British Columbia and Massachusetts) that signal future direction.

The final case study reviews a successful developer-led commercial office project certified to the Living Building Challenge (LBC) in Portland, Oregon. While owner occupiers have other interests than pure economics including productivity and retention, for developers however, their view is primarily financial and short term. PAE Engineers, however, found real-estate investors that would invest in a LBC building

when they were able to demonstrate that tenants would pay more in rent to cover the cost of a more expensive building and commit to a long lease. They identified three magic ingredients for developers:

- **Achieving a 10% rent premium** in return for the expectation of a reduction in staff turnover and / or increases their productivity. It only took a 2% improvement in one of those metrics to pay back this rent increase.
- **Holding the building for 10 years** to achieve the benefit of a long-term anchor tenant with a lease rate premium. In opportunity zones, investors pay no tax on sales of assets after 10-years which provides additional benefit.
- **A Nominal 10% internal rate of return** which is slightly lower than typical commercial buildings at 12%. If the anchor tenant signs a 15+ year lease they have guaranteed income for more than the 10-year opportunity zone holding periods.

A blueprint for change

Based on the many barriers identified, ideas from stakeholders and the case studies, an expansive blueprint has been developed that supports addressing challenges to deployment across the breadth of the value chain. There is no one single silver bullet that will accelerate market deployment – even sweeping nationwide adoption of the newest model codes (unlikely though that may be) needs capacity building, tools, and enforcement. A coordination of approaches including tools, training, standards, codes, innovation, and incentives is needed. A piecemeal approach will likely not be effective.

Ten high priority cross-cutting solutions developed are summarized as follows and are expanded upon in the body of this report:

- **Concept 1:** Develop an above code certification program for high-performance façades that can be referenced by incentive programs to drive market deployment. There are several foundational tools that are needed to support this effort.
- **Concept 2:** Create tools and programs that improve the ability to communicate the overall economic value of high-performance façades to owners
- **Concept 3:** Make windows the next “marble countertop” – a must have for owners and tenants alike
- **Concept 4:** Ensure there is sufficient selection of high-performance curtain wall and window wall systems and trained installers available for a competitive market
- **Concept 5:** Create and/or identify certification programs for practitioners to verify competence, build capacity and improve facade simulation, design and execution.
- **Concept 6:** Increase façade knowledge and education across the full value chain
- **Concept 7:** Create façade incentive programs
- **Concept 8:** Deploy code related recommendations
- **Concept 9:** Implement strategies to solve the retrofit challenge
- **Concept 10:** Enhance domestic supply chain competitiveness

A full list of all ideas generated through this research project, categorized by type (policies and programs, education and capacity building, tools, innovation, incentives, code and regulatory), can be found in Appendix C.

Next step recommendations

Many of the concepts identified above and fleshed out further in the body of this report need further vetting to explore technical and implementation feasibility, while others need less evaluation and can be considered basic foundations for market transformation. Cross-cutting education and training programs are clear needs and could be initiated with a scoping activity to identify the key learning outcomes for each constituency.

While developing policies and programs to drive high-performance façades in new construction and retrofit, it will also be important to identify ways to support capacity development and competitiveness in domestic supply chains to ensure the domestic industry is positioned to support decarbonization needs across the country in future decades and prevent unintended consequences.

The following are recommendations (not yet prioritized) for taking the next steps:

- Initiate work on the foundational activities of concept 1 – defining high-performance.
- Initiate scoping work for concept 2 to work towards non-energy benefit quantification.
- Initiate research in the existing San Francisco Bay eco-system of high-performance non-residential buildings to understand drivers and a first step to developing an education and awareness campaign for “why windows matter” (concept 3).
- Initiate research to determine detailed market requirements for high-performance curtain wall and window wall including long-term serviceability requirements (concept 4).
- Scope an installer training program for high-performance façades (concept 4).
- Evaluate and scope a façade engineering certification program (concept 5).
- Scope and outline a cross-cutting educational program on façades (concept 6).
- Engage the insurance industry to explore opportunities for using insurance vehicles to de-risk new façade products for manufacturers, installers, owners, etc.
- Evaluate façade carbon credits.
- Evaluate how DOE can enhance its role in code development and adoption to change its structure and align with an envelope first approach.
- Develop an awareness campaign for energy service companies and building owners for secondary glazing retrofits.

This project has identified a comprehensive map of the interactive barriers to the adoption of high-performance facades and created a cross-cutting conceptual roadmap of potential means to address them. The gap between what we know to be possible and business-as-usual is wide, but the research results and ideas generated present an exciting future opportunity for the next phase of this project.

A comprehensive façade initiative incorporating some or all of the key program elements outlined above will require the extension of existing industry collaborative efforts, the launch of new initiatives with new partners and will take significant resources if it is to have impacts on the façade and building industry in the time frame necessary to meet environmental goals. While a comprehensive program has the best chances of achieving the desired outcomes, with limited resources we recognize the value in identifying and launching smaller, carefully targeted efforts with industry partners. We believe this report can assist in identifying and launching both these immediate efforts to accelerate a market transformation to high performance facades and build new partnerships to address the longer-term challenges.

Introduction and context

Why façades matter

Façades are the linchpin of building performance. As the barrier to the outside, they must maintain safe, healthy and desirable indoor environments within a relatively narrow range of environmental conditions, despite highly variable, and often extreme, exterior environmental conditions. And to the extent that the façade is unable to effectively modulate the exterior environment, causing indoor environmental conditions to deviate from desired conditions, then heating, ventilation, and air-conditioning (HVAC) equipment must be utilized to warm or cool a space and electric lighting supplements daylight.

Façade performance is critical for reducing building energy consumption, enabling building electrification and decarbonization strategies, preserving life in extreme climate events and creating human-centric healthy environments. These, sometime conflicting dynamics, are reviewed below for context.

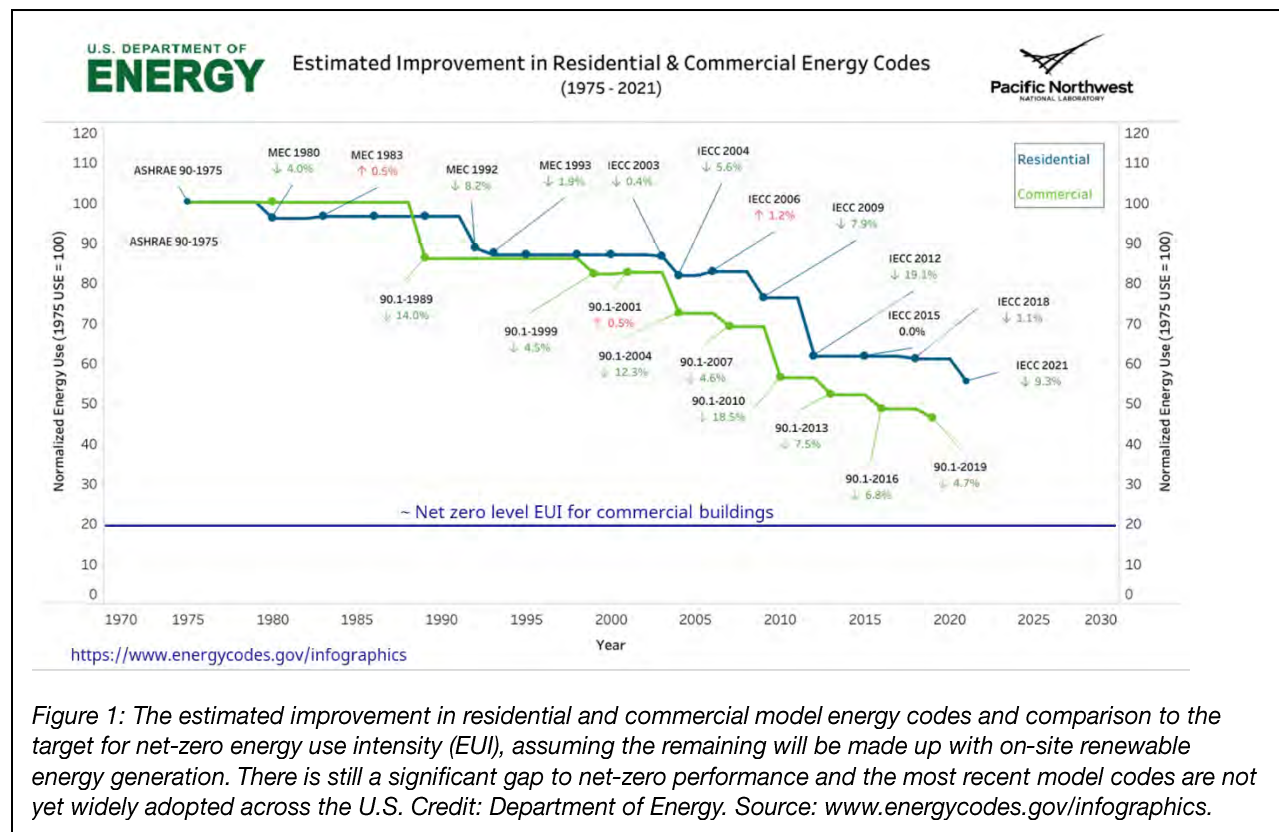


Figure 1: The estimated improvement in residential and commercial model energy codes and comparison to the target for net-zero energy use intensity (EUI), assuming the remaining will be made up with on-site renewable energy generation. There is still a significant gap to net-zero performance and the most recent model codes are not yet widely adopted across the U.S. Credit: Department of Energy. Source: www.energycodes.gov/infographics.

Driver for reducing building energy use

Buildings account for 40% of all energy use, for 75% of electricity use and 35% of carbon emissions¹ in the U.S. today. Much of this energy use is driven by the performance of the building envelope, or lack thereof. And as we look ahead to the ambitious national decarbonization targets for 2035 and 2050², a step change is required in the energy performance in the façades of both our new and existing building

¹ <https://www.nrel.gov/news/features/2023/nrel-researchers-reveal-how-buildings-across-the-united-states-do-and-could-use-energy.html#:~:text=Buildings%20are%20responsible%20for%2040.0%20of%20the%20nation's%20carbon%20emissions.>

² <https://www.energy.gov/eere/decarbonizing-us-economy-2050-national-blueprint-buildings-sector#:~:text=The%20Blueprint%20aims%20to%20reduce,equity%20and%20benefits%20to%20communities.>

stock to substantially reduce energy use (and its associated carbon emissions) and peak demand to support grid resilience³.

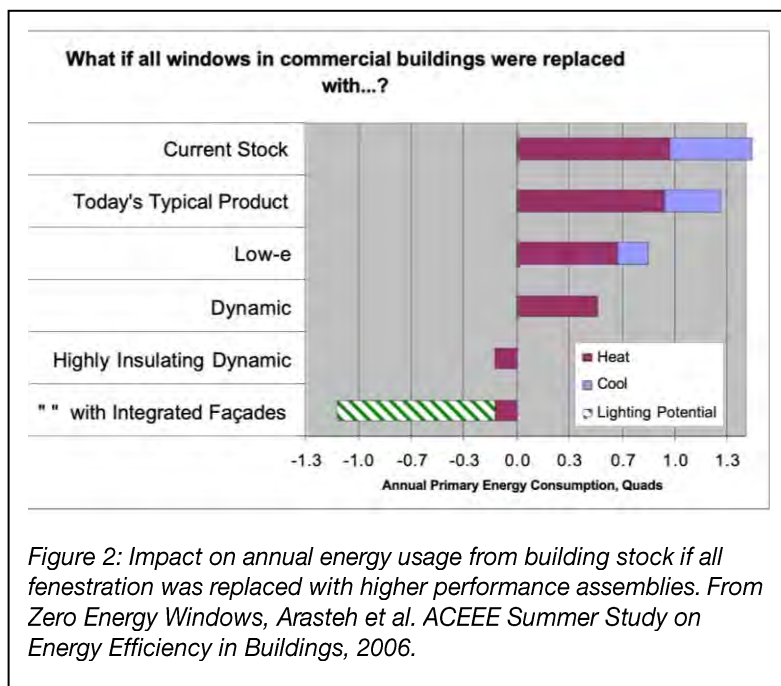
While the thermal properties of building envelopes in new construction have improved over time, their performance (and that of the newest model energy codes) still trails significantly that needed to achieve net-zero operational energy performance as indicated by figure 1.

Model code performance shown in figure 1 represents expected energy levels achievable, not actual measured levels achieved. There is a significant gap between meeting nominal code numbers and actual performance, often called the “performance gap”⁴. Also, as will be discussed later, most states do not use the most recent model codes. Thus, while the trends to tighten national model codes for new construction point us in the right direction, there is no guarantee that buildings constructed following these code guidelines will achieve the desired performance levels when occupied and operated.

The gap between what is possible and what exists is even more pronounced for existing buildings, 40% of which, according to DOE⁵, still contain single glazed windows which lose heat at 50 times the rate of a well-insulated wall.

A 2006 analysis by LBNL compared energy impacts of a hypothetical replacement of fenestration in all U.S. existing buildings with a series of ever more efficient solutions⁶. The study’s results (figure 2) show that implementing highly insulating dynamic façades in the non-residential building stock can transition windows from causing a net annual energy cost of \$20B (1.5 Quads)⁷ to an annual savings exceeding 1

Quad, providing a cost benefit of \$15B annually.



Highly insulating dynamic facades integrated with lighting controls can admit solar energy in winter to offset heating loads, and they can manage daylight to reduce electric lighting energy consumption offsetting energy savings. When these façade management strategies are intelligently applied to building designs, the role of the façade changes from an energy cost to a “net-zero” solution and then to a “net energy/carbon positive” solution.

Improving energy performance of multi-family residential buildings can also improve comfort and health outcomes, as well as address fuel poverty in low-income housing.

³ <https://www.energy.gov/eere/energy-efficiency-buildings-and-industry#:~:text=Environmental%20Benefits,and%20contribute%20to%20air%20pollution>.

⁴ Li, J., Iulo, L. D., & Poerschke, U. (2023). A Review of the Energy Performance Gap between Predicted and Actual Use in Buildings. *Building Simulation Conference Proceedings*, 18, 1973-1980. <https://doi.org/10.26868/25222708.2023.1430>.

⁵ <https://www.energy.gov/eere/articles/doe-launches-2-million-prize-advance-cost-effective-energy-efficient-commercial>

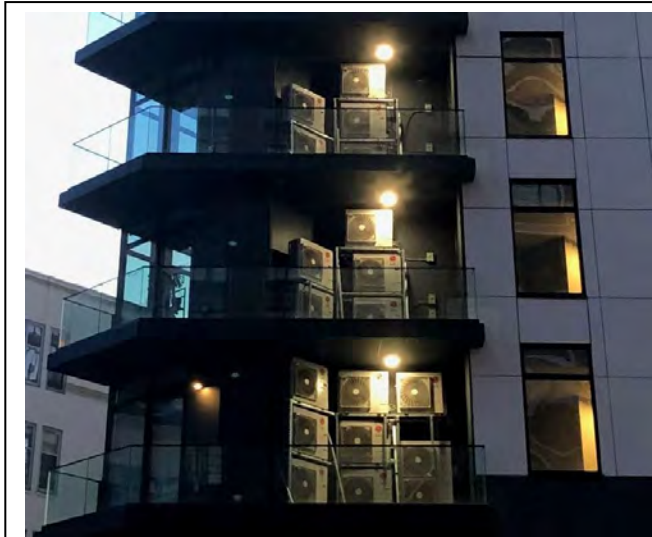
⁶ Zero Energy Windows, Arasteh et al. ACEEE Summer Study on Energy Efficiency in Buildings, 2006

⁷ 1 Quad is 1 quadrillion (10¹⁵) BTUs

Decarbonization enabler

High-performance façades (and fenestration) are critical to the implementation of two of the U.S.'s 2050 decarbonization strategies – electric grid decarbonization and building electrification. Grid decarbonization involves the transition from carbon intensive generation sources such as gas and coal to renewable electric sources such as solar, wind and hydro-power. Electrification of buildings involves a shift from on-site fossil fuel use to electric use, which will ultimately result in zero operational carbon emissions once the electric grid is fully decarbonized. This means replacing gas heating with electric heat pumps and heat pump water heaters.

Building electrification requires heating and cooling loads to be reduced sufficiently such that electric heat pumps can be effectively deployed – both in scale and cost. High-performance façades are a heat-pump enabler (figure 3).



*Figure 3: If envelope performance is not improved, the heat pump capacity needed can be unfeasibly high.
Credit: Enrico Bonilauri, Emu Systems.*

A renewable grid is subject to the availability of renewable sources which can be more variable than fossil fuels that can be burnt on-demand. Reducing the loads on a renewable grid to support its resilience is therefore critical. Buildings already create high loads in summer due to air-conditioning needs, however building electrification creates a new peak load in winter mornings (for heating needs). High-performance building envelopes will be critical to minimizing both of these loads.

Since grid decarbonization is progressing at different rates across the country, it is critical to focus on reducing annual energy use, operational carbon emissions, and peak loads during the building decarbonization transition. Owners should also consider embodied carbon reductions

and the trade-offs with operational carbon emissions.

The quality of the façade, which also manages air and water infiltration, is a determinant of lifetime. Poor moisture management, which can degrade façade materials and cause mold, shortens façade service life, and can result in poor indoor air-quality. The longer an assembly's service life, the less embodied carbon investment needed over the building's lifetime.

Life safety – thermal resilience

With increasing numbers of extreme heat and cold climate events and concurrent power outages, the building envelope is becoming increasingly important in maintaining indoor temperatures that are consistent with sustaining human life. When HVAC systems can no longer operate or are not adequate to meet demand, interior temperatures can climb or fall rapidly if the façade is of low-performance, reaching temperatures that can cause human mortality within a few hours. Excess deaths have been recorded in the Pacific Northwest during the “heat dome” in 2021^{8,9} and in Texas during the winter storm of 2021¹⁰ indicating the inadequacy of buildings to maintain a safe interior temperature. A recent study led by PNNL¹¹ showed the positive impact of high-performance building façades constructed to the

⁸ <https://doh.wa.gov/sites/default/files/2023-09/422243-ExcessDeathsCOVID19HeatDome.pdf>

⁹ <https://www.nytimes.com/interactive/2021/08/11/climate/deaths-pacific-northwest-heat-wave.html>

¹⁰ https://www.dshs.texas.gov/sites/default/files/news/updates/SMOC_FebWinterStorm_MortalitySurvReport_12-30-21.pdf

¹¹ https://www.energycodes.gov/sites/default/files/2023-07/Efficiency_for_Building_Resilience_PNNL-32727_Rev1.pdf

newest model energy codes on reducing mortality during power outages in extreme heat and cold events. They demonstrated an even greater impact when building significantly above code, to Passive House¹² standards.

Human health and well-being

Façade performance also drives the quality of the occupant experience from daylight, views to the outside, thermal, acoustical, and visual comfort, and ventilation. Access to daylight, views, comfort and good indoor air-quality are all critical to human health and well-being and are requirements for high-performance sustainable buildings¹³.

Fenestration, more than opaque walls, is relied on to deliver this diversity of performance. Windows are typically described as the “weak link” in the thermal performance of a building, a reputation that appropriately defines much of current practice, but certainly not the performance potential based on state-of-the-art commercially available systems. Because of current practice that does not use state-of-the-art fenestration, there is often a tension set up between achieving a façade energy efficiency goal, delivered thermal comfort and access to comfortable daylight and views.

There are those who suggest the solution is a building envelope with highly insulating walls and minimal window area. However, since fenestration is a unique and essential element of all buildings, providing benefits that are essential for the health, wellbeing, and productivity of building occupants, it is critical to strike an appropriate balance. Indeed, existing commercially available high-performance fenestration technologies can make larger window areas possible, without compromising energy efficiency.

Market dynamics

A large, complex building industry ecosystem has evolved to design, fabricate, install, maintain and upgrade façade systems in non-residential and multi-family buildings. This industry changes slowly over time given that the cycle time of a single large commercial building project can span up to 10 years, from definition of the need for the new space, to procurement of financing, site selection, building design, permit approvals, construction, commissioning and occupancy. The non-residential / multi-family building sector is diverse and complex: It consists of at least 20 distinct building types, with footprints ranging from 1,000 sq.ft. to 2,000,000 sq.ft., from single-story to over a hundred stories, budgets that typically fall in the range of \$100/sq.ft. to over \$1000 sq.ft. and with ownership and operating models that vary from owner-occupied to developer leased to tenant and public versus private sector.

Façade system and component manufacturing and their supply chains are also complex, with thousands of insulating glass options including tints and coatings, dynamic glazing, processed glass, spacers and sealants, multicomponent framing elements with operating hardware, fixed and operable shading systems, and sensors and control systems.

A complex ecosystem of architects, engineers, and consultants provides design and consulting services to optimize façade design which evolves simultaneously with the overall building design to meet owner requirements. Many consultants can be engaged to address site specific issues or special needs such as fire-resistance, hurricane codes, security, and earthquake resistance. The team also engages with building code officials through plan approval and manages a host of other public and private permitting needs.

Technology innovation in support of high-performance solutions to reduce energy and carbon has been steady but with slow market adoption. Double glazing is now the norm for new construction but the transition from single glazing occurred over approximately 40 years nationally, driven largely by minimum code requirements. Insulating glass units (IGUs) with low-emissivity (low-e) coatings now dominate

¹² https://passipedia.org/basics/what_is_a_passive_house

¹³ <https://www.lheschong.com/visual-delight>

market share and provide a wide range of daylight transmittance and solar heat gain options for different climates, orientations, and occupant needs. However, triple glazing has only a 2-3% market share at best, although it is a standard product mandated by code, in much of northern Europe. Vacuum glazing has also been available for over 20 years but has minimal U.S. market penetration.

Dynamic glass has been researched for over 30 years, has been available for use for 20 years, and is now available from three suppliers, yet still has a market share of much less than 1%. Developing dynamic integrated façades as identified in figure 2 requires an even more complex ecosystem and supply chain that involves not just all the façade players, but also the electrical lighting, shading, and building control ecosystems, which do not typically collaborate.

Polyamide thermal barrier technology for insulating aluminum fenestration framing has been driven over the past fifty years by European market requirements, increasing size (up to 3-inches), complexity and performance. In comparison, business-as-usual fenestration systems used in the U.S. typically utilize much simpler, narrow thermal barrier technology of 1980's or 1990's vintage, which is 1/2-inch or less wide. In contrast, many U.S. aluminum fenestration manufacturers have R-5 windows or better available for purchase, but that is not what is typically requested.

An earlier market characterization study from 2002¹⁴ when low-E glazing was still in the early phases of commercial adoption captured the new market pressures for change but also reinforced the complex forces of the market status quo that make significant change a slow and tedious process, that continues today.

Current challenge

As identified above, new construction façade performance today rarely achieves the level of performance that is possible by using currently available high-performance products and best practice construction processes and falls even further short of what is needed to reach net zero carbon building goals.

The performance gap compared to existing building façades is even wider, and estimates suggest 70 to 80% of these buildings will still be operational in 2050. The size of the potential impact of state-of-the-art façade technology on the existing poorly performing building stock shown in figure 2 identifies that any attempt to reduce overall energy use dramatically and rapidly must address the existing building stock. Conventional façade retrofit / replacement rates are very low, at approximately 0.5% of the current building stock compared to the addition of 1-2% for new construction. Any serious attempt to dramatically reduce energy use and carbon emissions by 2050 must aggressively pursue retrofit / replacement options at much higher rates than are currently practiced¹⁵.

Closing the gap between the best-in-class available product performance and the current installed base and with today's code minimum would have a significant impact on building energy use and resilience, as well as on delivering better occupant thermal and visual comfort next to the façade.

The business-as-usual world of a slowly evolving non-residential / multi-family residential façade industry is now juxtaposed against an increasingly urgent societal need to address global warming. The needed large-scale shifts to promote high-performance façade solutions at scale will need to be driven by a coherent and sustained set of programs and policies that address the current barriers to faster technology adoption. While classic research and development (R&D) to develop affordable emerging

¹⁴A Characterization of the Nonresidential Fenestration Market, Final Report; 2002; Eley Associates, Prepared for LBNL/NEEA <https://live-etabiblio.pantheon.io/sites/default/files/52699.pdf>

¹⁵ <https://www.us.jll.com/en/newsroom/retrofitting-buildings-essential-to-reduce-energy-costs-and-combat-the-global-energy-crisis#:~:text=JLL's%20research%20reveals%20that%20in,alone%20to%20meet%20these%20targets.>

technologies is still needed, an infrastructure that also supports and accelerates widespread deployment to knock down business-as-usual barriers is critical.

Study description

As discussed, high-performance façade products are commercially available today and more are under development and refinement. There are built examples and measured data that demonstrate the technical feasibility of achieving much higher façade performance levels than are currently achieved. This study investigates why this gap exists and what steps might be taken to rapidly move to a new normal where most of our new buildings, and much of our existing building stock, can achieve dramatically better facade performance than today's "business-as-usual".

FTI has engaged with over 100 façade industry professionals in a series of roundtables and one-on-one discussions to better understand the underlying market context that drives façade design and construction practices today and identify the barriers to implementing higher performance. A series of case studies are also provided that illustrate situations where change is happening more rapidly in the performance of as-built façades. Key drivers, success factors, learnings and impacts are identified. Based on input from the roundtables and interviews and the case studies, recommendations have then been made for actions that, if implemented, could reduce or eliminate the identified barriers to achieving high-performance façades – both in new construction and existing buildings.

Because of the nature of the research, based primarily on focus groups and discussions with different stakeholders, the data is qualitative and to some extent subjective. Cross-validation across stakeholders has been used to confirm and consolidate findings. Reviewers have made comments such as: "Seems like it's a catalogue of the story of what we go through on every project" and "You are covering all the barriers that we experienced in the last few years," underscoring the validity of the consolidated barrier summary.

The focus of this study is on façades and fenestration in non-residential and multifamily buildings, although many of the underlying issues are relevant to single family residential. This report is divided into four sections: (1) A description of the barriers identified to adoption of higher performance façades, (2) the case studies where change is happening faster, (3) concepts for reducing or removing the barriers and (4) recommendations for next steps.

A summary of data generation methodology can be found in Appendix A and a glossary of key terms can be found in Appendix B.

Participants

The following professionals participated in the project, contributing as part of in-person or virtual roundtables, one-on-one or small group interviews, and/or through review and feedback of this document.

Name	Specialty category	Company	Location
Agnosti, Davide	Glazing fabricator & sub-contractor	Focchi	New York, NY
Aksamija, Ajla	Academic	University of Utah	Salt Lake City, UT
Alberto Alcaron	Material supplier	Kuraray	New York, NY
Allwood, Mel	Sustainability Consulting	ARUP UK	London, UK
Altshuler, Blake	Architect	Skidmore Owings & Merrill	Los Angeles, CA
Anderson, Casey	Material Supplier	ICD High-Performance Coatings	Portland, OR
Ayon, Angel	Architect, Historic preservation	Ayon Studio	New York, NY
Babbington, Will	Façade consulting / engineering	Studio NYL	Denver, CO
Barret, Richard	Architect	Goettsch Partners	Chicago, IL
Barry, Bronwyn	Architect (Passive House)	North American Passive House Network	San Francisco, CA
Betzantos, Adrian	Owner/occupier	Apple Inc.	San Francisco, CA
Bicchierelli, Roberto	Glazing fabricator & sub-contractor	Permasteelisa / Gartner Group	New York, NY
Blakeslee, Alexandra	Material Supplier	Technoform North America	Twinsburg, OH
Boswell, Keith	Architect	Skidmore Owings & Merrill	San Francisco, CA
Bouchard, Steve	Material Supplier	Glass Distributors Inc	Washington, DC
Brainard, Gabrielle	Architect	Skidmore Owings & Merrill	New York, NY
Cervantes, Sergio	Façade consulting / engineering	Curtain wall design and consulting	Chicago, IL
Christoph Timm	Architect	Skidmore Owings & Merrill	New York, NY
Clabbers, Joe	Glazing sub-contractor	National Glass and Mirror	Philadelphia, PA
Clabbers, Mike	Glazing sub-contractor	National Glass and Mirror	Philadelphia, PA
Conover, Joe	General contractor	Clark Construction	Irvine, CA
Culp, Tom	Code consultant / Trade association	Birchpoint Consulting / National Glass Association	La Crosse, WI
Daniels, Tony	Energy retrofits for multifamily	Cycle Retrotech	New York, NY
Davis, Brad	Glazing fabricator & sub-contractor	Focchi	Hartford, CT
Dehaven, Chris	General contractor	McCarthy Construction	Los Angeles, CA
Diep, Tom	Glazing sub-contractor	Giroux Glass	Los Angeles, CA
Doebbel, Florian	Material supplier	Sika USA	Lyndhurst, NJ
Franceschet, Alberto	Façade consulting/ Engineering	Socotec (previously Vidaris)	New York, NY
Georges, Rowan	Architect	Skidmore Owings & Merrill	New York, NY
Goldenberg, David	Glazing fabricator and sub-contractor	TRU Architectural	Los Angeles, CA
Green, Richard	Façade consulting / engineering	Green Facades	Seattle, WA
Grey, Christopher	Façade consulting / engineering	Simpson Gumpertz Heger	Boston, MA
Haaland, Daniel	Building science consulting (thermal analysis / analytics)	RDH Building Science	Vancouver, BC
Harpell, Mike	Engineer	Salient Engineering	Toronto, ON
Heymann, Jeff	Glazing sub-contractor	Giroux Glass	Los Angeles, CA
Hoffman, Stephane	Façade consulting / engineering	Morrison Hershfield	Seattle, WA
Hubbs, Brian	Building science consulting	RDH Building Science	Vancouver, BC
Ingalls, Scott	Material Supplier (independent rep)	Scott Ingalls Sales	Los Angeles, CA
Jacobson, Mark	Material Supplier	Kuraray	Wilmington, DE
Jay Argus	Glazing sub-contractor	Karas & Karas	Boston, MA
Jayson, Ben	Material Supplier	Bendheim	New York, NY

Jonlin, Duane	Code Official	City of Seattle	Seattle, WA
Kamper, Matt	Glazing sub-contractor	Woodbridge Glass	Los Angeles, CA
Kensek, Karen	Academic	USC	Los Angeles, CA
Kesik, Ted	Academic / Façade consulting	University of Toronto	Toronto, ON
Kimberlain, Jon	Material Supplier	DOW	Grand Rapids, MI
Kimmel, Todd	Material Supplier	ROCKWALL	New York, NY
King, Mark	Stone cladding façade fabricator	Eclad	Chicago, IL
Krouse, John	Material Supplier	Boston Valley Terracotta	Buffalo, NY
Lalonde, Chris	Glazing sub-contractor	W&W	New York, NY
Lam, Wei	Building science consulting	RDH Building Science	Boston, MA
Lee, Ivan	Façade consulting / engineering	Morrison Hershfield	Vancouver, BC
Levenson, Ken	Non-profit association	North American Passive House Network	New York, NY
Li, Charling	Government	City of Vancouver	Vancouver, BC
Loftness, Vivien	Academic	Carnegie Mellon University	Pittsburgh, PA
Loughran, Patrick	Architect	Goettsch Partners	Chicago, IL
Madzarevic, Jana	General contractor	Ellis Don	Toronto, ON
Marino, Steve	Glass supplier	Vitro Architectural Glass	Pittsburgh, PA
Martin, Irene	Façade consulting / engineering	ARUP	Los Angeles, CA
McMahon, Denise	Glazing fabricator / sub-contractor	Roschmann	New York, NY
Montes, Vicente	Façade consulting / engineering	Curtain Wall Design and Consulting	Washington, DC
Mulhern, Michael	Fabricator (hardware)	Tri-Pyramid	Boston, MA
Nahrgang, Luc	Building science consulting	RDH Building Science	Boston, MA
Natividad, Kayla	Material supplier	NSG	Toledo, OH
Neary, John	Architect	HOK	New York, NY
Neary, Michelle	Architect	Gensler	New York, NY
Neme, Becher	Façade consulting / engineering	Neme	Long Beach, CA
Noble, Doug	Academic	USC	Los Angeles, CA
Norris, Neil	Building science consulting	RDH Building Science	Vancouver, BC
O'Hara, Chris	Façade consulting / engineering	Studio NYL	Boulder, CO
Oliver, Tim	Fabricator/installer	Kreysler & associates	American Canyon, CA
Olsen, Erik	Climate responsive building engineering	Transsolar KlimaEngineering	New York, NY
O'Malley, Lori	General contractor	PCL	Toronto, ON
Ormond, Paul	Government	State of Massachusetts	Boston, MA
Parisi, Nick	Material supplier	Boston Valley Terracotta	Buffalo, NY
Patterson, Mic	Glazing sub-contractor (ret)	Façade Tectonics Institute	Los Angeles, CA
Pawlynsky, Areta	Façade consulting / engineering	Heintges	New York, NY
Payne, Chris	Architect	Gensler	New York, NY
Pennetier, Sophie	Glazing fabricator & sub-contractor	Enclos	Los Angeles, CA
Peterson, John	Architect	McCallum Sather Architects	Toronto, ON
Pratt, Bob	Owner developer	Tishman Speyer	New York, NY
Rammig, Lisa	Façade consulting / engineering	EOC Engineers	Los Angeles, CA
Reed, Ryan	Glazing sub-contractor	Architectural Glass & Aluminum	Los Angeles, CA
Rust, Brienna	Façade consulting / engineering	Simpson Gumpertz Heger	New York, NY
Schulte, Dirk	Glazing sub-contractor	Roschmann	New York, NY
Schwer, Paul	Building Engineering	PAE Engineering	Portland, OR
Smith, Cheryl	Architect	Nelson	Philadelphia, PA
Smith, Greg	Architect	Skidmore Owings & Merrill	Chicago, IL
Smith, James	Owner developer	RELATED	Boston, MA
Sowell, Urmilla	Trade association	National Glass Association	Washington, DC
Staublin, Matt	Architect	Self-employed	San Francisco, CA
Steingiser, Andrew	Building science / Passive House consulting	RDH Building Science	Boston, MA
Sullivan, Bill	Glazing sub-contractor	Brin Glass	Minneapolis, MN

Szotkowski, Melissa	Fabricator (Glass & Fenestration)	Oldcastle BuildingEnvelope®	Toledo, OH
Talun, Shu	Façade consulting / engineering	RDH Building Science	Boston, MA
Tankha, Sanjeev	Architect	Starq Design	Los Angeles, CA
Viise, John	Structural engineer	Desimone	Chicago, IL
Vockler, Kris	Material Supplier	ICD High-Performance Coatings	Portland, OR
Vossoughi, Hamid	Façade consulting / engineering	WSP	Toronto, ON
Ward, Otto	Fabricator (glass)	Garibaldi Gass	Vancouver, BC
Weinryb, Stephen	Architect	HOK	New York, NY
Weismantle, Peter	Architect	AS+GG Architecture	Chicago, IL
Wheaton, John	Structural engineer	Wheaton Sprague	Stow, OH
Wolf, Max	Built environment innovation scientist	Skidmore, Owings & Merrill	New York, NY
Wurster, Stephan	Glazing fabricator & sub-contractor	TRU Architectural	Los Angeles, CA
Yap, Humphrey	Glazing sub-contractor	Architectural Glass & Aluminum	Los Angeles, CA
Young, Jessica	Façade consulting / engineering	Heintges	New York, NY
Zahner, Bill	Engineering	Zahner	Perryville, MO
Zani, Andrea	Glazing fabricator & sub-contractor	Permasteelisa	Mendota Heights, MN
Zhu, Yue	Architect	Skidmore Owings & Merrill	Chicago, IL

Barriers to adoption of high-performance fenestration and façades

Many barriers to the adoption of high-performance façade systems (including fenestration) have been identified from eleven roundtables and additional one-on-one discussions held throughout the course of this project. We heard time and time again from the stakeholder group that there is just no incentive to do better than the minimum allowed by code, and there is an inertia in the system that defaults to the status quo building project after building project. The goal of this research study was to understand the root causes for this complex dynamic and other challenges at play and to begin the complex process of developing practical and scalable programs and policies to change the commercial façade landscape.

For the purposes of gaining feedback, we defined high-performance relatively loosely, as performance which was recognizably beyond current business-as-usual in a given climate zone/location. Indeed, one of the challenges identified is that there is no clear definition of what constitutes high-performance fenestration or façades in non-residential or multifamily buildings.

Some barriers were clearly communicated by the participants, others were identified by triangulating feedback and then validating them through additional stakeholder review. Barriers were identified across the entire value chain from owner, to designer, contractors, fabricators, and material suppliers. Many barriers are interlinked with multiple causal connections. Some are part of a cascading series of barriers (barrier chains) each a result of the preceding one(s). Finding the primary root cause(s) that drives the more obvious barriers is critical to understanding how to reduce or eliminate them.

Seven major barriers have been identified, each with multiple root causes that cause high-performance facades to not be specified and/or installed. These are illustrated in figure 4 and listed below.

Barriers to high-performance façades:	1. There is a significant increase in first cost over business-as-usual (BAU)
	2. There is insufficient return on investment (ROI) or payback on the initial first cost increase
	3. Design and product selection decisions are driven to the status quo to manage risk
	4. Standard project delivery methods drive to lowest cost and status quo
	5. Project design is HVAC driven
	6. Code compliance is lax
	7. There is insufficient capacity at architects, engineers, façade consultants to design better façades

Figure 4: Illustration of the over-arching barriers to the use of high-performance fenestration or façade systems.

An overview of these identified barriers, their root causes, connections, and consequences are shown in **Figure 5** and described in detail below. **Figure 6** takes an even deeper dive into the four main root causes of the first barrier category related to the increased first cost over BAU:

1.1 Codes set the baseline cost and don't require any better

1.2 The risk premium on new/different

1.3 Insufficient competitive solutions

1.4 Insufficient resources for R&D in architecture firms

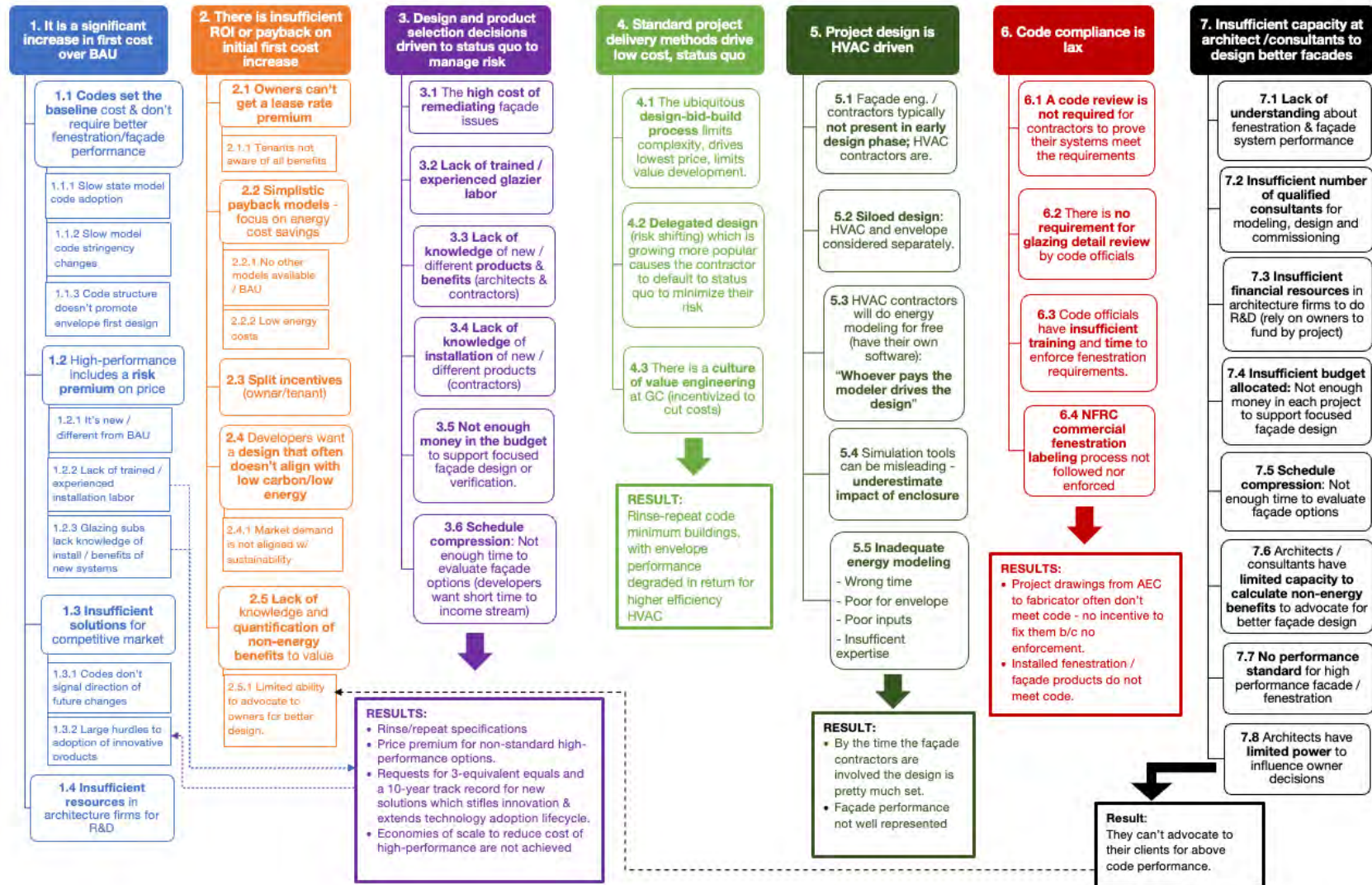


Figure 5: Overview of barriers to widespread adoption of high-performance fenestration / façade systems.

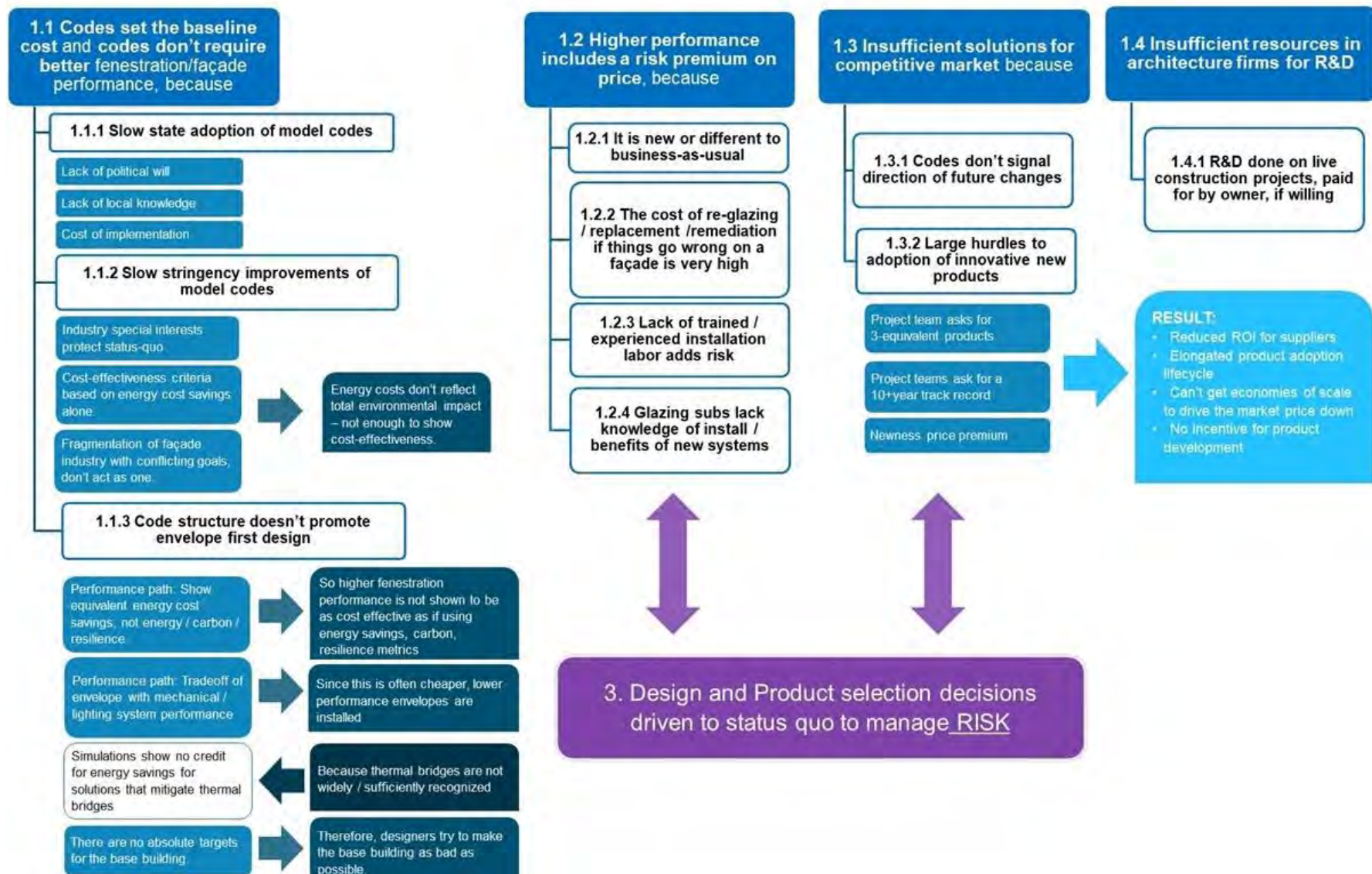


Figure 6: Drill down into the reasons why high-performance façades cost significantly more than business-as-usual (BAU), barrier #1 and how it links to barrier #3

The following is a detailed description of the barriers' root cause hierarchy.

Barrier 1: There is a significant increase in first cost over business-as-usual (BAU):

1.1 A jurisdiction's energy code sets an implicit baseline construction cost

This is because it defines the lowest legally allowable performance level. Currently energy codes do not require high-performance fenestration or façade performance (even though better is commercially available). Our project findings suggest that codes do not require higher performance for several reasons:

- 1.1.1 **Slow statewide adoption of the national model codes**, which can be due to lack of political will, lack of local policymaker knowledge and awareness and engagement in the process, and cost. The Northeast Energy Efficiency Partnerships (NEEP) recently completed a study highlighting the barriers to code adoption by states¹⁶. They concluded that the main drivers were cost and politics and both were intertwined, stating “costs influence politics and politics influence costs in the building energy code process”. NEEP identified 1) disagreements about the change in cost of construction and its relative impact, 2) the cost to implement and enforce new codes, and 3) the cost to build capacity in the workforce.

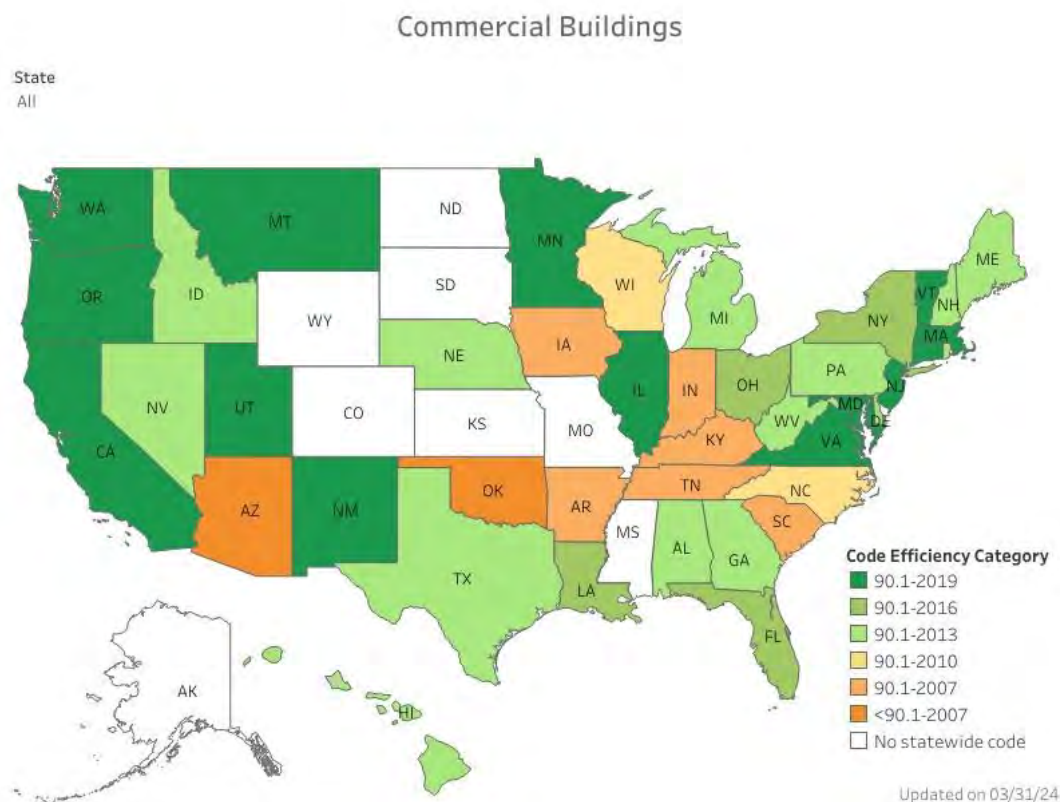


Figure 7: Commercial model code adoption in the U.S. (March 2024). Source: <https://www.energycodes.gov/state-portal>

¹⁶ https://neep.org/sites/default/files/media-files/final_systemic_barriers.pdf

In the U.S., individual state governments, or in some cases, cities and towns determine building regulations. For energy regulation, most adopt one of the two U.S. model energy codes (ASHRAE Standard 90.1 or the International Energy Conservation Code (IECC)), which are updated on three-year cycles. They often amend the code to customize it for their jurisdiction.

The current versions are ASHRAE 90.1-2022 and 2024-IECC. As of April 2024, no states have adopted the 2022 version, 14 states had adopted the 2019 version of ASHRAE 90.1, ten states are still on the 2010 version or worse. Seven states have no state-wide code at all. (See side bar, note 1 and figure 7).

1.1.2 Slow speed of stringency improvements in new versions of the model codes. Three factors were identified that appear to throttle improvements based on stakeholder feedback:

- Industry special interests protect the status-quo.
- Cost-effectiveness of stringency improvements must be shown and is based on the cost of energy savings alone. Savings in the cost of carbon, or other potential savings that could be achieved from a holistic design such as reducing HVAC size, perimeter heating etc. are typically not considered. This means that, because energy costs are relatively low, there are often not enough life-cycle energy-based cost savings to show cost-effectiveness as narrowly defined. (Side bar, notes 2 and 3).
- The fragmentation of the façade industry which does not act as one and often has conflicting goals. It does not present a unified industry front to the code change process that might promote more high-performance options.

1.1.3 The structure of the code itself doesn't promote envelope-first design. There are several causes for this, and four that came from interviews and roundtables are highlighted:

- The performance compliance path in the U.S. model energy codes is **based on showing equivalent or better energy cost savings than a baseline building**, not on energy savings, carbon savings or resilience performance. Compliance can often be shown without having to utilize high-performance façade systems.
- **The performance compliance path allows for a tradeoff of envelope performance with shorter lifetime mechanical and lighting system performance.** Envelopes with lower performance combined with higher performance internal systems (compared with the prescriptive requirements) are often installed because this tends to be the cheaper option. There are typically no minimum targets for envelope performance (also known as a 'backstop'), thus allowing facades with poor thermal performance to be accepted as part of larger design package. (Side bar, note 4).

A code official noted that energy modeling for code compliance is always used to make a lower performing façade: *"That's the only reason that owners will pay an energy modeler to do the simulations"*.

Notes

Note 1: A handful of cities and states (Washington state, City of Seattle, Massachusetts, New York City) have been rapid adopters of the latest version of the model code and have made significant amendments to them to increase stringency further. See the **case study section** for more details on the drivers that supported these moves.

Note 2: A method to calculate the social cost of carbon payback of proposed measures was developed for the 2024-IECC for information only. The decision-making committee could take payback on carbon into consideration when voting on new measures if they chose to, but it was not a requirement.

Note 3: In jurisdictions where energy codes are moving to greater stringency faster (City of Seattle, Washington state, Massachusetts), cost-effectiveness requirements were more flexible and holistic. **See case studies section.**

Note 4: In recent years, in several jurisdictions (Massachusetts, Washington, City of Seattle, British Columbia, New York City, and most recently ASHRAE Standard 90.1-2022), minimum envelope thermal performance requirements (backstops) have been set to limit the tradeoff possible. This is making a step change in fenestration and façade performance installed. See **case studies below** for more details.

Also, typically the lighting, boiler and fan allowances are not all used, since *“projects routinely beat the lighting power density target; the fan power calculation is almost inevitably higher than is needed; boilers are typically 92% efficient, which is higher than the required 85%. The over-performance in these areas is used to downgrade the façade performance through either lower performance fenestration or elimination of insulation around slab edges.”* They noted that in their experience it is rare for projects to do better than minimum code for the envelope.

- **Model codes don’t show the benefits of high-performance thermal bridge mitigation** solutions because thermal bridges aren’t recognized in the codes and may not be available in the modeling tools used for code compliance. Simulations show no energy savings of thermal bridge mitigation since the baseline building is assumed to have zero thermal bridging (even though we know that this is not close to reality), and thus no benefit of doing better can be demonstrated. (Side bar, note 5).

One consultant provided a project example in which they showed that mitigating thermal bridging would have reduced the insulation depth by 2-in over the entire façade, but the benefit could not be shown against the “perfect” base building.

- **There are no absolute targets** (like energy use intensity (EUI)) for building energy performance. There is just a relative comparison with a base building which is created based on the prescriptive path component performance requirements. Designers can make their baseline building as bad as possible to reduce the performance that the proposed design must meet. (Side bar, note 6).

1.2 The price of higher performance systems includes a risk premium

This premium is added by installers and fabricators because it is new or different compared to their BAU to cover the potential cost of unknowns such as increases in labor costs, rework, replacements, schedule slippage etc. Since the cost of re-glazing and/or remediation if things go wrong on a façade is very high, these cost premiums for risk management can be quite high (see [Barrier 3: Design and product selection decisions driven to status quo to manage risk](#)). The risk is further increased by the current lack of trained and/or experienced installation labor and the fact that the glazing subcontractors may lack the experience or knowledge of how to install newer more complex systems. They may also lack the knowledge of the full range of benefits of such systems, so they are unable to promote them effectively to their customers and translate that into benefits to their revenue and profits.

In some situations, contractors may provide a very high price to discourage selection of high-performance systems that they do not want to tackle because the risk is too high. They may default to proposing the less expensive status-quo and encouraging rinse-repeat designs to manage their business based on their risk tolerance and organizational capacity.

Note 5: The newest ASHRAE Standard 90.1-2022 and 2024-IECC have started to recognize the presence of thermal bridges. The British Columbia step code and the newest Massachusetts Stretch Code consider thermal bridging in a more significant way, and this is changing the quality of the interfaces on buildings.

Consultants from Massachusetts report that the clear field opaque insulation value is now de-rated by up to 50%. As a result, thermally broken cladding attachments have become the norm and steel shelf angles are no longer used. Attention is now paid to balcony design (must be thermally broken) and the window/wall interface to ensure that the thermal barriers are aligned with the insulation. Since the best opaque wall performance is now R13 to R15 when de-rated, there is less ability to trade-off higher opaque wall performance with lower transparent area performance.

Note 6: British Columbia’s step code and the Massachusetts Stretch Code have set specific building EUI and envelope thermal performance targets (TEDI). These performance-based targets are driving measurable reductions in energy use and a step change in installed façade/fenestration performance. See case studies below for more details.

Fabricators often charge more for products that they do not typically process. For example, triple pane insulating glass (IG) is 30% less expensive when sourced from Europe compared to the U.S. This is because triple pane IG is a standard product in Northern Europe where the building energy codes require that level of performance. In contrast, triple pane IG is typically a special order for commercial insulating glass fabricators in the U.S. since few jurisdictions' energy codes require it.

We note that different classes of high-performance solutions may address some, but not all, of these risk and cost issues. For example, in the case of switching from double to triple glazing, the costs will increase, and the availability may be more challenging, but the installation is not likely to be significantly different or impose new costs due to uncertainty. However, the specification of a dynamic glazing system not only adds product cost, but a new process involving wire integration, and potentially a more complex controls integration challenge, new commissioning tasks etc., which are unique to that technology and present new risks to the contractor team.

1.3 There are insufficient high-performance solutions for a competitive market

This is because there are large hurdles to the adoption of innovative products, codes don't require that level of performance, and they don't signal the direction of future changes to the market. (See also barrier 1.1).

There are many hurdles to product innovation in markets that change slowly and where the risk of innovation is often seen to outweigh the benefits. These market dynamics act to further constrain new product introduction, creating a vicious cycle suppressing step changes in, and speed of, façade product innovation. Two market behaviors are consequences and drivers of this vicious cycle:

- Project teams often ask for **3-equivalent equal products** in their specification because they fear manufacturers and fabricators charging a high price because of lack of competition. This is especially true on government projects where proprietary specifications are discouraged or rejected outright. This means that innovative companies must wait for their competition to catch up before they can realize full market demand.
- Project teams also often require a **10-year track record** when specifying new/different products and systems to manage their perceived risk. Failures on the façade are often highly visible and impact the building, especially if water related. And as mentioned above, the cost of remediating a façade can be very high compared to other building systems.

Both requirements elongate the product adoption lifecycle and reduce a manufacturer's ROI on the development of new fenestration / façade systems and thus reduce their willingness to innovate. They also drive longevity of the market risk-price premium. As a result, many companies offer incremental improvements on existing products (e.g. improvements in low-emissivity coatings) and prefer to wait to be a fast follower, or even third to market for more disruptive technologies (like vacuum insulating glass and dynamic glazing).

1.4 There are insufficient resources in architecture firms to do adequate research and development (R&D) in façade design.

Many façades are custom designed and fabricated for a particular building and thus require some R&D to optimize the design, perhaps in a mockup. Also, evaluations are desirable to mitigate the risk of using new assemblies or combinations of assemblies, or installation methods. Typically, R&D needed to optimize a design or evaluate new assemblies or methods, are done just-in-time during actual construction projects, paid for by an enlightened owner, if they are willing. If architecture firms (and design teams in general) had the resources to fund R&D outside of billable hours, then this could reduce the risk that they have in using new systems and trying new designs.

These barriers work to maintain the status quo cost differential between code-minimum and higher performance. This reduces new technology adoption rates, making it harder for products to achieve the market volume and associated economies of scale needed to bring prices down and to support further adoption.

Barrier 2: There is insufficient return on investment (ROI) or payback on the initial first cost increase of using high-performance solutions:

2.1 Owners can't get a lease rate premium because tenants are not aware of the full range of benefits.

Tenants understand that they want interior finishes like marble floors and countertops, but typically they have insufficient knowledge or awareness of the benefits/issues to ask for high-performance envelopes. There are of course exceptions to this, but they are not the rule. One of the more recent trends in building design is to begin to identify, quantify and promote the non-energy benefits of facades such as view and thermal and visual comfort. Given the fact that on a per-square-foot basis occupant salaries are typically 100 times higher than energy costs, and 10 times higher than lease costs, this might help change the perspective on investment in high performance facades.

2.2 Simplistic payback models that focus on energy cost savings

Current models do not show the full benefits of high-performance façades / fenestration. Architects report that the energy savings estimated even for office buildings are insufficient to show the required financial payback, and for high load buildings like laboratories and medical buildings it is impossible.

One participant provided an example in which a design was simulated with an R24 spandrel that saved 1.9% operational energy. However, the payback on this saving was too long for the developer. Low energy costs continue to make it difficult to make the upfront cost difference pencil out. The cost of improving fenestration and/or façade performance is too high compared with the energy cost savings. If capital expense (CAPEX) savings from MEP downsizing (elimination of perimeter trench convectors, duct size reduction and implementation of heat pumps) can be captured then the ROI story becomes more compelling (see [Barrier 5](#)).

Ted Kesik, University of Toronto asserts *"when a full life cycle cost analysis is performed, high-performance facades always come out on top. Simplistic payback and ROI are simply means of profiting from unethical building performance which is subsidized by passing on externalities to the next generation. Payback and ROI metrics from cost effectiveness analyses should be discouraged."*

Currently there are no other validated payback or ROI models available which monetize the non-energy benefits, although there is growing recognition that these impacts are potentially important.

2.3 Split incentives accruing to the owner and tenant

Leased spaces reduce the perceived benefits to the owner who is required to make the upfront investment. The owner does not benefit from the energy savings if the tenant pays the energy bills. Also, the building developer may not be the ultimate owner, and so has even less incentive to reduce operational impacts. As a result, there is no incentive to invest in higher performance, unless lower operating costs can be reliably marketed to potential tenants to support higher lease rates.

2.4 Developers want a design that often doesn't necessarily align with a low-energy, low-carbon, resilient building because of perceived market demands.

The market (e.g. tenants/building buyers) may not be aligned with sustainability goals and/or they are asking for design features such as floor-to-ceiling glazing that would require a significant upfront investment to deliver low-energy and low-carbon performance. Form factor, building articulation and appendages (that cause thermal bridges) also play into this challenge. Lack of market education / awareness of the impact of the façade on energy, resilience, comfort, wellness etc. is a contributing factor (Side bar, note 7).

2.5 There is a lack of knowledge and quantification of the non-energy benefits to value the investment in high-performance fenestration / façade systems. Heat loss and heat gain and now even daylight energy savings can be calculated with some confidence using tools that have been validated over the last decade. In contrast architects and consultants typically have a limited ability to quantify these non-energy benefits to advocate for investments in better design (see barrier 7: Insufficient capacity at architect / consultants to design better façades)

Barrier 3: Design and product selection decisions are driven to the status quo to manage risk

3.1 The high cost of remediating a façade drives a conservative stance when considering the use of new and/or different products, systems and designs.

This typically results in a risk premium (see above) or a lower performance alternative offered. Façade / fenestration systems do not necessarily have to be new to the market to have a higher risk profile, even systems that are just different to those usually installed or specified can add perceived risk to project participants.

3.2 The lack of trained and experienced glazier labor

This increases the risk profile of the use of new and/or different solutions for installing firms, adding to the price, or increasing the chance of the contractor offering a lower cost, lower performing alternative instead.

3.3 The lack of awareness of new / different products and knowledge of their benefits

This lack of awareness on the part of both architects and contractors, and also owners and/or owners' representatives drives them to repeat the same past proven designs and specifications. This default to the status quo is also driven by the compressed design schedule (see barrier 7: "Insufficient Capacity at architect / consultants to design better façades")

Note 7: An outlier in the U.S., real-estate developers, local owner-occupiers, and tenants (technology and biotech companies such as Apple, Google, Genentech) in the San Francisco Bay Area are highly focused on delivering sustainable, healthy, low-carbon building design, and the high-performance façades that accompany them.

These companies are using their high-performance office space as a competitive advantage in the labor market, supporting their sustainability commitments to capital markets, and are bought into the productivity benefits. This is driving the construction of higher performance façades, with several buildings already adopting dynamic façade systems.

While this market orientation is the exception rather than the rule, understanding better the reasons behind how these large companies got to the point of being willing to invest in high-performance façades may help provide a blue-print for influencing other real estate markets.

Examples:

- <https://flexlab.lbl.gov/genentech>
- <https://blog.google/inside-google/life-at-google/bay-view-campus-grand-opening/>
- <https://appleinsider.com/inside/apple-park>

3.4 Lack of contractor knowledge of installation of new / different products

This drives contractors to default to what they know and have used in the past, a trend that contributes to slowing innovation. This lack of knowledge can also add a risk premium, resulting in higher costs, if they are asked to do something different (see above).

3.5 Insufficient budget

There is typically not enough money in the project budget to support a focused façade design or verification process, which is essential to the adoption of higher performance design solutions.

3.6 Schedule compression

Developers want a short time between their initial investment and their income stream from an occupied building, so schedules are compressing. This means that there is not enough time to evaluate novel façade options or even those more conventional high-performance solutions that the team has never used before.

Barrier 4: Standard project delivery methods drive to lowest cost and status quo solution selection

4.1 Design-bid-build

The ubiquitous design-bid-build process tends to limit the complexity of proposed solutions that can be achieved because there is limited collaboration between contractors, fabricators, material suppliers and designers at the design phase, limiting value development. The bidding process itself leads to the lowest price, with the lowest value offer being chosen.

4.2 Delegated design

This process shifts risk to the contractor, is growing more popular. However, the movement of risk causes the contractor to default to what they know best – the status quo – to minimize their risk. This trend also tends to discourage innovation.

4.3 Value engineering culture

There is a culture of value engineering at the general contractor (GC) level and often they receive bonuses to bring in projects under budget. This incentivizes cost cutting, which often means reducing value and performance on the façade. We heard that GCs often break the design specification to reduce cost and may bring in lower cost sub-contractors who aren't comfortable with the complexity of higher performance systems.

It was noted that in rare cases where projects structure incentives to exceed measured energy use after the first year, this has led to both high performance façades and MEP systems.

These issues and pressures may commonly result in:

- Rinse / repeat use of “status quo” specifications.
- Code minimum buildings with envelope performance degraded in return for higher efficiency lighting and HVAC.
- A price premium for non-standard high-performance options.
- The stifling of innovation and extension of the technology adoption lifecycle.
- Inability to achieve the economies of scale needed for volume production of high-performance products to reduce their cost.

Barrier 5: Project design is HVAC drive

5.1 The façade engineer and/or contractors typically are not present in the early design phases

However, the HVAC contractors typically are present and can steer the design with an HVAC lens. Stakeholders conveyed that often new façade products are introduced into a design when it is already at an advanced stage. At this point, there may also be nuances to the structure that make façade changes harder to accommodate, again underscoring the need for façade-related stakeholders to be involved much earlier in the design process. (Side bar, note 8).

5.2 The HVAC and envelope design are often done in a siloed way

This does not allow for synergies to be leveraged. HVAC design and sizing are based on worst case scenarios without considering the potential for lowering envelope loads via new façade designs. Even if some effort is made to improve façade performance, the earlier independent HVAC design may have resulted in an oversized HVAC system design which may then run inefficiently at part load throughout the year. Cost savings from downsized or right sized HVAC might be used to offset the first cost of the high-performance facade elements.

Another issue that façade designers have encountered is that when the enclosure is improved, HVAC systems are generally still sized to their standard business-as-usual. While the idea is that by improving enclosure performance, systems could be reduced or eliminated, this is not being adopted by the mechanical community. Enclosure consultants have been told it is not because mechanical engineers don't want to, it's because smaller system sizes for larger buildings do not yet exist so mechanical engineers / contractors essentially provide the same equipment as they would have previously, and it operates at a lower percentage of its design capacity. (Side bar note 9).

5.3 Whoever pays the modeler drives the design:

The HVAC contractors will often do the building energy modeling for free. Many of the HVAC system manufacturers have their own building simulation software that is primarily used for sizing their systems, but which is often used for design. Glazing contractors told us that the HVAC contractor gives input into the façade performance based on what their system performance can achieve and by the time they are involved the design is pretty much set and there is little opportunity to offer improvement suggestions. The clear takeaway was that glazing

Note 8: An envelope first approach in codes helps to reduce HVAC driven design.

For example, the code changes in Massachusetts and Vancouver that have put a much higher emphasis on envelope performance have reportedly had the effect of bringing the façade experts into the design process at that early stage, because the challenges associated with the design cannot be overcome without their expertise early in the design process.

The City of London's new requirement for documentation showing that a proposed project's operational carbon emissions be 35% less than the prescriptive building baseline, in combination with a requirement to get even preliminary design approvals from the planning board is also driving façade experts to be present at the very early concept development.

Note 9: In the few cases when collaboration has been possible with the MEP engineers from the early stages, the extra performance of the façade has been successfully used to downsize the mechanical system by eliminating perimeter trench convectors, reducing duct size and enabling heat pump technology. In these instances, the ROI story is much more compelling than relying on energy savings alone.

Andrea Zani from Permasteelisa, stated: "In a recent case study carried out with a MEP engineer, we noticed that on all-electric medium-to-large size projects, being able to downsize the heat pumps can bring massive capital expense savings. In addition, if you start considering lower amounts of carbon tax spent in cities like New York City and Boston, high performance façades become more attractive."

contractors felt that they could have offered different, more efficient, solutions if they had been involved in the earlier stages.

Feedback also suggests that energy modelers are doing their best to deliver the HVAC system that will support the floor-to-ceiling glass wall that many developers still want. If they do not have access to sufficient façade expertise, it is more likely that they will rely primarily on HVAC systems to manage the fenestration heat gain and losses, rather than trying to minimize those loads to begin with.

5.4 Simulation tools can be misleading:

According to some experts, simulation tools can underestimate the impact of building envelope loads.

5.5 Inadequate energy modeling:

Even with appropriate tools, AEC professionals clearly identified that building simulation to be inadequate because it is done at the wrong time in the design process, is poorly done for the envelope, using poor inputs and is done by those with insufficient expertise. This leads to a great deal of variation of simulation results between professionals, and poor representation of the performance of the building envelope. (Side bar, note 10).

Educating the mechanical engineers on how to properly simulate complex facade systems is fundamental to get more accurate cost savings and payback. Andrea Zani, Permasteelisa noted “they are much more conservative than their European counterparts.”

Kesik believes that there should always be a prescriptive path for most architecture offices that lack the sophistication to properly deploy energy modelling. He says, “*They usually end up with a third-rate consultant because it's all they can afford (the HVAC engineers throw in the energy modelling if they are awarded the work) and these amateurs overwhelm the architects with too many options, and then appear to save the day by recommending a muscular HVAC solution. You end up with a building that looks like a major league baseball pitcher with one freakishly muscular throwing arm and the rest of the body just flab.*”

Note 10: The Architectural Institute of British Columbia and the Engineers & Geoscientists of British Columbia have created a Whole Building Energy Modeling Services Guideline to address these issues (see also note 15).

Reference:

<https://www.egbc.ca/News/Articles/Practice-Guidelines-on-Whole-Building-Energy-Model>

Note 11: In the City of Seattle, code enforcement is more rigorous than in other jurisdictions because they have a funding structure that facilitates it. The local utility – Seattle City and Light – considers the code office an efficiency program, and so they funnel their efficiency program funding there. They provide funding to the office for a manager and 50% of 6 full time engineers, all of whom have the capability of reviewing building simulations and façade details for code compliance. Not only are they able to do detailed code reviews, but they are also funded to spend time developing new codes.

Barrier 6: Code compliance is lax

6.1 Code officials have insufficient training, resources, and time to enforce fenestration requirements.

Fenestration and façade details can be complex. Most cities rely on permit fees to fund their code enforcement office, and those fees are often constrained to keep them affordable. The result is that few jurisdictions can afford to properly fund compliance and code development. (Side bar, note 11).

6.2 A code review is often not required for contractors to prove their systems and / or glazing details meet the requirements.

Project drawings from the contractor and/or architect to the fabricator may not meet code (some feedback suggests this is not an unusual occurrence), and there is no incentive for the contractor/architect to fix them because there is no enforcement of code via a glazing detail or systems review. (Side bar, note 12).

6.3 The National Fenestration Rating Council's (NFRC) non-residential fenestration labeling and certification process is neither followed nor enforced in most jurisdictions.

This is despite the model codes requiring fenestration to be labeled and certified. While such a system would help code officials enforce compliance, it is not widely used because of the complexity and cost of the original system. In some cases, the code official may be offered a simulation report completed using the NFRC software by the fenestration manufacturer to demonstrate compliance, instead of an official label certificate, validated by NFRC. As a result, installed fenestration/façade products may not always meet code. (Side bar, notes 13 and 14). NFRC ratings are also not very effective at capturing the common arrangements of opaque areas of curtain wall and window wall (e.g. bypass conditions).

Barrier 7: There is insufficient capacity at most architect / façade consultant firms to design high-performance façades

7.1 Lack of understanding of fenestration and façade system performance:

Feedback suggests that there is much misunderstanding and miscommunication and that the first educational gap begins with the lack of appropriate façade level curricula at the university level. There is also insufficient professional-level continuing education to close this initial gap leaving architects ill-equipped to design and detail better façade systems.

FTI has published a report on the state of façade education in architecture degree courses in North American universities¹⁷. The study concludes that “courses are predominantly graduate-level and elective courses, indicating that the pool of students who gain exposure and knowledge of facades and facade systems in the U.S. is significantly smaller than anticipated and alarmingly small given the importance of this subject matter.”

Recent research by Peters and Kesik¹⁸ indicates that architects need much better climate action competence, and this means knowing how to select and detail enclosures. They note a need for “*adaptive reskilling of architecture*”, “*in order to manage massive change*”.

Note 12: Where code officials have the resources, such as in the City of Seattle, thorough assembly detail and code reviews can be done ensuring that there is good enforcement and providing an incentive for compliance.

Note 13: NFRC plans to launch a new non-residential labeling and certification system in 2024 that addresses many of the complexity and cost concerns that impacted the initial system. It will be important to track the rollout of this program, its adoption by states and cities, and its impact on the quality of fenestration design for which it is used.

Note 14: In places such as City of Seattle and California, NFRC labeling is enforced by the code officials, including the requirement of label certificates for site-built systems. This ensures that what is on the plan is what is delivered to the job site and installed.

¹⁷ The State of Facades Education in Academic Institutions: U.S.-based perspectives., Façade Tectonics Institute, <https://www.facadetectonics.org/publications/collection/publications>

¹⁸ T. Peters, T. Kesik, “FUTURE FORWARD: ADAPTIVE CHANGE IN ARCHITECTURE EDUCATION AND PRACTICE”, Canadian Architect, 11/2023.

In an ideal world architects might not only do a better job of design but might also be champions addressing many of the other systemic failures noted above that revolve around lack of expertise in designing and promoting high performance design solutions.

7.2 Insufficient number of qualified consultants to conduct whole building and façade modeling, design, and envelope commissioning:

The poor quality and/or inconsistency of building energy simulations (which are also used to demonstrate code compliance – see barrier 5.5 above) were highlighted as significant issues. (Side bar, note 15 and note 10).

7.3 Insufficient financial resources in architecture firms to do research and development (R&D) for façade and building level design concepts:

Architects typically rely on willing owners to fund research as part of specific building projects. While there are certainly exceptions to this, mainly in very large architectural firms with economies of scale to do so, independent R&D is typically not common. The additional challenge is that every building is a one-off. Unlike the automotive industry which can make millions of each car model, every building is different, and learnings from the last project need to be transferred to the next and built upon.

7.4 Insufficient budget allocated:

There is not enough budget allocated in each project to support a full façade design. Developers are eager to reduce the first cost as much as possible to get a faster return on their investment.

7.5 Schedule compression:

There is not enough time to spend on fully evaluating façade options because owners want to deliver projects as rapidly as possible to start to earn a return on their investment as soon as possible and take as few risks as possible in the process.

7.6 Limited capacity to calculate the non-energy benefits to advocate for better façade systems:

While there are standards and tools for assessing thermal and visual comfort, they are not in widespread use and require special expertise. While there is growing interest in these issues, for example, in building rating systems like LEED¹⁹ and WELL²⁰, there are no validated methods to monetize these benefits. Methods for assessing and quantifying resilience benefits are also in early stages of development.

Note 15: To address the simulation quality issue, the City of Vancouver has instituted specific guidelines and procedures for energy simulations for code compliance. These have now been adopted by the Province of British Columbia (see case study). There are also training programs for simulators supported through a local technical college.

Note 16: The combination of the Energy Star window program, which identifies an above-code performance standard for residential windows, and tax incentives for homeowners, has driven the single-family residential window market to much higher performance level than the fenestration typically installed in non-residential/multi-family buildings (figure 8).

Energy Star windows have achieved over 80% market penetration since 2010, despite stringency increases throughout that period. With appropriate modification, this model might be appropriate for some non-residential building types and markets.

¹⁹ <https://www.usgbc.org/leed>

²⁰ <https://www.wellcertified.com/>

7.7 No performance standard for high-performance façade / fenestration in non-residential / multi-family buildings:

Without such a standard, incentive programs cannot be utilized to drive improvements in fenestration / façade performance. Such a standard might provide a starting point for high-performance design and conversations with owners. Incentives from government, utilities, etc. could then be tied to specifying solutions that met those criteria. (Side bar, note 16)

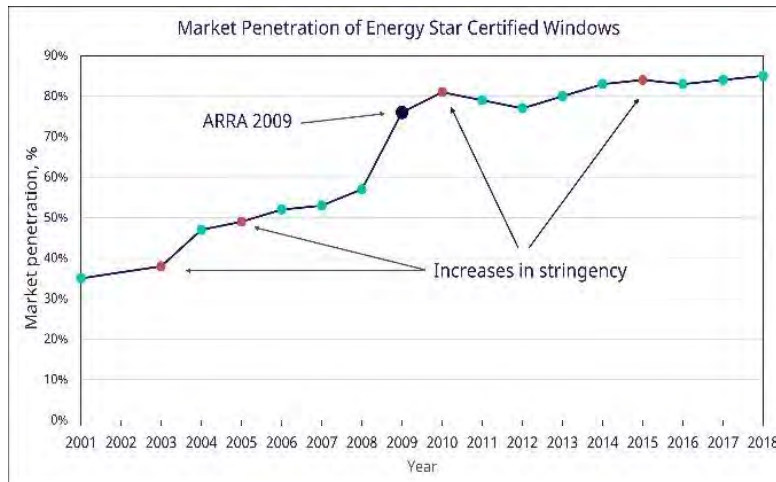


Figure 8: The residential window Energy Star® program market penetration from 2001 to 2018. Data from U.S. EPA.

7.8 Architects have limited power in the supplier relationship with owners to drive high-performance design choices:

If an architect takes a principled stance with an owner to drive to a higher performance façade, the owner can simply walk down the street and engage another firm who will design what they want.

According to Max Wolf of SOM, “the tiny subset of architects that lead architecture and engineering firms generally lack the courage or technical competence to pitch ultra-low carbon proposals for fear of losing a sale or alienating a client. Since most clients are indifferent to or ignorant of what comprises their share of responsibility for reducing emissions, this risk aversion is somewhat understandable, as design leaders in isolation have little leverage with clients on what a building’s performance targets or design life will be. These nearly always come down to the code and market forces, both of which are inadequate to address climate change.”

He went on to say “the vast majority of US architects, engineers, manufacturers, contractors, suppliers and building officials do not understand that an 80% reduction in whole life carbon is required to level off global warming and ocean acidification, that buildings are globally about 40% of the problem, and that most of the damage to climate is irreversible on a timescale of human civilizations²¹. Anecdotally, bringing up these topics at the start of even ‘cutting edge’ projects amongst some of the most skilled designers in the world often elicits looks of disbelief or comments of subtle hostility. Yet they form the underpinning for conceiving of ultra-high-performance, and without understanding them, implementation will eventually retreat to short term costs”.

²¹ Solomon, S., Plattner, G. K., Knutti, R., & Friedlingstein, P. (2009). Irreversible climate change due to carbon dioxide emissions. *Proceedings of the national academy of sciences*, 106(6), 1704-1709. <https://pubmed.ncbi.nlm.nih.gov/19179281/>

These dynamics are likely why most architects and consultants surveyed for this work said they believe that the way to drive performance is by enacting more stringent codes. In this way, owners must invest in better façades, and it levels the playing field.

As a result of these issues, many architects and façade consultants cannot effectively propose designs nor advocate to their clients for above code performance. Of course, there are exceptions, where forward thinking owners, and specialist consultants and/or façade experts in large architectural firms come together to construct exemplary façades, but this does not represent most of construction.

Additional barriers to the retrofitting of façades

In addition to the barriers listed above, there are yet more barriers to the retrofitting of façades in existing buildings. Figure 9 lays out these challenges pictorially and the details are summarized below.

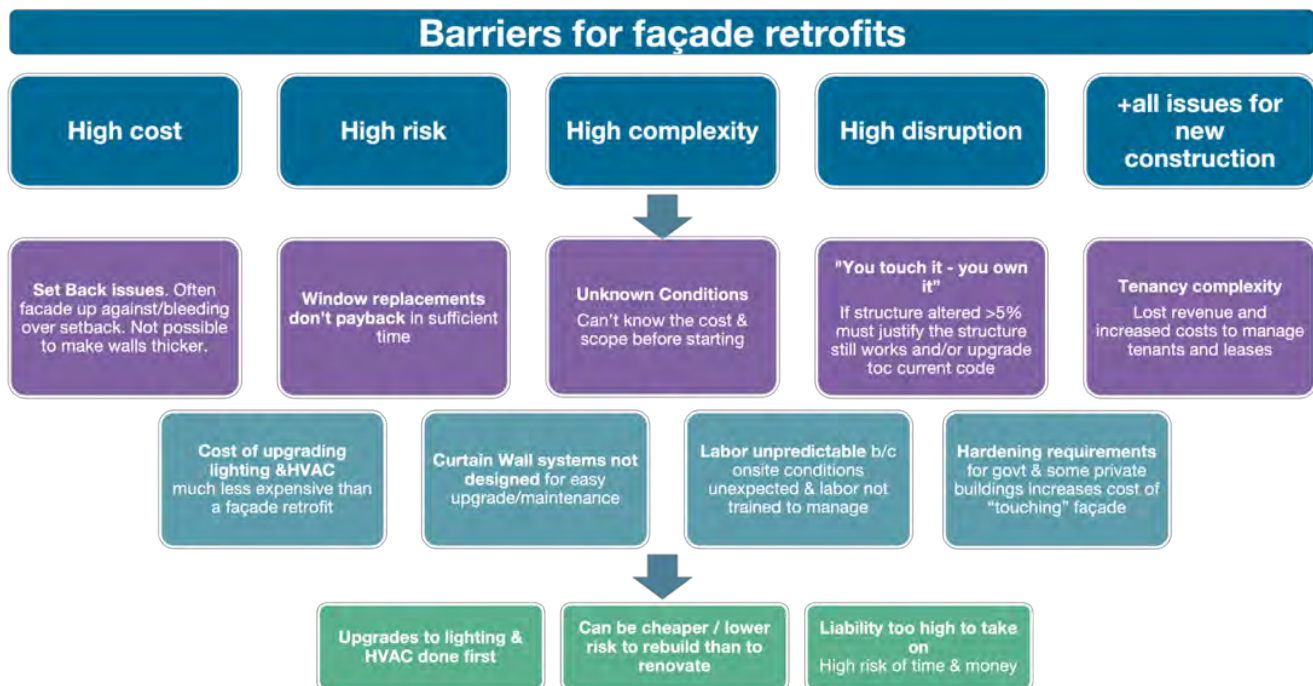


Figure 9: Additional barriers to retrofitting façades with high performance systems

The four additional high-level barriers we have identified to façade retrofits are:

- **High risk**
- **High cost**
- **High complexity**
- **High disruption**

There are several interlinked drivers that cause these barriers that are laid out below:

Unknown existing conditions:

With existing buildings, there are a lot of unknowns about the state of the façade and its anchoring that often cannot be assessed and known before starting the project. In many cases the original documents or as-built drawings have been lost, and the architect is forced to design an overclad by site investigation only. The scope and therefore the cost of the project cannot be well defined upfront. It is unlikely that the project team will know the design load for the existing anchors, since there often are not “as-built” drawings available. Existing anchors often must be removed to assess their depth. If they are not long enough to support the new loads, longer anchors will need to be installed which may then run into existing rebar in the concrete structure. This can substantially increase costs and may impact the structure of the building. The challenge is that an owner may need to spend \$1M to do an assessment of whether an upgrade is even possible on a \$10M upgrade, only to find that it cannot be done.

The unpredictable site conditions present a challenge with on-site labor, which typically is not trained to manage these unexpected façade conditions. This increases risk yet further. Architects note that requiring owners to retain shop drawings of their buildings would help retrofits tremendously.

“You touch it, you own it”:

In some jurisdictions, any change to the façade means it must be upgraded to meet current structural or seismic standards. In California, if the framing is touched, it must be upgraded to be seismic code compliant, which, according to one glazing contractor, basically means reconstructing the building. While technologies like vacuum insulating glass can be used to replace single pane infill without touching the frame, leaving a poor frame in place continues to degrade building thermal performance.

In other jurisdictions, if the structure is altered by more than 5% the design team needs to be able to justify that the structure still works.

For government and some private sector buildings there are also additional “hardening” (e.g. blast resistance) requirements which increases the cost of “touching” the façade. Often that is enough to prevent the retrofit.

With such high risk in both time and money, few owners want to take on the liability of large façade replacement projects.

Set back issues

Many existing buildings often have the façade built right up against or even bleeding over the setback, which means that it

Note 17: In the City of London (see case study below), the planning authority's requirement to calculate any proposed project's embodied carbon is helping to increase the barrier to demolition and rebuild. The city has already denied an application for the demolition and rebuild of a retail site on London's Oxford Street, preferring renovation. That said, this planning decision has recently been overturned by the UK's high court.

Note 18: The implementation of secondary glazing systems (either internal or external) has the potential to eliminate many, if not all, of these barriers. There are several manufacturers with solutions available for non-residential applications. While they do not have quite the same level of energy performance as a full retrofit, they have the potential to offer more nationwide energy and carbon savings since deployment rates would likely be higher than regular façade retrofits because of lower cost, complexity, disruption, and risk. This is a key reason why DOE is heavily supporting the deployment of this technology and key owners of large existing building stock like GSA are exploring their use. While there are several products on the market now, DOE is encouraging the facade industry to invest in further research, development, and deployment by offering a \$2M prize competition for the design solutions that provide the best performance at affordable cost.

References:

1. <https://www.architectsjournal.co.uk/news/breaking-gove-rejects-ms-oxford-street-demolition>
2. <https://www.dezeen.com/2024/03/01/mark-s-spencer-oxford-street-demolition/>
3. See for example: Alpen Windows' WinSert; Inovues' insulating glass retrofit system.
4. <https://www.energy.gov/eere/articles/doe-launches-2-million-prize-advance-cost-effective-energy-efficient-commercial>

is not possible to make the walls thicker or add an element such as shading that might extend beyond the current boundary.

High disruption causing lost revenue and incurred costs

Changing out the façade can be extremely disruptive to tenants and may require them to move out of the building or owners to wait until leases run out (which may be staggered) to upgrade, resulting in many months/years of lost rental income. For retrofits which aim to keep tenants in place, there are non-trivial logistics involved in managing occupants' disruption from noise, thermal discomfort, indoor air quality etc. In-place occupants may also limit the type of façade systems that can be practically installed. In larger buildings and those in urban centers, accessing the façade can be even more challenging, involving shutting down streets to provide crane access, for example. This further adds to the cost of the project.

Window / façade replacements do not provide fast enough payback on energy cost savings

This is because the cost of the fenestration systems themselves, in addition to the cost of installation, is typically too high (because of the reasons laid out above). Feedback suggests that typical payback periods often exceed 20 years. Since the cost of upgrading lighting and HVAC systems tends to be much lower than window or façade replacement, these former strategies are the first to be implemented before taking on the challenge of a building façade or window upgrade. This happens despite HVAC systems' useful lifetime typically being shorter than that of a new facade, and despite an envelope first strategy potentially allowing a lower cost HVAC replacement, by allowing a downsizing.

Curtain wall systems are not designed to be easily upgraded or maintained

Curtain wall systems are good until they are not. Seals and gaskets are inaccessible in unitized curtain wall, so that the curtain wall must be removed and replaced in its entirety when those fail. And seals and gaskets are relatively short-lived compared to the metal frame. One architect noted recently that they try hard to get contractors to use more durable materials in those hard-to-access places, but, ironically, is often told that the cost is too high. However, the real solution is to redesign curtain wall systems to allow the sealants and gaskets to be readily accessible for upgrade and replacement to extend the life of the system.

Resulting impact

In combination, these existing building challenges underscore why the façade retrofit rate remains at 0.5% or less – far from the rate needed to meet national decarbonization targets. In some cases, the dynamics mean that it can often be cheaper and easier to demolish and rebuild in the U.S. than it is to renovate (although some note that buildings are typically only demolished to make way for a larger one). Put another way, the barrier to demolition and rebuild is not high enough to drive retrofitting. (Side bar, notes 17 and 18).

Some note that most U.S. architects also prefer starting new and establishing their vision for the site with the least interference. They have no aesthetic incentive to retain anything.

Where and why market transformation is happening:

Case studies - translating theory into action

Many barriers and issues that constrain progress on higher performance façade implementation have been identified above. The challenge now is to identify strategies to address enough of them to initiate meaningful change. Theories about promoting change are interesting, but robust performance data and documented experience in real buildings is a stronger catalyst for producing significant change in our business-as-usual world. The following case studies provide detailed information about jurisdictions where transformation in installed façade and fenestration systems is happening. The key reasons why change is happening, lessons learned and what issues have been encountered in their transformational journey have been identified, based on information gathered through interviews with jurisdiction officials, local architects, consultants, fabricators, and manufacturers.

While our long-term goals are based on national impacts, it is interesting that some of the most innovative and promising new programs are occurring at the local city and state level. Iterative innovation and learning cycles are happening more quickly there, perhaps because it is easier to get alignment for action and support at the local level than at the national level, where there are many more actors and forces at work.

There are a few key themes that are common denominators for the most successful programs:

1. Political will and support
2. Financial support for code development and validation
3. Flexible cost-effectiveness criteria that do not rely on simplistic energy cost payback
4. Market support and training for capacity building

The final case studies review the adoption of Passive House certification and aligned performance and a successful developer-led commercial office project certified to the Living Building Challenge.

Case Study #1: British Columbia and the City of Vancouver

Background and drivers

Between 2015 and 2016 the province of British Columbia worked on the development of a novel code construct, consulting with a broad range of stakeholders from local governments, developers, the trades, architects and engineers, utilities, which would provide steps in stringency, reaching net-zero energy performance by 2032 at step 4. It is appropriately named the “BC Step Code” and in 2017, the Step Code Council was born²². The council’s purpose is to provide guidance on the BC step code and support implementation. In 2018 the step code went live.

The City of Vancouver has a goal of being the greenest city by 2030 and has had continuity of supportive leadership for the past eight years. Vancouver is leading BC jurisdictions in its rate of adoption of the step codes. While the rest of the province has just moved to a minimum of step 2, the City of Vancouver is at a step 3 equivalent or higher.

What’s game-changing about the step codes?

There are several requirements that set it apart from other North American energy codes and which drive better façade performance:

²² <https://energystepcode.ca/history/>

- A code road map:** The step codes lay out 4 building performance steps, with the last one equivalent to net zero energy performance, showing the direction in which code requirements will be moving. Over the course of time, subsequent steps will be mandatory. As such this provides a roadmap for industry to prepare and create capacity in products and services. It has allowed the market to take incremental steps and introduce some, but not all technologies at once. This is a significant benefit for manufacturers who can plan their product development with reduced risk. As of May 1st, 2024, the BC building code requires an equivalent of Step 2 for non-residential and multi-family residential (Part 3) buildings. The City of Vancouver requires performance of at least Step 3.
- There is no prescriptive path:** The only compliance path is through building energy simulation. This is to preserve design freedom with significantly more stringent energy requirements.
- Sets absolute targets:** The step codes set absolute targets for energy use intensity, not a relative performance compared to a base case. Different targets are set for different building types. This prevents the strategy of making the base building as bad as possible. Note, that there are some building types that are still allowed to use the relative performance path because of the challenges with their specific use.
- Sets specific performance targets for the building envelope:** Targets are set, based on building type, for Thermal Energy Demand Intensity (TEDI). Thermal energy demand intensity is the energy (heat) that a building needs to provide space heating and conditioning air ventilation. It is unique in that it considers the heat load independent of the efficiency of the heating system and is therefore highly impacted by the performance of the building envelope. To minimize TEDI, there is a significant focus on building massing and orientation, and the thermal efficiency and air-tightness of the building envelope. Because of the implementation of TEDI, envelope consultants, material manufacturers and envelope sub-contractors are more likely to be at the design table earlier, because of the multi-disciplinary, holistic approach needed. This indirectly solves one of the barriers identified: Envelope specialists not being involved early enough in the design process.
- More rigorous compliance:** Simulation inputs must be validated and there are specific requirements for energy simulation. There are modeling guidelines and rules set out that are required to be followed for compliance. Notably, there are rules for how to model spandrels, which are a known challenge for thermal simulation. This ensures that everyone is playing by the same rules. The City of Vancouver developed these rules that were then adopted by the province. Whole building air-leakage testing is also required.
- Thermal bridging must be considered:** This is highly significant because thermal bridging had been ignored until then and can significantly impact the thermal performance of the envelope. For example, the actual thermal transmittance of opaque cladding can be increased by more than 50% over its nominal value by using highly conducting aluminum Z-girts. Consideration of thermal bridging changes how opaque panels are attached, how balconies are constructed, how windows are installed and how other penetrations to the building envelope are managed.



Figure 10: Vancouver, BC. Photo by [Matt Wang](#) on [Unsplash](#)

Incentives

There was one incentive introduced by the City of Vancouver through the “higher buildings policy” of 2017²³. It targets buildings of greater than 40 stories in the downtown core and requires them to meet a more stringent TEDI and/or EUI requirement in order to build a taller building. There are also floor space ratio (FSR) exclusions that give back area that is otherwise needed for the additional insulation. Other BC jurisdictions have different incentives to create upward pressure for the market to ready itself for the next step up in stringency.

British Columbia provided funding to increase the number of high-performance fenestration systems on the market²⁴. They provided up to \$40,000 per manufacturer for the development and certification of façade products and systems that met or exceeded Passive House performance levels.

Critical success factors

Stakeholders identified several factors that have contributed to the success of the step codes: [Stakeholder collaboration and communication, technical information, training and market capacity building, creating feedback loops and problem solving, and project demonstration.](#)

The province engaged in a highly **collaborative target setting process**. The process had a defined governance structure, and consultants were engaged to do the building simulations as the targets were developed.

Peer²⁵ and technical networks were set up to bring together local government, consultants, code officials and other stakeholders to share implementation challenges with the provisional step code. They were able to bring issues to the province for them to be resourced and resolved.

The **Zero Emission Building Exchange (ZEBx)**²⁶, launched by the City of Vancouver, along with the Real Estate Foundation of BC, the Bullitt Foundation and the Carbon Neutral Cities Alliance, was created to focus on education and networking to keep the industry posted on step codes and implementation. They are “an industry hub that facilitates knowledge exchange to accelerate market transformation”. It has been able to reduce barriers to the development of cost-effective high-performance buildings, by providing the industry with case studies and valuable project cost details, research, training and demonstrations.

The **Energy Step Code Council**²⁷, is an advisory board that supports creation and implementation of training to all stakeholders. It provides technical clarification and advice related to the Energy Step Code and resolves implementation issues. It bridges local governments, utilities and industry and has council members spanning these stakeholders as well as academia and non-profit organizations. This is the forum where leaders in stakeholder organizations such as high-level program managers and decision makers, meet to address and resolve implementation issues.

The **British Columbia Institute of Technology**, a vocational college, drove a lot of practical training for installers and design and engineering professionals²⁸. They have a high-performance building lab where they train builders and have training for specific building types. They also provided space to do training needed for the tallest Passive House building that was built in Vancouver.

The **Thermal Bridging Guide**²⁹ was prepared by Morrison and Hershfield for a consortium of sponsors, including BC Hydro and BC Housing, in collaboration with many industry partners. It provided a much-

²³ <https://guidelines.vancouver.ca/policy-higher-buildings-for-rezonings.pdf>

²⁴ <https://news.gov.bc.ca/releases/2017MEM0015-001090>

²⁵ [https://www.communityenergy.ca/peer-networks/#:~:text=Step%20Code%20Peer%20Network%20\(SCPN\)&text=The%20mandate%20of%20the%20Step,peer%20learning%20and%20knowledge%20sharing](https://www.communityenergy.ca/peer-networks/#:~:text=Step%20Code%20Peer%20Network%20(SCPN)&text=The%20mandate%20of%20the%20Step,peer%20learning%20and%20knowledge%20sharing)

²⁶ <https://www.zebx.org/>

²⁷ <https://www.energystepcode.ca/about/>

²⁸ <https://www.bcit.ca/zero-energy-buildings/>

²⁹ <https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/power-smart/builders-developers/building-envelope-thermal-bridging-guide-v1-6.pdf>

needed guide for assessing thermal bridging and overall effective R-value in façade assemblies. It provided a catalogue of assemblies with pre-calculated performance including thermal bridge de-rating.

Lessons learned / improvement opportunities

The step code currently does not require proof of compliance – that is, there is no third-party review of the simulation output, nor is building commissioning a requirement. This is something that the City of Vancouver would like to implement in the future to ensure any gaps between as-designed and as-built are closed.

Kesik states *“Step codes may appear to be the answer, but they lack proper enforcement. Compliance through energy modelling is only required at the site plan approval stage in Canada. When the project reaches the building permit stage, only the basic code requirements are checked. Plans examiners and field inspectors do not enforce the high-performance specifications since these are left to consultants who write letters of attestation. The evidence indicates the performance gaps are atrocious and most of the malperformance can be accounted for through thermal bridging and air leakage - in other words, shabby enclosures.”* He believes that **enclosure commissioning and air-leakage testing must become mandatory.**

Despite the focus on market education and capacity building, there is still a lack of awareness in some segments, six years on. There was a challenge in reaching those who are slowest to adapt, and especially the smaller residential builders who had less capacity to support energy simulations and other technical changes in the new code. While some builders were resistant to change, and there was also a lack of professionals (“energy advisors”) who could do the technical work and facilitate the move to 100% energy modeling in single family residential construction. As a result, the province rolled back some of the requirements for single family homes. More time and help were needed to support the smaller builders.

The focus on TEDI has done much to improve the thermal performance of installed fenestration. They have not changed the targets since 2021 since they are “getting what we want” out of them. However, after reports of over-heating in new buildings and the recent increasingly frequent high temperature weather events, there is a concern that designers are **over-using the solar heat gain coefficient** to help meet the TEDI requirements using passive solar gains. To date, there have been **no targets to prevent overheating**. However, research with the University of British Columbia, has been started to identify thresholds for passive survivability. In high-rise residential buildings in Vancouver, there is a new requirement to do a cooling study and minimize the number of overheating hours there are by active cooling or external shading. The city expects a new metric for passive survivability soon that should address these resilience issues in face of overheating events.

The current focus is turning to **embodied carbon**. There is now a new requirement to report embodied carbon in new construction. By 2025 the city expects there will be a requirement to reduce the embodied carbon in new construction. Consultants are concerned about the lack of capacity in the market to support the analysis including both the underlying data and the assessment tools. There is extensive work underway with many groups on this topic, including by the U.S. EPA, but they are not necessarily ready for widespread application.

Impact on façade and fenestration performance

The city has been able to demonstrate that code compliance can be achieved at about the same cost of conventional construction.

There has been a significant increase in the performance of installed fenestration. The city hasn't tracked window to wall ratio (WWR), but they notice that market development buildings still appear to be quite glassy, since they are selling views to their market. They observe that rental or low-income housing appears to have less glass. Consultants note that there is a misconception that larger window areas are a non-starter, but it is attainable with the selection of the right products and design details. They report average WWRs of 30-35%, although WWRs of as high as 40% or 50% are being seen across BC,

including Vancouver. The higher end market has implemented triple-pane fenestration to achieve the desired higher window areas, whereas others default to a high-performance double-pane, with argon gas fill and warm-edge spacer, sometimes using fourth surface low-e coatings, and reducing glazed walls and spandrel areas. Low-e coatings, argon gas fill, warm-edge insulating glass spacer and low conductance frames are now ubiquitous in the market. This also suggests costs are lower in competitive markets. In Toronto, which has similar stringency through the Toronto Green Standard³⁰, we were told that façades are routinely getting to 50-60% WWR, and design teams are doing what it takes in terms of window and opaque performance to achieve that. Note that a 60% WWR represents close to a floor-to-ceiling glazing design after accounting for the typical plenum in a multistory building.

While glass spandrel panels can meet the Step 2 code requirements, it is increasingly challenging to use them for Step 3 or 4 compliance. Mega-panel systems like Flynn's Speedwall®³¹ and MiTek's ONEWALL®³², developed to meet the tighter step code requirements, are increasingly being used in lieu of unitized curtainwall as it gives similar speed of construction, but better thermal performance. This is similar to systems used in Europe.

Case Study #2. Massachusetts

Background and drivers

Massachusetts has significant political support for increasing the stringency of its building energy codes. Its Global Warming Solutions Act of 2008³³ required the state to reduce greenhouse gas emissions by 80% from 1990 levels by 2050. In 2016, the state EPA was sued³⁴ because it was not moving fast enough to comply with the law. This action catalyzed the state to drive faster to meet the targets across all emission sources. In 2021 "The Next Generation Roadmap Act"³⁵, was signed into law which requires that Massachusetts reduce GHG by at least 50% by 2030 and achieve net zero emissions by 2050. It sets targets for individual sectors, including non-residential and residential buildings. The state also has a 2050 decarbonization roadmap³⁶.

According to the state³⁷, *"In 2009, Massachusetts became the first state to adopt an above-code appendix to the "base" building energy code" – "the Stretch Code". The Stretch Code, which emphasizes energy performance, as opposed to prescriptive requirements, is designed to result in **cost-effective construction that is more energy efficient than that built to the "base" energy code.**"* According to local façade consultants, studies commissions that assessed the impact of new construction anticipated that the cost impact would not be severe.

Currently, the most recent **updated Stretch Code** is the 2021-IECC with Massachusetts amendments plus the Stretch Code amendments.

Municipalities choose whether to adopt the stretch code, and currently 85% or about 300 communities have elected to use the stretch code (figure 11). Only 50 communities are currently using the base code, and they tend to be rural communities. Once a community adopts the stretch code, updates to it are automatically adopted.

In addition to the stretch code, there is also a **"Specialized Municipal Opt-in Energy Code"** overlay to the Stretch Code, which is "designed to ensure new construction is consistent with a net-zero Massachusetts economy in 2050"³⁸. With a focus on electrification, it has a mixed fuel pathway, an electric only pathway, and a net zero pathway. It was new in 2023, but adoption is already growing and

³⁰ <https://www.toronto.ca/city-government/planning-development/official-plan-guidelines/toronto-green-standard/>

³¹ <https://flynncompanies.com/systems/speedwall/>

³² <https://www.bensonglobal.com/onewall/>

³³ <https://malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter298>

³⁴ <https://www.wbur.org/news/2016/05/17/sjc-ruling-global-warming-act>

³⁵ <https://malegislature.gov/bills/192/S9>

³⁶ <https://www.mass.gov/doc/ma-2050-decarbonization-roadmap/download>

³⁷ <https://www.mass.gov/info-details/building-energy-code>

³⁸ <https://www.mass.gov/doc/stretch-energy-and-municipal-opt-in-specialized-building-code-faq/download>

at the current time, the majority of cities and towns responsible for new development have already adopted this code.

Because of the focus on electrification to decarbonize, the state recognized the need to reduce heating loads in buildings to enable the electrification transition. As a result, they felt that just targeting energy use intensity (EUI) was not specific enough to yield progress towards decarbonization and would give a false sense of progress, especially since they noted that space heating is not typically a large part of EUI in their buildings.

Paul Ormond, from the Commonwealth of Massachusetts' state energy office, gave an example of a building with an EUI of 40 kBtu/ft²/year. Of that, he asserted, 6 kBtu/ft²/year may be space heating. While it doesn't look large, he says that "if we continue to build with loads of 6 kBtu/ft²/year, then we may not be able to effectively implement heat pumps."

The focus of the stretch code, then, is to "crush" space heating in multi-family residential and non-residential buildings. However, they have learned from Vancouver's experience and have not ignored cooling loads, which are increasing as climate zones move poleward and to higher altitudes due to climate change. With the requirements outlined below, they believe that they have reduced the 6 kBtu/ft²/year to 1 kBtu/ft²/year. While they recognize that dense multi-family and non-residential buildings generate heat and admit gains through windows, and tighter envelopes keep the heat inside, they feel that these changes put the state in the best position to decarbonize.

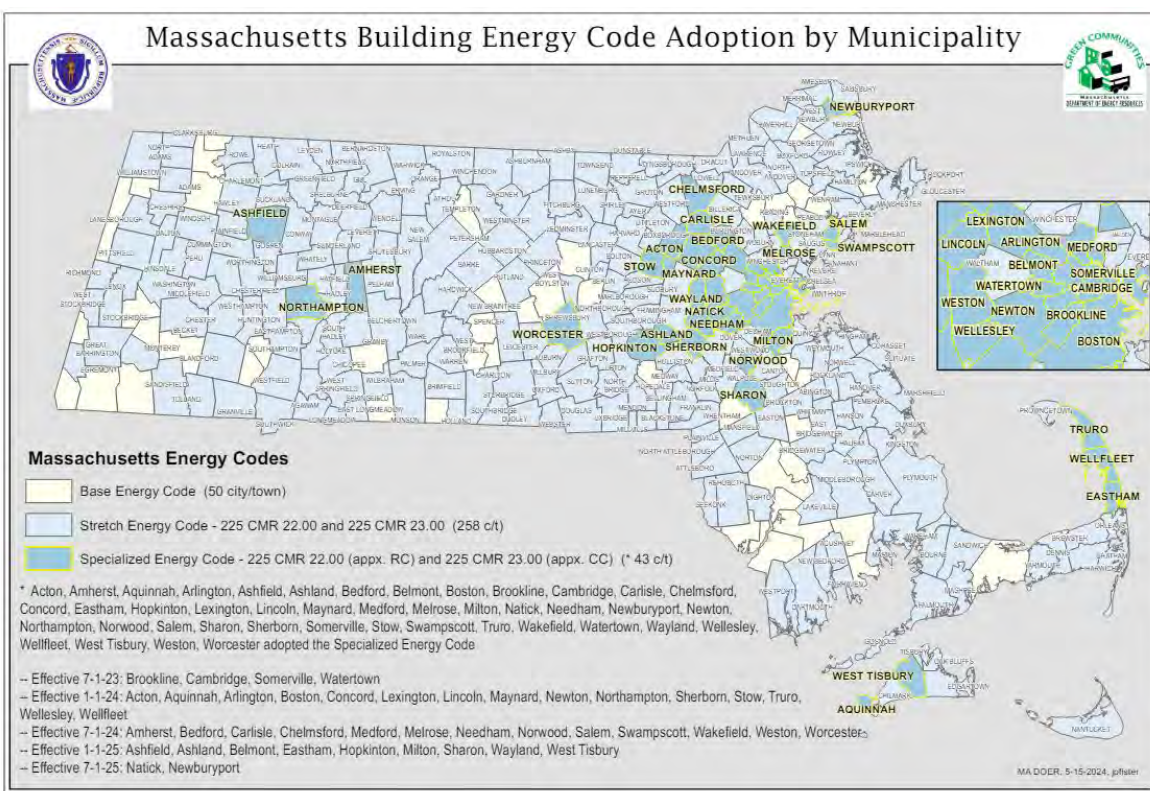
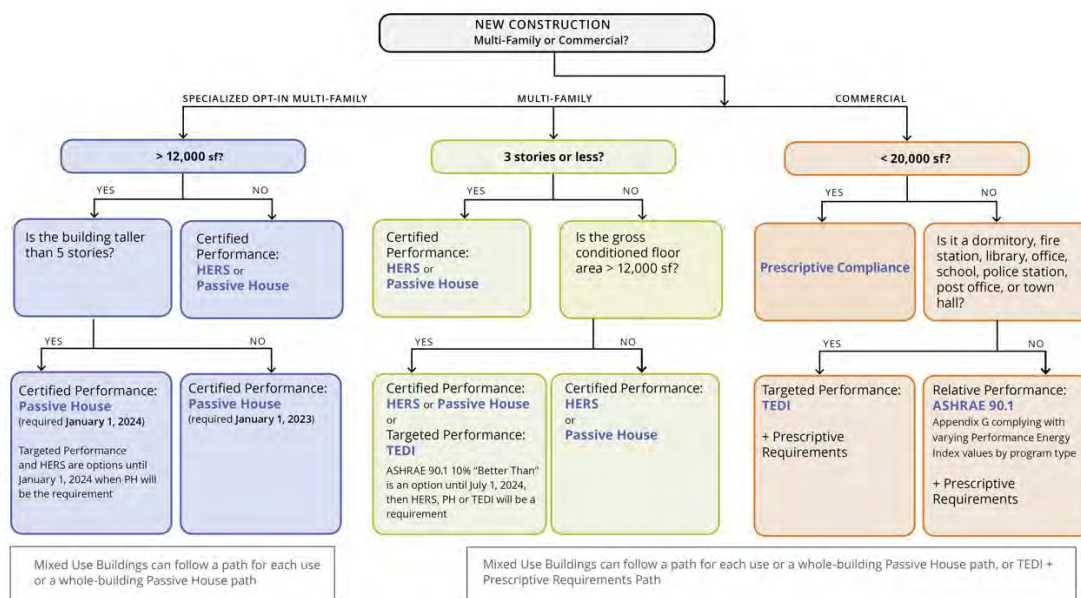


Figure 11: Massachusetts Building Energy Code adoption by municipality, 15 May 2024: Source MA DOER.
<https://www.mass.gov/doc/building-energy-code-adoption-by-municipality/download>

What is game-changing

The 2021-IECC was adopted with four key amendments and new compliance pathways were created, as identified below. In addition, what allowed significant jumps in stringency was the approach to **determining cost-effectiveness**. Instead of assessing envelope measures in isolation, like is done for

model code changes, their approach was more holistic. They contracted with building energy consultants and a construction company. They evaluated changes in combination at the whole building level and were able to get price estimates for all key building components and systems³⁹. The stretch code increases the cost of construction by between 0% and 4% depending on the building type, and in one case it decreases the cost of construction by 4%. According to Paul Ormond, on a 25-year lifecycle basis they have been able to show that it is always much less expensive to use the new stretch code.



STRETCH + SPECIALIZED OPT-IN CODE MINIMUM REQUIREMENTS

Passive House is a code compliance pathway for ALL building types.

Figure 12: The compliance pathways for the Massachusetts Stretch and Specialized Opt-In Codes. Courtesy of RDH

- **A target performance compliance path:** New in 2023, many non-residential buildings, such as offices, schools, dormitories, libraries, municipal buildings over 20,000 sq.ft., must demonstrate compliance through energy simulation and meet specific targets for EUI and TEDI targets, as is done in Vancouver. In addition, there is a requirement for maximum cooling demand (learning from Vancouver). The envelope backstop requirements must still be followed. Note that the TEDI limit is not as strict as that of the Passive House Standard and Massachusetts also has created climate specific limits for TEDI and cooling demand.

High load buildings such as offices and laboratories can still use the performance compliance method in ASHRAE 90.1 Appendix G, but it is modified to be based on energy savings, not cost savings, and must be 10% better than required by ASHRAE Standard 90.1. There is also no credit for renewables.

Small buildings under 20,000 sq.ft., except multi-family buildings, may use the prescriptive path.

- **Passive House certification** can be used as an alternative way to comply with the code for ANY building type. This is important as it reduces the barriers to implementing higher performance buildings as two energy models do not need to be created. Massachusetts was heavily influenced

³⁹ <https://fileservice.eea.comacloud.net/FileService/download/file/Massgov-uploads/ijecfhjj>

by the Passive House standard, but the state believes that the other compliance pathways are easier to meet. They did iterate on some strategies and evaluated the cost-effectiveness of aligning all requirements with Passive House, but they found it not to be cost-effective. They therefore backed off the requirements a little to achieve cost-effectiveness with the main compliance pathways.

That said, in municipalities, like Boston, adopting the specialized opt-in code, Passive House certification is the only pathway for multi-family residential.

- **Envelope backstop to preserve envelope performance:** While the state believes that windows do not have to be highly insulating in many non-residential building types because of higher internal loads than smaller residential buildings, their premise is that their performance should not be sabotaged. That is, performance should not be traded away with internal systems, such as HVAC and lighting. In 2020, a first version of the envelope backstop was introduced, which required the as-designed envelope to maintain the same area-weighted U-factor (UA) as the prescriptive building. At the time, this UA backstop was the tightest of its kind in the U.S., allowing no ability to degrade the envelope compared to the performance defined by the prescriptive compliance path. This is often referred to as a 0% UA envelope backstop.

In 2023, a further revision was made to prevent additional trade-offs between roofs and above grade walls, and with spandrel performance. Spandrel thermal performance is widely understood to be over-estimated by conventional 2-dimensional thermal modeling⁴⁰ and rating systems and so taking advantage of this undelivered performance is inappropriate. As a result, new specific requirements for buildings utilizing glazed wall systems containing spandrel (such as curtain wall and window wall) have been introduced.

- Buildings with glazed wall systems covering less than 50% of vertical wall area must have an area-weighted vertical wall U-factor $\leq 0.1285 \text{ BTU/}^\circ\text{F}\cdot\text{hr}\cdot\text{ft}^2$
- Buildings with glazed wall systems covering more than 50% of vertical wall area must have an area-weighted vertical wall U-factor $\leq 0.16 \text{ BTU/}^\circ\text{F}\cdot\text{hr}\cdot\text{ft}^2$

There is also a mandatory **maximum U-factor of $0.25 \text{ BTU/}^\circ\text{F}\cdot\text{hr}\cdot\text{ft}^2$** for the **vision glazing** (frame and spacer included) in glazed wall assemblies to prevent trading transparent area performance off with better spandrel performance. Note that area-weighted averaging is still possible across the fenestration, so not all vision area needs to meet the $U=0.25 \text{ BTU/}^\circ\text{F}\cdot\text{hr}\cdot\text{ft}^2$ requirement. There is also a 10% relaxation for existing buildings.

This requirement seems counterintuitive, as a building with 51% of its vertical wall covered with glazed wall is easier to implement than a building with 49% of its wall area covered in a glazed wall. However, the code recognizes that glazed walls need to be used on some projects and thus provides an additional relaxation of the U-factor to account for the reduced performance that comes with that system decision. It was important that curtain wall clad buildings not be made impossible. The use of curtain wall is considered “uncomfortable, but not impossible”, forcing designers to be more judicious with the use of poorer performing glazing systems in their designs.

For buildings with **non-glazed walls**, when following the targeted (TEDI) performance path with the envelope backstop, the area-weighted U-factor for the vertical enclosure must still meet the area-weighted U-factor of the prescriptive path.

⁴⁰ <https://www.rdh.com/blog/thermal-performance-of-spandrel-assemblies-in-glazing-systems-research-roadmap-phase-1/>

For vertical fenestration the prescriptive U-factors are 0.30 BTU/°f.hr.ft² for fixed windows and 0.32 BTU/°f.hr.ft² for operable windows. The prescriptive maximum WWR is 30%, rising to 40% if specific lighting control requirements are met.

The combination of the backstop and the TEDI pathway creates a greater challenge for the envelope in those building types where it is mandatory, because the TEDI pathway typically drives designs with significantly more insulation and much lower air-infiltration than that required by the envelope backstop⁴¹.

- **Thermal bridge mitigation requirements:** In the newest stretch code revision, step-by-step rules have been implemented that force designers to account for clear field and linear thermal bridges. According to Ormond, there are 11 conditions that must be accounted for – three clear fields and eight linear bridges – in their building code submission. There are three options for addressing thermal bridging: (1) using overly conservative default formulas, (2) using precalculated values (from the Thermal Bridging Guide from British Columbia) or (3) custom thermal modeling.

Note 19: For windows there are technology solutions for thermal upgrades of frames and glass edges in combination with hybrid vacuum insulating glass or triple pane glazing to produce "R10", or close to R10, overall product performance. For curtainwalls achieving this level of performance is more challenging, especially because of the structural requirements, and requires additional development.

Critically, three-dimensional thermal simulations are required for spandrels within glazed walls, unless default or precalculated values are used. Although two-dimensional thermal modeling tends to over-estimate spandrel performance, in some instances, consultants have reported that 2-dimensional thermal modeling can swing the other way, over-predicting the negative impact of thermal bridges. They note that the use of three-dimensional thermal modeling helps to keep the impact of thermal bridges realistic and aids compliance.

- **Air infiltration limits:** Massachusetts adopted the 2021-IECC requirements with tweaks, but the newest stretch code has the new air-leakage requirements adopted in the 2024-IECC.
- **Heat recovery is ramped up:** A universal requirement has been set for 75% of the heat from exhaust air to be transferred to inlet air through a heat exchanger. This requirement is aligned to the Passive House Standard.

The state issued a full set of technical guidance documents to support interpretation and implementation of the stretch code⁴², including a set of models conforming to the TEDI requirements.

Existing buildings

Boston's 2021 Building Emissions Reduction and Disclosure Ordinance (BERDO)⁴³, a building performance standard, sets requirements for reporting and reduction of total greenhouse gas emissions in existing buildings over 20,000 sq.ft. While there is nothing specific to façades, buildings will need to address the building envelope performance when the energy use intensity targets become more stringent and lower cost options such as lighting and HVAC upgrades have been exhausted. The first report is due May 15, 2024, through EPA's Energy Star Portfolio Manager. Penalties for non-compliance have some teeth, with failure to comply with emissions standards racking up fines \$300 to \$1,000 a day, and \$1,000 to \$5,000 for failure to accurately report information.

⁴¹ <https://www.greenengineer.com/education/energycodema>

⁴² <https://www.mass.gov/info-details/stretch-energy-code-development-2022#final-guideline->

⁴³ https://www.boston.gov/sites/default/files/file/2024/04/Regulations_1.pdf

The "Equitable Emissions Investment Fund" is available to financially support evaluation, design, implementation and management of projects to reduce emissions from energy use in buildings to support compliance. Other support and incentives are available through the Mass Save program (see below).

Incentives

Mass Save⁴⁴ is a collaborative of Massachusetts' electric and gas utilities and energy service providers. It supports energy efficiency upgrades for buildings through incentives and rebates as well as providing training and information. According to some stakeholders, Mass Save's programs are extensive and well thought through. They include:

- Energy assessments for existing buildings
- Incentives for upgrading thermal insulation in walls and roofs, adding weatherstripping around doors and windows and making air-leakage improvements.
- Technical support for new construction and major renovation. On larger projects this includes energy modeling services, design charrettes and financial incentives to meet EUI reduction targets⁴⁵.
- Incentives for deep energy retrofits, including building envelope and ventilation upgrades. Benefits also include a no-cost energy assessment and scoping study.
- Low-cost loans from \$5000 to \$500,000 for up to 7 years.
- Incentives for multi-family construction that pursues Passive House⁴⁶. The incentive is up to \$5,000 for a feasibility study and up to \$500 per unit to cover energy modeling costs. Post certification, the incentive is \$2,500 per unit with a performance bonus reflected in lower utility rates.
- Training courses focusing on a wide range of audiences, including training for workforce development, code officials and other professionals.

Lessons learned / improvement opportunities

In 2020, the backstop introduction went well. Even though the initial response was "the sky is falling", the practitioners quickly figured out how to deal with it.

Thermal bridging assessment

Any table with clear field U-factors or R-values for opaque wall assemblies is meaningless without rules for thermal bridging. It is critical to deal with thermal bridging first as a priority and ensure there are rules about how to de-rate performance.

The industry does not know how to calculate accurate installed R-values, de-rating for thermal bridging, and it is not clear whose responsibility it is to provide the data. Two-dimensional thermal models (using THERM) do not cut it. This is a gap that needs to be closed. Training on thermal bridge calculations for the industry is critical. Massachusetts provided examples and guidelines to support more accurate thermal bridge assessment.

Complexity

While the multiple compliance paths are helpful, according to many, the Massachusetts stretch code and overlay are very complicated, vague, and hard to follow and interpret. Additional education, simplification and/or flexibility in achieving compliance was requested.

Market capacity: Experience and education

According to market participants, there remain some significant education gaps and capacity-building

⁴⁴ <https://www.masssave.com/>

⁴⁵ <https://www.masssave.com/en/business/programs-and-services/new-construction-and-major-renovations>

⁴⁶ <https://www.masssave.com/en/residential/rebates-and-incentives/passive-house-incentives>

needs in the market, that are not being addressed. More education is needed and outreach to the community to show how to navigate and comply with the code requirements.

Feedback suggested that the requirement for all multi-family housing in Boston to be Passive House Certified will have the most impact because of the current experience gap in the market. There is a concern if there will be sufficient experience or knowledge and infrastructure in the city to be able to cope with the need for Passive House construction. It remains to be seen if there will be any impact on multi-family volume because of the current economic slowdown.

Code impact on façade and fenestration performance

Has it gone too far or is it “just right”?

It depends on who you ask. According to the state, the intent of the Stretch Code update was not to be too disruptive, which is why significant increases in prescriptive performance were not introduced. However, the addition of the TEDI target and minimum requirements for the building envelope has resulted in a pretty challenging code, which appears to be driving innovation in design and products.

In the words of one stakeholder, who supports the need to drive building energy efficiency but has to manage the practical challenges, ‘it is going to take some time for the market to learn and innovate, and the state may be “over their skis” on this latest revision’. Because of the challenges, they believe that the architectural community will need to rethink how they design buildings and bring in new partners early into their design process. They hope that the design community will be more innovative than just reducing window area and resorting to “grim concrete designs”.



Figure 13: Boston, MA. Photo by [Ozzie Stern](#) on [Unsplash](#)

In contrast, envelope consultants have noted that, while there is an increased focus on enclosure performance analysis and the overall design process for enclosures is more complex, there are still many levers and components in an enclosure design that can be adjusted to bring a project into compliance and achieve an architect’s vision. However, it is not as straightforward as under previous code, but it is typical for those designers used to Passive House design.

Because of challenges experienced with code implementation, “A Better City”⁴⁷, a Boston organization which develops solutions and influences policy in transportation and infrastructure, land use and development, and energy and the environment, is advocating for convening practicing professionals to improve the codes, increase state resources to support timely answers to code related questions, and develop a State-managed relief pathway⁴⁸.

NAIOP - Massachusetts⁴⁹, the local chapter of the commercial real estate development association, is challenging with the state the cost-effectiveness assessment for multi-family residential construction in Boston where the Specialized Opt-In code has been adopted and now requires Passive House compliance. In a letter to the state energy office, they state that it adds \$30-\$50/sq.ft. of cost to a

⁴⁷ <https://www.abettercity.org/>

⁴⁸ <https://www.abettercity.org/news-and-events/blog/doer-requests-comments-on-the-stretch-codes>

⁴⁹ <https://www.naiopma.org/>

building, results in a project cost increase of 10% with current interest rates, and a premium that makes it worth less than the construction cost.

Current design and delivery implications

The increase in envelope performance stringency means that architects are currently relying heavily on enclosure consultants to guide the team to a compliant building because they don't have in-house capabilities. It also has the benefit of the envelope experts being brought in much earlier in the design process than previously. Being involved earlier ensures that the enclosure gets sufficient focus so that the project gets through the permitting process without problems.

After going through several projects with the guidance of enclosure consultants, architects will learn how to design and detail to the new codes, including the window perimeter tie ins, balcony thermal breaks, managing thermal bridging through fins, etc. But additional education of the architectural community is needed to support building capacity.

Manufacturers and glazing contractors are also getting involved much earlier in the design process. But to be successful they must understand the vocabulary and have the aptitude to speak this new conversation and provide data to support the design. While some are up to speed with the new needs of the design team and have been providing project-specific thermal modeling of their systems since 2020, many are not.

To support design teams, manufacturers must be able to:

- **Provide project-size specific fenestration performance data** rather than NFRC standard size data.
- **Provide the thermal performance of the frame/wall linear interfaces (psi-install) values;** This means that the entity who is providing thermal performance of the glazing system would need to include the adjacent opaque wall in their model. Coordination of performance at the interfaces is not typical for manufacturers who typically do not know the details of the wall.
- **Have access to and/or budget to engage in third-party 3-D modeling capability for spandrel assemblies** or have the knowledge and ability to navigate the free online database if following the other pathway(s). Because it isn't required elsewhere in the country, manufacturers are not necessarily incentivized to get up to speed on it. Also, since such simulations are not commonly used in the industry, and if fabricators are unaware of the requirements and submit the regular NFRC 2-D values, they may be severely limited.

Glazing subcontractors are being asked to be engineers and prove that systems work and include the interface with the wall. In turn the glazing contractors are looking to the manufacturers to help them with the thermal modeling and to supply the psi-install values. Psi-install factors often occur at the interface between trades, and often the glazing contractors may have no ownership of the adjacent opaque wall construction, leading to a challenge with assigning responsibility. There is a significant gap currently. Consultants assert that the enclosure consultants/architects should have responsibility for coordination and to produce models.

Since the implementation of the new stretch code, the typical installed **transparent fenestration** performance in glazed walls (not including spandrel) has transitioned from a U-factor of around 0.35 BTU/°F.hr.ft² to one that is no worse than U=0.25 BTU/°F.hr.ft², and typically closer to U=0.16 BTU/°F.hr.ft². A transparent glazing U-factor of 0.25 BTU/°F.hr.ft² in a glazed wall often isn't sufficient to meet the overall wall UA requirement for even modest WWRs below 50%.

One curtain wall fabricator reported that high-performance façades are the only way to get a WWR above 60% and noted that the backstop requirement is making it quite hard to have horizontal and

vertical shading systems attached to the curtain wall. To address this issue, they explained “we end up adding a lot of interior insulation to hit the number, with really small associated energy savings.”

Challenges

In many respects the MA Stretch code is ahead of the market, and even with mandatory requirements, many of the barriers associated with risk mitigation identified in the preceding section have been encountered and listed below. It appears that there is still insufficient market education and capacity built. Unlike Vancouver, **there is also no road map for manufacturers to plan against**. This is a key differentiator and why manufacturers may be reluctant to deliver or supply higher performance products to the U.S. markets since they don't know what will be demanded next.

System availability: To meet a U-factor of 0.25 BTU/°F.hr.ft² and below, triple pane is standard and aluminum fenestration systems need to incorporate wider and/or more complex thermal breaks and materials to reduce the frame effects, to improve assembly U-factors. With triple pane in-fill, there are choices in aluminum systems, but it is still difficult to find sufficient options in glazed wall systems (window wall, curtain wall).

Curtain wall designs that use larger glass panes and fewer mullions can provide the needed performance. For solutions to meet demanding U-factors below U=0.25 BTU/°f.hr.ft² alternative framing systems are being evaluated such as uPVC, fiberglass, wood, as well as fiberglass integrated into aluminum frames. In residential towers, better thermally performing systems with these alternate materials are being proposed and project teams need to weigh the benefits and risks associated with the proposed systems to determine if they are the correct fit for the project.

It can be complicated (and therefore expensive) to make unitized curtain wall achieve needed thermal performance. To achieve the required thermal performance, a very high R-value opaque assembly is also required, to balance the traditional thermally inefficient unitized curtain wall. That said, the consultants feel that the cost to thermally improve curtain wall systems is still small compared to the positive impact they have on schedule, site access, and the quality benefits of using them on large tower projects in urban areas.

As a result, they believe that curtain wall will continue to be used as long as it is thoughtfully designed, and appropriate systems selected. They do not believe that the cost to procure higher curtain wall performance will drive the market to stop designing 100% glazed curtainwall towers. It will require further industry innovation towards lowering system U-factors, primarily thermally improved framing but also continuing to lower the U-factor of the glazing in-fill. High performance options are offered by some glazing and curtain wall suppliers today; if there is a clear signal to manufacturers that the market will purchase these products, they will be more likely to be added to the supply chain.

Acceptable pricing for high performance fenestration is hard to get on small projects, as the project type may not be able to afford the improved solutions. Smaller developers are not used to being held to these strict requirements and there is a definite learning curve to building to the new requirements.

Contractor change: It is hard to get large glazing contractors to change what they currently are used to installing. Consultants want contractors to use the same systems project to project for consistency and familiarity rather than installing whatever system they can procure. They recognize that it is a riskier decision for a contractor/glazier to be forced to install a system that they have never installed before. The consultants note that the burden must fall on the fenestration manufacturers to improve their systems to give contractors and consultants more options.

Value engineering: Historically, high performance European fenestration systems were specified, but they often were value-engineered out of the project. Since thermal performance is critical now, value-engineering may be more difficult unless swapping to an equivalent performance system.

Fiberglass fenestration systems, which can be useful in complying with the backstop, are not common in Massachusetts (unlike in the Pacific Northwest and Canada) so there is not much experience with installation. A premium is often applied to fiberglass systems by contractors who are not familiar with them, until the experience is developed.

Building appearance changes?

Since there has been no concurrency period in the timing of code implementation, the first tranche of highly glazed buildings being constructed to the 2023 Stretch and Specialized Opt-In codes have been designed to look like they did under previous code, with a similar amount of glazed wall assemblies. Because of this, highly glazed first-generation projects have massing/designs that often are not compliant with the new code and design teams are having to work hard to make them comply by using alternative materials, insulating glazed wall assemblies from the interior (introducing condensation risk) or redesigning, all of which adds cost to projects. That said, highly glazed projects are not in the majority and “even a building with 50% of its envelope covered in glazed wall assemblies can comply with the right systems as long as the team is paying attention to the systems being selected.” For the most part, design teams are not seeing a significant change in the building design and are able to get a 30-50% window to wall ratio (WWR) building to comply.

Case Study #3: Seattle, WA

Background and drivers

Washington state enacted legislation in 2008 which requires a reduction in new building energy use of 70% by 2031. Seattle also has a climate action plan which aims to achieve net zero carbon emissions by 2050. The City of Seattle typically takes the lead in terms of developing and adopting new energy codes to support compliance with this law, and typically the state refines it and adopts the measures state-wide. There is good political support and funding across the city for building energy code improvements. The state is on track to meet their 2031 target, although they have used up most the obvious ideas, and now the path is becoming more challenging.

Washington state law was recently revised to require new state code provisions to be the most cost-effective available means of progressing towards the 2031 target, on a life-cycle cost basis, rather than having to pass cost-effectiveness tests. Seattle does not enforce a numerical cost-effectiveness standard, instead striving to ensure that measures remain economical.

However, the biggest issue they encounter is the assessment of the **real cost** of new measures in advance of a new code going into effect. When a measure is not yet familiar it is seen as a risky special order, so a significant cost premium is applied. Of course, this is the wrong cost to use, since typically that risk premium will evaporate once it becomes business-as-usual for designers, contractors and the supply chain. This “learning curve” process has occurred with the arrival of several new code provisions, such as low-e glass, air barrier testing, and continuous insulation.



Figure 14: City of Seattle, Photo by [Andrea Leopardi](#) on [Unsplash](#)

According to Duane Jonlin, code official from the City of Seattle, *“The ‘Seattle Process’ for code development is infamous for being detailed and time-consuming, but as we develop new code requirements, they are inevitably improved with input from stakeholders over the course of many public meetings and follow-up exchanges.”* The advantage of using the public process, is that any stakeholder that has a better idea, or has a way to reduce costs while getting similar results, is sure to offer it, thereby optimizing the cost-effectiveness of code changes.

What is game-changing

While one may not see this as game-changing, the most impactful thing that the city does is to seriously **enforce its code** – in plan review and in the field. This is a critical success factor (see more below). In terms of additional stringency, Seattle has implemented and enforced:

- **NFRC label requirements:** Fenestration contractors are required to comply with NFRC rules; punched windows all have NFRC labels affixed, and site-built fenestration must obtain NFRC label certificates before installation.
- **Air barrier testing** for every new building with a low leakage rate of 0.25 cfm @75 Pa. This measure, according to Jonlin, provides the biggest bang for the buck. He notes that *“It is hard for the first couple of projects, but by the third building, the teams have it figured out (quality assurance, testing etc.)”*. In Seattle, they started out only requiring testing and reporting, but not actually meeting a leakage target. After several code cycles giving contractors time to master air barrier tightness, a hard leakage target was implemented.
- **Rigorous Insulation** and U-factor requirements for all components, equivalent to that required in Upper Midwest climates.
- **An envelope backstop:** For projects complying through the performance (trade-off) path, there is a backstop that limits any compromise of the envelope’s insulating value to 10% below the prescriptive code (a 10% UA backstop). In their experience, the performance compliance path had primarily been used to worsen the façade without meaningful counterbalancing improvements in other systems.
- **Thermal bridging limits** for concrete balconies and fenestration-wall interfaces, and for metal penetrations through continuous insulation.

Existing buildings

Washington state is implementing a new building performance standard (BPS) which will require mandatory compliance for buildings over 220,000 sq.ft. in 2026, with dates for smaller buildings coming in subsequent years. The BPS will require performance upgrades to many existing buildings, but whether building owners choose to comply by upgrading façades is not yet known. Seattle complements this policy with its “building emissions performance standard” (BEPS), which will require large buildings to eliminate carbon emissions from equipment over the next two decades.

The Washington BPS⁵⁰ does have teeth and will impact the lowest-performing 60% of buildings. The penalty for non-compliance is \$5,000 plus up to \$1/sq.ft./year⁵¹, although owners can also comply by making annual progress towards an approved target date.

Since heat pumps will be part of the transition, it may be that envelope retrofits, especially to fenestration, prove to be an economical means of reducing heating loads and thus minimizing the size of the heat pump system.

In Seattle, building owners rarely demolish a building unless they are replacing it with a taller one. An unintended consequence of BPS could be that if the cost of retrofitting a building is too high, a full replacement may be more cost-effective (with a negative impact on embodied carbon). This dynamic should be carefully monitored.

⁵⁰ <https://www.commerce.wa.gov/growing-the-economy/energy/buildings/how-to-comply/>

⁵¹ <https://app.leg.wa.gov/rcw/default.aspx?cite=19.27A.210#:~:text=The%20penalty%20may%20not%20exceed,square%20foot%20of%20floor%20area.>

Incentives

According to Jonlin, while there are incentive programs for higher performance buildings, project teams rarely use façade improvements for that purpose, since typically it is more economical to reduce energy use through improving mechanical and lighting systems.

They have found that change at a scale large enough to meet their climate targets must happen through regulations, not purely through incentives, because there are insufficient funds available to transform the entire building stock.

Critical success factors

As mentioned above, enforcement of Seattle's code is a key factor in its impact. Part of their ability to enforce the code is driven by its unique funding structure.

The funding source and structure for the City of Seattle code development and enforcement is a major driver of its leadership in energy code stringency and enforcement. The local utility – Seattle City Light⁵² – considers energy code development and enforcement to be one of its efficiency programs, and state legislation requires them to invest in such programs. They provide funding to the office for a department leader and 50% of the six full-time engineers, so that they are internally capable of reviewing building simulations and façade details. They are equipped to complete detailed code reviews and invest time in developing new code provisions. The utility funding also supports participation in the development of state and national model codes.

In contrast, other jurisdictions rely on permit fees to fund their code departments, and those are constrained because keeping permit fees low is important. Therefore, few jurisdictions can afford to fund compliance and code development. It was noted that Washington DC has a special tax levy to support code enforcement, and New York City also has dedicated funding.

The detailed code development process, which involves many public meetings and follow up exchanges to gather input from stakeholders, drives new proposals to become more effective and constructible.

Training and educational presentations are provided by the City to all types of design and construction organizations. They post on-line detailed explanations for compliance with complex code issues and provide on-line support.

Lessons learned / improvement opportunities

As identified in other jurisdictions, it is difficult to get information on code changes to all stakeholders. The city noted that it could make additional effort to reach out to those who have not been engaged in the code development process, so they are not surprised nor unprepared for the changes. It was noted that firms in the supply chain and smaller design/build firms are often out of the loop, and that information about code changes does not always get to manufacturers and fabricators outside the urban areas.

Jonlin notes that *“There's definitely a learning curve involved, but our local design and construction teams have learned by now to build these advanced facades as a matter of course. However, the first couple of projects can be challenging.”*

One improvement that Seattle would like to see is curtain wall and window wall design to significantly reduce the heat loss along vertical framing members between vision glazing and spandrel areas.

⁵² <https://seattle.gov/city-light>

Impact

PNNL analysis has shown that Seattle's energy code results in buildings using 30% less energy than comparable buildings constructed to the current ASHRAE 90.1 standard, and 10% better than the current Washington state energy code.

According to Jonlin, *"In the last 12 years the overall annual and peak energy consumption in Seattle has reduced about ½ to 1% per year every year, even though there has been a boom in new building construction."* This is likely attributable to the impact of the energy code on both new and renovated buildings.

Jonlin notes that they do not have an accurate means of evaluating the code's impact on façade performance, since changes take place in concert with changes to other building systems. The 10% UA backstop makes it almost impossible to construct façades with a transparent area much greater than 50%. A 50% WWR is doable, if using high-performance fenestration. He notes that designers manage to keep the glassy look but must be more strategic with daylight and views. There are typically only two types of buildings that are impacted by the window area limitations that the 10% backstop could impose: high-rise residential and high-rise office buildings. Other building types, such as schools, hospitals, or medium-rise offices, have no problem managing the backstop and window area.

Case Study #4: London, UK

Background and drivers

The City of London, UK, is moving much faster towards low-carbon buildings than elsewhere in the UK: There is ten times more sustainable building design work in London than in the rest of the U.K. This is driven by three key drivers:

- **Things owners must do** (regulation and codes) – the City of London's 3-year plan makes a step change in stringency.
- **Things owners like to do** (incentives creating economic benefits) – E.U. green financing for low-carbon buildings provides a valuable incentive for projects funded from European sources.
- **Things owners do because they like to brag** about them (marketing, brand image).

It is interesting to note that, as well as having regulations that are typically more stringent than in most, if not all, of the U.S., along with the political support for them, the market is also asking for sustainable, high-performance buildings and façades to match. There is an interesting dynamic set up where there is competition between many owners for the highest-performance sustainably designed building. Indeed, building performance is being driven "through shame" according to one participant. This also indicates that the public and/or tenants are educated and care about high-performance buildings.

What is game-changing?

- **Regulation:** The Mayor of London's three-year plan provides a step change in the robustness of the documentation required to be submitted before planning permission (building permit) is given. It focuses on both operation and embodied carbon:



Figure 15: City of London, Photo by [João Barbosa](#) on [Unsplash](#)

- **Embodied carbon:** Every large project must provide a calculation of the embodied carbon of the whole building. This opens the discussion of whether to drive renovation or allow demolish and rebuild.
- **Operational carbon:** Energy modeling must show that regulated energy (heating, cooling, lighting, ventilation) is **35% lower than the prescriptive baseline**. Unregulated loads must be reported under a set of pre-defined scenarios.

This is very important for façades because very early in the design process (concept development) there is a requirement to go to the planning board to get some preliminary approvals. While it can seem like a “beauty parade”, it fixes the project’s aesthetics, of which the façade is a key component, which can’t be easily undone. At this early point, the façade is relatively fixed, and so the focus is then on getting it “right”. This early planning review and the stringent energy requirements force façade design to happen much earlier in the design process and more prescriptively than previously.

- **Green funding sources:** Building owners are starting to see the impact of European Union (E.U.) directives on Environmental, Sustainability and Governance. Even though the U.K. is no longer in the E.U.), if funding for a building project comes from a European source, it needs to meet their requirements for energy efficiency. There is cheaper green funding available for projects if they can demonstrate appropriate energy efficiency.
- **Above code outcome-based sustainability standards drag market upwards:** NABERS⁵³, the National Australian Built Rating System, has been adopted in the U.K. The standard was developed to expose the gap between as-designed and as-built performance and to force design teams to make appropriate decisions at the right time. It is a voluntary program which requires buildings to be tested after one year of completion to compare energy performance to predicted energy performance from the original energy model. Stars are awarded **based on the building’s actual energy performance**, which is a unique attribute for sustainable standards. The USGBC’s LEED program does not require such measurement, and studies have shown the large gap between as-designed and as-built^{54,55}. NABERS has surpassed LEED and BREEAM because of the as-built energy performance measurement.

The magic of the outcome-based nature of the standard is that it introduces a responsibility for the quality of the modeling back to early concept design. Rigorous quality assurance processes need to be in place, including for procurement and construction, to ensure that what is designed is built. Because owners don’t want to be ashamed that their building performs poorly, and want “stars”, it unlocks budget for early-stage energy modeling, which is not normally available, and drives a focus on envelope performance. According to one market participant, “the program is driving building performance improvement through shame: Owners want stars!”

Impact

- **Façade design has moved earlier in design process.** The focus on “getting it right” because of early planning approvals for aesthetics **dials in high-performance facades**.
- Green financing **lowers cost barrier** to high-performance
- Outcome based voluntary standard **unlocks budget for early-stage building modeling** to optimize the façade, **improves accuracy of energy modeling**, drives rigorous processes in design and delivery to ensure what is designed is built. It is also driving competition in the real-estate market which drives up façade performance and **encourages innovation and risk taking** “to be the best” in the real-estate competition.

⁵³ <https://www.nabers.gov.au/about/what-nabers>

⁵⁴ https://www.aceee.org/files/proceedings/2008/data/papers/3_320.pdf

⁵⁵ https://rshare.library.torontomu.ca/articles/thesis/Examining_the_performance_gap_in_LEED_certified_MURBs/14646909/1

Case Study #5: Certified Passive House Deployment

Background

Passive house design is a high-performance design philosophy that focuses on these five main building performance principles:

- Highly insulating building envelope
- Airtight building envelope
- Thermal bridge free envelope
- High performance fenestration with appropriate orientation and shading
- Continuous ventilation with heat recovery

Typically, the benefits of a building designed to Passive House standards include not only high energy efficiency but also thermal comfort, indoor air quality, passive survivability, durability and sound insulation.

There are two main certification programs to which buildings can be certified run by the Passive House Institute⁵⁶ (PHI) based in Germany, and Phius⁵⁷, a U.S. based non-profit organization. The Phius program identifies as having more climate specificity than the PHI standard with enhanced cost-optimization, although others argue that PHI is equally climate specific. Note that the name derives from the German “Passiv Haus”, where “haus” means more generically “building”, and is applicable to all building types, including retrofits. It typically results in a building performance that is far superior to typical model code compliant buildings. The impact of this difference on passive survivability during severe hot and cold weather events has been illustrated by recent work by several of the National Laboratories and DOE⁵⁸.

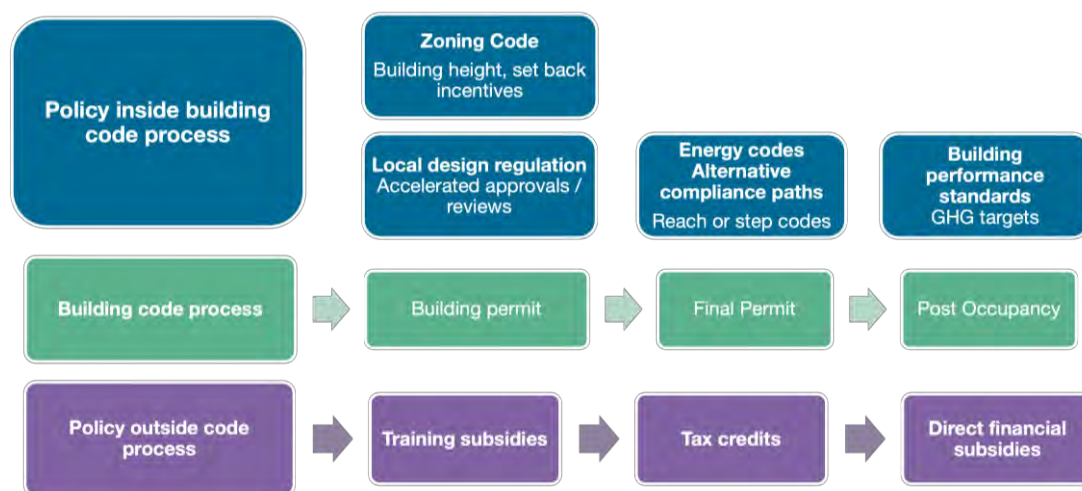


Figure 16: Policy and incentives driving Passive House performance in key markets. Image adapted from the Passive House Network's Policy That Works: An investigation into policies driving Passive House adoption in North America, 2022.

Drivers of Passive House adoption in North America

In 2022, the Passive House Network⁵⁹, a 501(c)3 non-profit focused on the rapid implementation of Passive House building standards in the U.S, analyzed the policies and code-making in three jurisdictions in North America which are ahead in both building energy code stringency and application

⁵⁶ <https://passivehouse.com/>

⁵⁷ <https://www.phius.org/>

⁵⁸ Enhancing Resilience in Buildings Through Energy Efficiency, PNNL-32737 by PNNL, NREL, LBNL, DOE, July 2023; https://www.energycodes.gov/sites/default/files/2023-07/Efficiency_for_Building_Resilience_PNNL-32727_Rev1.pdf

⁵⁹ <https://passivehousenetwork.org/>

of high-performance Passive House standards: British Columbia, New York, and Pennsylvania⁶⁰. They distilled the policies down to the following categories that drive the market.

- **Approved alternative high-performance compliance pathways**, such as allowing Passive House certification. Allowing Passive House Certification removes the “double modeling” barrier that was often necessary to show compliance with the regular code if doing Passive House projects.
- **Framework of incentives and policies** allow alternative compliance pathways to be activated. For example, in Washington state, there is no incentive to accelerate use of their alternative pathway, so there is little passive house adoption. The incentives lie within and outside of the building code process, including direct subsidies, tax credits, training subsidies, zoning incentives, accelerated plan approvals and existing building performance standards (BPS).

Incentives must focus on building capacity in the industry as well as providing incentives for the building owner. They cited training incentives for workforce development (installers as well as design professionals) focused on relevant skill development, as key, as well as providing funding for developers to offset the incremental upfront cost increases and zoning incentives. Providing incentives for manufacturers to develop passive house appropriate fenestration was also noted. The BC Mines program helped create a critical mass of fenestration meeting passive house performance in British Columbia.

- **Setting clear performance targets** (EUI, TEDI), which are measurable and with tools connected to support outcomes, is important. They recommend TEDI because of its focus on envelope performance. They note that typical building energy modeling software used for compliance doesn't work for passive house designs. It is important that tools are available to support the process.
- **Tiered code adoption programs** (like British Columbia's Step Code and Massachusetts Opt-In Reach and Stretch Codes) with weighted incentives directly tied to the long term-target, such as net-zero carbon, connecting voluntary standards and baseline codes.

It should be noted that the City of Vancouver and Massachusetts have leaned heavily upon supporting Passive House standards as helpful vehicles to drive local code transformation. Both jurisdictions readily admit to sourcing their TEDI metric directly from the Passive House standard's heating load target. Additionally thermal bridge modeling and envelope leakage testing protocols have leaned heavily on the muscle built by local Passive House practitioners, whose pioneering efforts have helped establish and build capacity to deliver and implement new code features to these markets.

Case Study #6: The world's first for-profit Living Building Challenge commercial office⁶¹

Previous case studies have identified where codes and regulation have been driving market transformation in fenestration and façade performance. In contrast, this case study, courtesy of Paul Schwer and PAE Consulting Engineers⁶², illustrates a recipe that encourages developers to invest in higher performance buildings.

PAE is a B-Corporation⁶³, focusing on the triple bottom line, with 6 offices on the west coast and over 350 employees. One of their focuses is designing to the Living Building Challenge (LBC)⁶⁴ standard of which they have designed many, including the Bullitt Center in Seattle, the Rocky Mountain Institute's (RMI) Headquarters in Colorado, and the Kendeda Building for Innovative Sustainable Design at Georgia Tech. While PAE designs the mechanical system design, calculates the interior loads, and performs the energy modeling, they rely on the architect to design the façade.

⁶⁰ Policy That Works: An investigation into policies driving Passive House adoption in North America, The Passive House Network, 2022. <https://passivehousenetwork.org/passive-house-reports/>

⁶¹ <https://www.pae-engineers.com/about/pae-living-building>

⁶² <https://www.pae-engineers.com/>

⁶³ <https://www.bcorporation.net/en-us/certification/>

⁶⁴ <https://living-future.org/>

Unique design approach

They have unique, innovative approaches to building design: For the RMI building, the design architect agreed not to design the façade until their energy modeling was started. They first created a code compliant envelope with no HVAC systems and calculated the internal temperatures at the expected extreme outside temperatures. Then they started to improve the façade and iterate the modeling without HVAC systems and, after many iterations, arrived at a minimum internal temperature of 50°F and a max internal temperature of 83°F.

This was in a climate where the winter temperatures can be as low as -20°F and the summer temperatures are in the mid-90s. Optimizing the façade first allowed them to have a very small HVAC system and include natural ventilation. For the RMI building, the entire heating system uses the equivalent of 15 hairdryers – and consists of electric heating under the carpet, and a heat recovery unit. The heating system rarely needs to operate because of the high-performance facade. This approach requires a quad pane in Colorado (RMI) but only a dual pane for buildings in the milder Portland climate.

Developer led buildings: The world's first for-profit LBC commercial building

While owner occupiers have other interests than pure economics including productivity and retention, for developers however, their view is primarily financial and short term. PAE however, found real-estate investors that would invest in a LBC building when PAE was able to demonstrate that they could get tenants to pay more in rent to cover the cost of a more expensive building. PAE became the anchor tenant in this building and was willing to pay a 10% rent premium and commit to a long lease.



Figure 17: PAE's Living Building Challenge developer office building, Portland. Image courtesy of PAE engineers

From their experience he believes that the magic ingredients for developers are:

- **Achieving a 10% rent premium:** Tenants must be willing to pay 10% more in rent. For professional practices where staff costs dominate, they feel that increasing rent by 10% is not a big stretch, especially if the environment can reduce turnover, increase productivity and improve recruitment. PAE convinced their board of directors to invest in a 10% higher rent based on achieving a projected 2% reduction in turnover or 2% increase in productivity. It only took one of those 2% options to pay back the entire rent increase. They believed in the impact on productivity and retention by creating a well-daylit, comfortable environment for their staff.
- **Hold for 10 years:** Investors must be willing to hold the building for 10 years. In opportunity zones, investors pay no capital gains when they sell if they hold their buildings for 10 years, which can incentivize building retention. There is an opportunity to expand the use of opportunity zones with a capital gains exemption and there are hundreds of designated opportunity zones in cities across the U.S.
- **Nominal 10% (8.33%) Internal rate of return (IRR)⁶⁵:** Investors must accept a slightly lower return on their investment compared to typical commercial buildings, which they estimate at 12% IRR. In the case of PAE's own building the IRR calculated was 8.33%, which they round up for ease of remembering the formula 10/10/10 (Schwer notes that Investors cringe when they round up 8.33 by 170 basis points to 10%). The sales price of a building is generally based on its net income. If the anchor tenant signs a 15+-year lease, they have revenue guaranteed for 15 years which is over the 10-year opportunity zone holding periods needed to take advantage of the capital gains tax exemption. There is an opportunity to develop incentives to encourage tenants to sign long leases alongside capital gains exemption incentives.

The resultant building is net-positive energy, with a carbon negative lifecycle, net zero water, and the resiliency of a 500-year building. The developer was Edlen & Co., Architect: ZGF., GC: Walsh Construction Co., with engineering by PAE.

They have published a book based on their experiences in building the world's first for-profit commercial building built to Living Building Challenge standards⁶⁶. The book includes a full financial analysis.

As mechanical engineers they recognize that façades last much longer than mechanical systems and thus may require a greater investment than mandated by code, and they then cleverly created alternative but acceptable financial incentives for the owner to provide the increased investment needed for the façades, optimizing their longer-term investment.

⁶⁵ <https://www.investopedia.com/terms/i/irr.asp#:~:text=IRR%2C%20or%20internal%20rate%20of,same%20formula%20as%20NPV%20does.>

⁶⁶ <https://www.amazon.com/PAE-Living-Building-Developer-Led-Nature-Inspired/dp/1736212907>

Recommendations to address key barriers

From our stakeholder roundtables, case study evaluation and one-on-one interviews, many opportunities to address the barriers have been identified. The full list is detailed in Appendix C for reference. They were initially grouped into several categories:

- **Incentives: Strategies and program concepts**
- **Tools, metrics, and criteria development**
- **Programs and policy**
- **Capacity building: Education and training**
- **Energy codes and compliance**
- **Product innovation**

From this list of potential opportunities, combinations of ideas have been created that are recommended for consideration for support by DOE. Many concepts need more work to evaluate and analyze in order to more fully assess feasibility and develop an appropriate path forward. We have identified what potential next steps would be and have suggested appropriate partners to support and/or lead the recommended work.

Our recommendations include immediate, short-term activities with target sectors, key stakeholders, influencers and potential partners, and longer-term opportunities. We have ignored barriers where we believe that there is low probability of affecting change and/or those not aligned with DOE's mandate, such as changing the cost of energy and influencing political will.

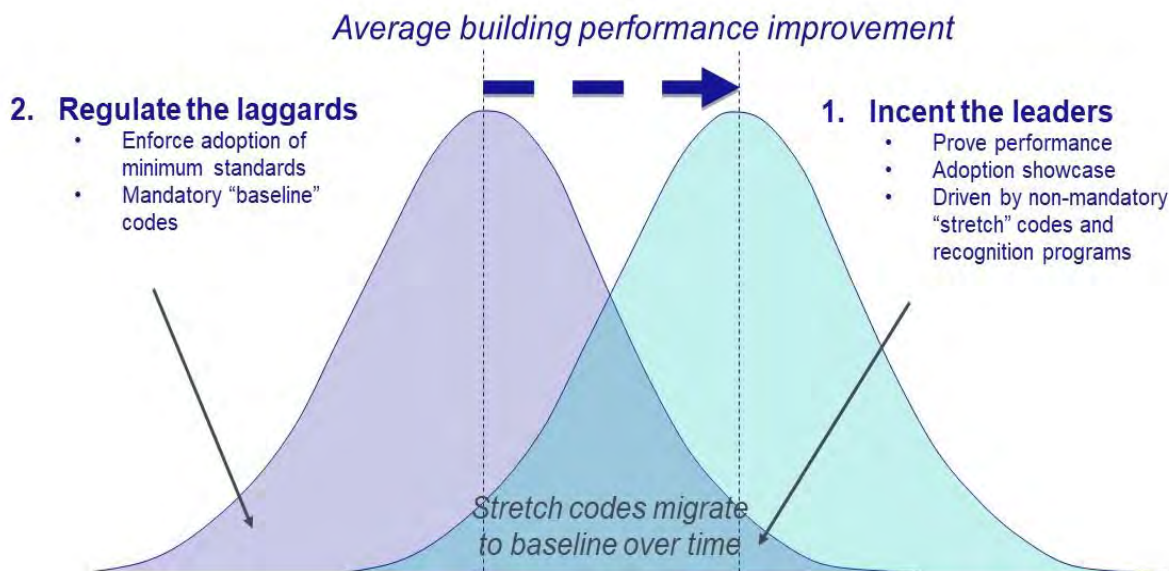


Figure 18: How stretch codes and above code programs can move the minimum codes over time

There are two main approaches to take to driving adoption that can be used individually or in tandem to move the market:

- 1. Incentivize the top end** of the market to create capacity, knowledge, and demonstration. The idea is that this work will eventually pull the bottom end of the market up bringing previously-exotic

technologies into the realm of business-as-usual. The speed of impact depends on the combination of above-code standard and incentive. The Energy Star® residential window program has been very effective in driving the residential window market by not being overly stringent and tied to valuable tax credits (see figure 8 above).

2. **Pull up the bottom end** of the market through regulation. Levers include accelerated state-wide adoption of the latest model codes and increasing their stringency as it relates to façade systems. The adoption of building performance standards (BPS), cap energy use or carbon emissions of existing buildings and act as de facto outcome-based code. With enough teeth, these BPS can encourage façade retrofits and drive above-code performance in new buildings to future-proof designs.

We believe a combination of the two strategies are needed to drive the needed change. In the words of Duane Jonlin from the City of Seattle, *“the only places you’ll find high-performance buildings being consistently constructed at massive scale are those places where it’s the only way to get a building permit”*⁶⁷.

A third strategy complements these two:

3. **Celebrate Success.** A very small fraction of the market today is already delivering buildings with high performance façade solutions. These typically involve motivated, leading building owners who have signed on to carbon pledges and sustainability goals, who have the resources to invest and the interest in promoting healthy workplaces, and have employed a team of architects, engineers and consultants to deliver on their vision. These projects should be identified, performance documented, and the lessons learned extrapolated so that key learnings related to high performance facades can be promoted in a much wider range of projects. It is much easier to sell a new idea if there is a proven success and real-world partners to work with.

Within each of these strategies are an array of programs, tools, innovation and education that must be provided to overcome systemic barriers to enable their success. Incentives and regulations require support from tools, training programs, standards etc.

The first four barrier-reducing concepts constitute an attempt to overcome the first-cost barrier without addressing code adoption, compliance, or stringency. Intertwined are aspects that also address perceived risk and capacity building. Concepts 5 and 6 target quality, consistency, education and capacity building. Concept 7 explores incentives and concept 8 explores opportunities in model energy code and standard development. Concept 9 explores façade retrofit solutions.

Concept 1: Develop an above code certification program for high-performance façades that can be referenced by incentive programs to drive market deployment.

Barrier(s) addressed: Barrier 7.7 “Insufficient capacity to design better façades because there is no performance standard for high performance façade / fenestration”. Facilitates addressing barrier 2: “Insufficient payback/ROI on increased first cost” where a certification or performance standard can be referenced as a target by incentive programs.

⁶⁷ Duane Jonlin, “No timid steps: Be bold and generous!”, Façade Tectonics Institute, July 13, 2021: <https://www.facadetectonics.org/articles/no-timid-steps-be-bold-and-generous>

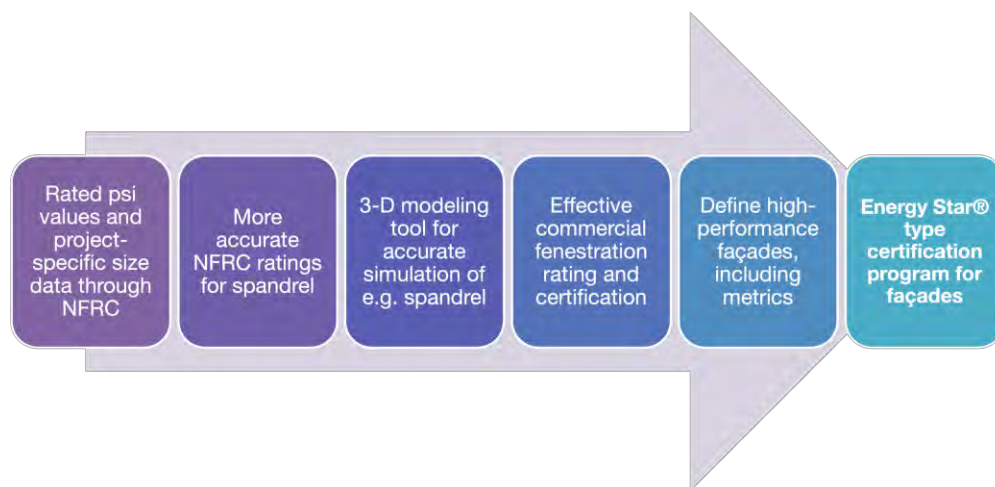


Figure 19: Concept 1 summary – Develop an above code certification program with foundational programs and tools.

1.1 Certification program for façades

To enable incentives to be put in place for high-performance façades, a definition of what constitutes a high-performance façade is needed, and that performance should be third-party validated to ensure performance is met. Consider a certification program for non-residential and multi-family façades as a solution. This could be managed by EPA as part of its Energy Star® program or achieved by another route. Such a program eliminates the barrier caused by not having a performance standard for incentive programs to reference.

Note that the National Fenestration Rating Council (NFRC) certifies the thermal, solar gain and visible light transmission performance of fenestration assemblies. The definition of high-performance non-residential / multi-family façades has a broader scope in terms of assemblies (includes non-glass opaque and glazed assemblies) and performance (comfort, daylight, etc., related, as well as energy related, and interface performance), but requires an effective certification for fenestration thermo-physical data from NFRC.

As noted previously, the Energy Star® certification program for residential windows has worked exceptionally well in combination with tax credits to move the residential window market to installing windows that consistently have a higher performance than mandatory code. As of 2023, the Energy Star windows program has consistently had a market share of 80% or more for the last decade, despite increasing stringency. The challenge will be to see if the overall structure of the program can be successfully adapted to the differing needs of the non-residential sector.

To enable an above code certification program for high-performance façades, the following would also need to be established as foundational:

1.2 A definition and metrics for high-performance façades.

For non-residential and multi-family buildings, the definition of high-performance varies depending not just on climate zone, but on orientation, building type/use case, structural requirements, and façade system chosen. As a result, the challenge to define a performance standard will be significantly more challenging than for windows in single family homes. This is therefore not an easy undertaking and will require significant analysis, creativity, and collaboration across industry participants to address the challenges.

The definition of high-performance façades could take the form of a design guide (like GSA's P100) or a more formal compliance standard with several levels of performance, the highest of which could be

aligned with net-zero operational carbon. To leverage the work of other groups, the guide could reference standards already in place that have been developed for individual performance items with or without amendments. These may include, for example, the daylighting, views and comfort criteria in LEEDv4 and in ASHRAE189.1. Jurisdictions such as City of Seattle, Massachusetts, New York State and City of Vancouver have already provided concepts for defining envelope thermal performance, air-leakage, and thermal bridging. These programs can be sources from which to compile a façade performance guide or standard.

A set of metrics will need to be agreed upon to allow the quantification of high-performance, including thermal and solar control, thermal resilience, moisture and condensation control, daylighting and thermal and visual comfort metrics as well as energy demand.

In the absence of a certification program, a high-performance façade guideline or standard could still be referenced by incentive programs. Those programs would need to find ways to verify adherence to the standard. As such, this proposed guideline or standard is foundational to the success of other programs and strategies.

Who: With funding support from DOE, the Façade Tectonics Institute has the breadth and depth of expertise in façade performance to lead in developing the high-performance façade standard/guide in collaboration with building simulation support from the U.S. National Laboratories. Other interested parties include the American Institute of Architects, US Green Building Council, Building Enclosure Council, the North American Passive House Network (NAPHN), the Fenestration Glazing and Industry Alliance (FGIA), the National Glass Association (NGA), the Air Barrier Association (ABAA), the Rainscreen Association in North America (RAiNA), the Institute for Market Transformation (IMT), and the New Buildings Institute.

1.3 The successful deployment of the NFRC's non-residential fenestration rating, labeling and certification program.

In 2024, NFRC will launch a new non-residential certification program that is expected to replace the existing program offerings that had low adoption because of cost, schedule, complexity and enforcement. DOE could provide resources to promote adoption of the program by states and local entities around the country and for the development and deployment of training programs for code officials, consultants, architects, and other key stakeholders for the new program, and feedback loops to further improve the program as needed. A process to validate the effectiveness of the implementation of the NFRC non-residential certification program would also be helpful to assure that it is sufficiently easy to use. This could be through post-launch market surveys and analysis. The gathered data would then inform making needed adjustments to the process.

Who: NFRC with support from DOE.

1.4 Three-dimensional thermal modeling tool (to update THERM) that facilitates accurate simulation of complex assemblies, like spandrel areas to support high-performance building standards

LBNL's THERM tool is used ubiquitously to calculate thermal performance of fenestration and façade assemblies and is an integral part of NFRC certification. It is a 2-D model which lacks the ability to capture all the necessary thermal bridging in more complex 3-D assemblies like spandrel panels, where it significantly overestimates thermal performance. A transformation to an easy-to-use three-dimensional thermal modeling tool is critical to achieving more accurate façade performance simulation. This supports not just the proposed façade certification program, but also facilitates other high-performance building standards. LBNL has explored the development of such a tool, and we encourage DOE to make this a major focus area by financially supporting its rapid development and providing on-going training and support. The new THERM 8 includes moisture transfer and transient modeling to assess moisture conditions. Moisture transfer analysis is critical as it allows

evaluation of the impacts of humidity and resultant risk of condensation and mold growth. A training component should also be included as participants have noted that THERM only gains traction if professionals can receive training, and the output uses parameters that then fit into the modeling software they are required to use.

Who: LBNL with support from DOE and other collaborators that can provide training and alignment with software.

1.5 More accurate NFRC ratings for spandrel

With a validated 3-D version of THERM available, the thermal performance of spandrels can be more accurately reflected in NFRC ratings and labels. NFRC will need to update their processes to require the new version of THERM, which will include validating and approving the software. Since some of the THERM updates will be too advanced for the industry at large to learn to use and 3-D Therm may take a long time to develop, NFRC should consider alternative means of reflecting the real performance of standard thermal bridging options in their performance ratings using, for example, standard de-ratings. Research will be needed to develop such de-ratings. Input from the research work being done by the Charles Pankow Foundation should be considered to support this work.

Who: DOE could fund any additional research on the derating of spandrel performance and incorporate input from the current research being completed by the Charles Pankow Foundation research, and the consultant firms involved in this research (Simpson Gumpertz and Heger, RDH Building Science, Morrison Hershfield). NFRC would incorporate the output into their ratings with support from LBNL.

1.6 Validated ratings for psi-values for the window/wall (psi-installation), glass/frame (psi-spacer) linear interface and fenestration project size specific performance data

To support the need to address thermal bridging, the linear thermal conductance, often referred to as the psi-value, of the window/wall interface is critical to determine. The window/wall interface psi-value and that of the insulating glass/frame interface (psi-spacer) is also important for facilitating those jurisdictions that allow passive house as a compliance path.

Psi-spacer values are ubiquitous in Europe, and European window manufacturers have no problem in supplying this data for projects in North America. However, for local manufacturers who use the NFRC rating process, providing these psi-values is more challenging. Values for psi-spacer can be derived from the data used to generate NFRC ratings, but they are not collected, validated nor rated by NFRC. Having validated translation procedures and rated psi-spacer values would provide North American window manufacturers access to more Passive House designed projects.

Without addressing this particular hurdle, North American manufacturers are less able to compete with the increasing volume of cheaper high-performance fenestration imports from Europe, where economies of scale have already been achieved.

In addition, more jurisdictions (British Columbia, Massachusetts) are asking for size-specific fenestration performance data to be used in building energy simulation for compliance because it results in more accurate results, and better equipment sizing. It is likely that more will follow. At the current time, NFRC only provides certified data based on standard sizes – this allows fenestration assemblies to be compared. However, NFRC is currently working on a tool to provide size specific data for certified products, which they believe should be available before the end of 2024. It will also be important for model energy codes to recognize size-specific data as appropriate inputs for performance path compliance, rather than using data based on model sizes.

Who: NFRC, with support from LBNL to add features to the NFRC modeling tools and experts such as façade consultants (Simpson Gumpertz Heger, RDH Building Science, Morrison Hershfield) and the Passive House Network.

Concept 2: Create tools and programs that improve the ability to communicate the overall economic value of high-performance façades to owners.

Barriers addressed: Barrier 2.2: Insufficient ROI or payback on initial first cost increase because of simplistic payback models; Barriers 2.5 & 7.6 Architects/consultants have limited capacity to calculate non-energy benefits to advocate for better façade design.

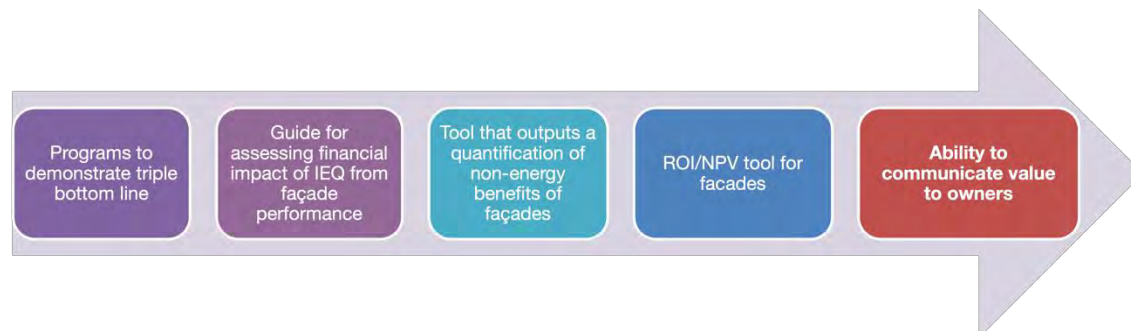


Figure 20: Concept 2 summary – Improve the ability to communicate value to owners.

2.1 Develop a credible, interactive, easy to use return on investment (ROI) and net present value (NPV) tool

This tool would be designed to support communication and quantification of the non-energy benefits of investing in high-performance fenestration/facades to building owners and developers. Such a tool would allow design teams to easily present to building owners/developers and tenants the estimated ROI and/or NPV on their increased investment in façade performance. It would include all aspects of a high-performance façade, including operational energy and carbon, HVAC size reduction, reduction in perimeter heat and cooling, estimates of the dollar value of employee productivity, attraction and retention of staff and tenants based on thermal and visual comfort and indoor air quality, the impact of façade durability, leasable space increase, lease rate increases, etc.

Step one would require a scoping and feasibility analysis to thoroughly understand the user audience, technical challenges and develop a roadmap. The outputs of the schematic design façade analysis tool described below could input into this tool to provide a holistic schematic design tool that evaluates different façade designs and outputs quantitative estimates of benefits (with uncertainty ranges).

Who: The National Laboratories, funded by DOE, to provide credibility with inputs from existing human factors research and with support from expert domain researchers and façade and mechanical design practitioners.

2.2 Develop a schematic design façade analysis tool that outputs energy and non-energy benefits

The goal of this tool is to allow design teams to do quick and easy analyses of a range of envelope systems in the early design phases to compare their performance against a range of metrics. It would output comfort and daylighting metrics, energy and peak demand estimates, HVAC size impacts, and perimeter heating and cooling requirements. The tool would be used to quantify the impact on thermal and visual comfort and daylighting of the façade (percentage of the time uncomfortable, daylit etc.) to support owner education and more sophisticated cost-benefit analyses. This tool could feed into the NPV/ROI tool (2.1) to quantify the full financial impact of different façade options, including non-energy benefits. COMFEN was developed by LBNL with DOE support and guidance from facade consultants. It provides many of these features with underlying energy data from EnergyPlus and Radiance but has not been updated in many years. Honeybee⁶⁸

⁶⁸ <https://www.ladybug.tools/honeybee.html>

tools also provide integration between daylight and energy modeling. These tools might be used as a starting point to explore development options and determine a final development plan.

Who: The National Laboratories, funded by DOE, could lead this activity with input from industry organizations, such as FTI and its members, and are best placed to integrate with their existing tools.

2.3 Create a guide for assessing the financial impact of non-energy benefits from façade performance

This guide would provide a framework for monetizing the impact of non-energy benefits such as comfort, daylight, passive survivability, grid resilience, HVAC size reduction, peak demand reduction, reduced carbon emissions etc. Along with the schematic façade design analysis tool, this would help define the inputs and calculation basis for the NPV/ROI tool.

Who: Then National Laboratories, funded by DOE, could lead this activity along with input from industry organizations such as FTI and its members.

2.4 Create programs for owners that help demonstrate the triple bottom line and what success looks like in real buildings

Funding more case studies across a range of climate zones and building types that demonstrate the triple bottom line (economic, environmental, and social) benefits is key to demonstrating to building owners that investments can pay for themselves and minimize perceived risk. Before and after comparisons or comparisons with minimally code compliance building stock are important as are post-occupancy assessments to demonstrate and quantify the triple bottom line impact. This data can feed into the ROI/NPV and schematic design tools.

There are several programs that currently support demonstration of the performance of new building technologies at the whole building level, such as GSA's Green Proving Ground (GPG) and Design Excellence Programs. There are also previously funded efforts to assess facade performance in new or renovated buildings such as the New York Times headquarters building in New York City⁶⁹. The Buildings of Excellence program in New York State⁷⁰ and Mass Save's commercial building incentive program⁷¹ offer other benchmarks for high-performance buildings. These programs could be referenced to create a nationwide "facades of excellence" program, with funding from DOE, utilities and state sources. In most cases, funded projects would be required to provide or support the generation of high-quality post-occupancy data.

The PAE Engineers living building case study⁷² would be an example of a project that was able to demonstrate the developer economics for the creation of a significantly above code office building, that could be used as a model.

Such programs could require façade performance based on the definitions of high-performance façade (different levels) in concept #1 and which could demonstrate the differences between performance levels.

Who: The GSA, as the nation's largest landlord, is well placed to continue and expand upon its past programs and field studies. As collaborators, DOE and the National Laboratories could, as they do with the GPG, support the measurement and verification of performance. The Center for the Built Environment at UC Berkeley could also provide expertise in post-occupancy survey and measurement of comfort

⁶⁹ https://facades.lbl.gov/newyorktimes/nyt_overview.html

⁷⁰ <https://www.nyserda.ny.gov/All-Programs/Multifamily-Buildings-of-Excellence>

⁷¹ <https://www.masssave.com/-/media/Files/PDFs/Business/2022-MS-NC-Summary-Overview-1222-Final.pdf>

⁷² <https://www.pae-engineers.com/about/pae-living-building>

Concept 3: Make windows the next “marble countertop” – a must have for owners and tenants alike

Barrier(s) addressed: Barrier 2.1 – Owners can’t get a lease rate premium for high-performance façades.

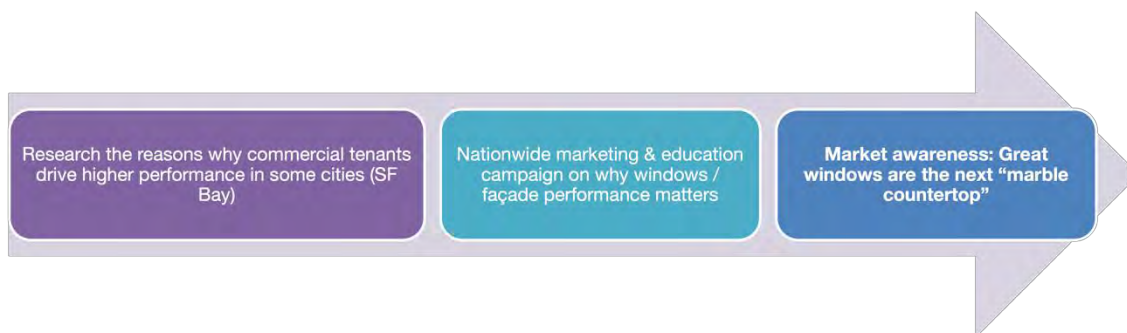


Figure 21: Concept 3 summary – Increase market awareness and desire to make high-performance windows into a must have for tenants and owners.

One of the largest barriers to developers not investing in higher-performance façades is that their potential tenants are not asking for it, do not appreciate the benefits and thus are unwilling to pay a higher lease price. Fenestration is often on a developer's radar, but primarily related to the provision of views, and control of cost, with little consideration to the impact on energy, comfort, resilience, or carbon. Consider requiring thermal imaging for existing and new buildings to identify lower or higher-performance fenestration products. These commonly available tools enable better visual communication to the market.

3.1 Launch a marketing program on why windows matter in non-residential and multi-family residential buildings

A marketing program, targeting owners and tenants of non-residential and multi-family residential buildings, focused on why windows are important and why should care about and demand higher performance from their windows and façades, could make a big difference to the market dynamics.

Floor-to-ceiling glass is a clear market “want” which developers respond to, but which is typically at odds with delivering comfort and energy efficiency, if the façade is not high-performance, as often is the case. The floor-to-ceiling glass trend needs to be turned into a desire for fantastic views delivered alongside *comfortable, well daylit, energy efficient, and resilient* spaces. To quote one roundtable attendee, we need to “find ways to encourage people to want their façades to be as good as they want their phones to be!”

Optimizing the design of fenestration and façades is a lot more complicated than heat pumps and LEDs, and so communicating the message is that much more challenging. It will require the expertise of a professional marketing agency skilled in business-to-business and business-to-consumer marketing, using social media and other channels to create grassroots awareness with building occupants (the public) as well as decision makers in tenant businesses (C-suite occupants).

The data from concept #2 derived from case studies and used to develop the ROI/NPV tool can be utilized in this program.

Who: External marketing agency in collaboration with category experts, such as those at the Façade Tectonics Institute and perhaps other groups like the Partnership for Advanced Window Solutions (PAWS) and industry groups like FGIA, NGA, NFRC.

3.2 Research the decision dynamics of the leading-edge property development ecosystem which already builds high-performance façades

The San Francisco Bay area already has an ecosystem of developers and large technology and biotechnology companies who are willing to pay extra for high-performance, sustainable buildings. Examples of building owners and tenants willing to invest include Genentech, Google, Apple, and Salesforce to name a few who have systematically invested in higher performance buildings. These companies already believe in the impact of building comfort and daylight on their employee's productivity and upon their attraction and retention. They also have supported an ecosystem of architects, engineers, consultants, facility managers etc. whose expertise can be transferred to other clients. To inform the overall marketing initiative, research could be done to understand the drivers of this ecosystem in the Bay Area. The blueprint uncovered could be used to replicate it elsewhere and/or used in the marketing campaign.

Who: The Façade Tectonics Institute could identify and work with the drivers of the Bay Area ecosystem to understand and document these market dynamics and recipe for market movement.

Concept 4: Ensure there is sufficient selection of high-performance curtain wall and window wall systems and trained installers available for a competitive market

Barrier(s) addressed: Barrier 1.3 – Insufficient solutions for competitive market. Helps by increasing the number of competitive products to address the 3-equivalents request and to manage price premium (Barrier 1.2) through competition.

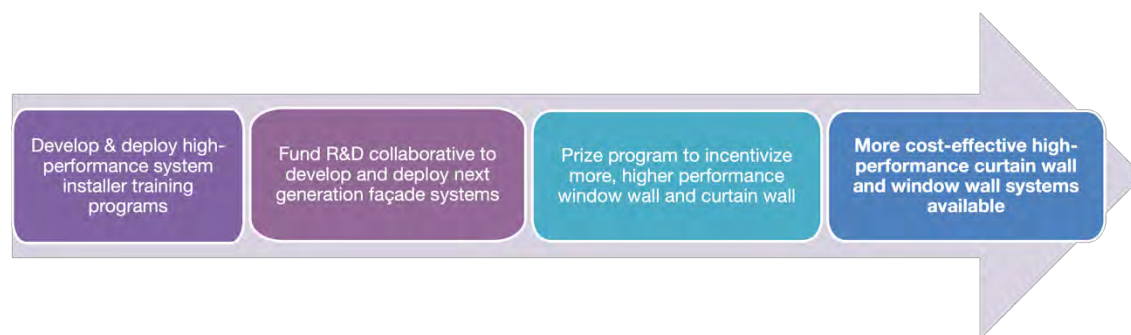


Figure 22: Concept 4 summary - Ensuring there are more cost-effective fenestration systems available through cross-cutting programs.

In places where building codes are moving more quickly, and/or the market would be willing to use higher performance if it were more cost-effective, it is reported that there are insufficient options for high-performance curtain wall or window wall to create a competitive market. Installers are unfamiliar with how to install new systems which adds to the cost premium. As a result, often higher performance systems are value-engineered out of the design. Interviewees noted that curtain wall has fallen significantly behind the needs of the market where code stringency is highest (e.g. Massachusetts, British Columbia) and needs to get much closer to the opaque wall thermal performance. They point to Europe, where higher performance precast concrete, GFRC and UHPC mega-panel approaches (that make installation easier) have displaced traditional unitized curtainwall.

4.1 Prize program for high-performance curtain wall and window wall

DOE could create and fund a development prize award program, like that which was successful in British Columbia, where relatively small prizes (say \$50K-\$100K) were given to several companies to develop high performance fenestration to create a critical mass of products on the market. This could incentivize several manufacturers to bring products to the market by reducing the investment needed, although the prizes are normally modest compared to product development costs. As

precedents, DOE has recently launched a prize program for secondary window systems⁷³ and in the past for other products like LEDs.

DOE could also provide additional funding for the necessary performance and durability testing once products meet certain criteria. The cost of testing is often a hurdle to market entry.

To further support product commercialization, the GSA could commit to using successfully developed products in new or retrofit projects (or in the “facades of excellence” program proposed in concept 3) once they meet certain performance targets. This would provide entry into the market for first product demonstrations and proof points. This might be an expansion of the existing GSA Green Proving Ground (GPG) program that has demonstrated innovative glazing/facades in its buildings over the last decade.

Who: DOE/GSA would create and manage the award program as they do now with GPG. FTI membership could support to help define the performance requirements. GSA could provide commercialization opportunities to validate the products.

4.2 R&D Collaborative to develop and deploy next-generation façade systems.

The DOE has funded individual projects at National labs, universities and private companies on the broad topic of high performance facades, but it could create and fund a broader R&D collaborative that creates a network of academics, practitioners, and industrial supply chain partners, pulling together a critical mass of knowledge and capability across multiple disciplines to develop practical high-performance façade assemblies and systems, train façade engineers and disseminate information. A similar program for an adaptive façade network was funded in Europe from 2014 to 2018 by the European Cooperation in Science and Technology (COST).

Such an initiative would need clear goals and deliverables aligned with market needs and would leverage multiple public and private partners to deliver results that any single entity could not. The collaborative would represent a cross section of the industry including manufacturers, fabricators, architects, engineers, consultants, specifiers, owners, building code representatives spanning local and federal levels. It would be North American focused, but with input from other key global players.

Who: With funding from DOE, an organization such as FTI could help organize and manage such a collaboration due to its broad membership structure and collaboration with European groups. The collaborative could leverage staff and testbed facilities at LBNL and other national laboratories and at a U.S. university which has a critical mass of academic and research activity in façade engineering.

4.3 Develop and deploy an installer training program

DOE could support the development of an installer training program for high-performance fenestration (and façade assemblies as appropriate), including addressing thermal bridges and air/water/vapor barrier continuity at wall interfaces and quality assurance. This would reduce the risk premium added to new systems quoted and reduce the risk of substitutions or no-bids by contractors.

Who: Collaborate with the Architectural Glass and Metal Certification Council (AGMCC) which runs the North American Contractor Certification (NACC) and the Architectural Glass and Metal Technician Certification programs to create the training program. Input from glazing contractors, façade consultants and high-performance system manufacturers would also be needed. It is recommended that DOE fund or subsidize deployment of the training to ensure greatest field impact of the investment.

⁷³ (<https://www.herox.com/envelopeprize>)

Concept 5: Create and/or identify certification programs for practitioners to verify competence, build capacity and improve facade simulation, design and execution.

Barrier(s) addressed: Barrier 7.2 Insufficient qualified façade consultants / engineers. Barrier 5.5 Inadequate energy modeling.

The goal of developing certification programs for façade design and implementation professionals, and their referenced standards, is to drive standardized, robust education and ensure a certain level of quality in façade design, simulation, and commissioning (figure 23). Jurisdictions and other entities can provide incentives aligned with certification to build capacity in their local markets. Codes could also be written to reference simulations and commissioning be carried out by certified professionals. Architectural specifications could also be written to require certified professionals to complete commissioning. In this way, a certification program in combination with these market dynamics, could drive an increase the number of qualified professionals and the quality of design, simulation and

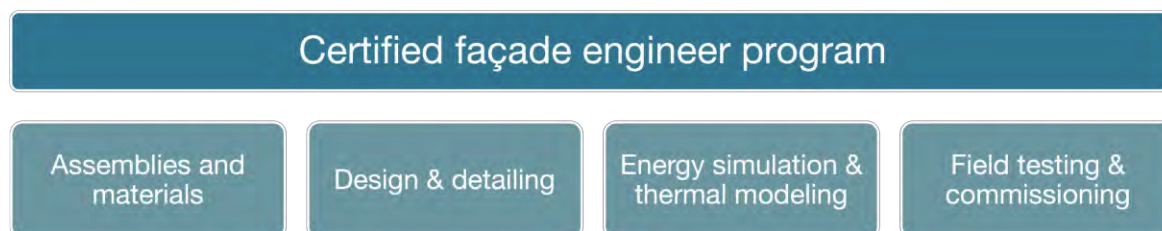


Figure 23: Concept 5 summary – Example of potential modules and topics in a façade engineer certification program

construction quality control.

5.1 Develop a certified façade engineer program

Such a program would create a full, practical education program that builds capacity in the industry to design, engineer, supervise installation, and commission high-performance façade systems. It would include specific training for field testing and commissioning, including air-leakage testing, energy simulation and thermal (THERM/WINDOW) modeling, education on fenestration and wall assemblies, materials and façade design and detailing, along with a certification program to verify competence.

There are models for certification programs that can be benchmarked from other fields and other countries to support development. The certified façade simulator module could be a standalone certification program for those whose focus is building simulation. The façade commissioning topic could also be available for certification in isolation for installers and individuals whose jobs are more narrowly focused in this area.

The first phase of work would be to scope out an educational program and a certification process, benchmarking current programs in façade engineering education, adjacent engineering fields and façade-related professional education globally.

Furthermore, there are at least two commissioning certification programs focused on whole buildings: The Certified Commissioning Professional (CCP) by the Building Commissioning Certification Board⁷⁴ and the BCxP certification by ASHRAE⁷⁵. A review of these existing building commissioning programs is recommended to identify if they already appropriately cover façade

⁷⁴ <https://bccbonline.org/>

⁷⁵ <https://www.ashrae.org/professional-development/ashrae-certification/certification-types/bcxp-building-commissioning-professional-certification>

commissioning and if there are opportunities to add content to them to adequately educate commissioning engineers whose focus is primarily on the MEP systems.

ASHRAE also offers a Building Energy Modeling Professional Certification⁷⁶. The first phase of the work would examine the current situation regarding energy simulation certification, any gaps related to the façade and how best to close gaps and integrate them into the façade engineer certification program. Another potential partner is the International Building Simulation Association (IBPSA)⁷⁷ which has a long record of collaboration with DOE and with AEC partners to enhance the role of simulation in the AEC world and provide a variety of training and support resources.

DOE could support widespread deployment of the façade engineer certification program, and modules thereof, by funding or subsidizing the cost of training and certification to build capacity. It could also follow that certified façade engineers would be required by architectural specifications to carry out commissioning, supervise installation, carry out simulations etc. to ensure quality assurance, and ideally, required by code where, for example, façade commissioning is mandated.

Who: The Façade Tectonics Institute, with funding from DOE, has the expertise and global connections to do this scoping activity. FTI's education committee has recently published a summary of current façade education in North America which can provide a place to start⁷⁸. A National Laboratory team could coordinate a review the current state of façade content and training within current building commissioning programs in collaboration with FTI members and with existing commissioning certification program operators.

5.2 Develop a standardized process for simulating facades in building energy simulations in support of codes

In order to have a certification program for simulating façades, a standardized procedure is required. Like that implemented by the city of Vancouver, a standard procedure for simulating façades is needed. Such simulation procedures would ensure that linear interfaces and point thermal bridges are modeled, clarify the use of project size specific fenestration performance data and how to source it, and identify other areas for standardization. Once in place, it could be available to be added as a requirement for performance path code compliance in model codes.

The DOE could support the development of the procedure and the integration into the model codes.

Who: One of the National Labs which has expertise in building simulation could coordinate this work, with support from FTI and its members and other interested parties, such as the International Building Performance Simulation Association⁷⁹ (IBPSA).

Concept 6: Increase façade knowledge and education across the full value chain

Barrier(s) addressed: Barrier 1.2.1/3.2 – Lack of trained installation labor adds risk; Barrier 1.2.4/3.4 – subs lack knowledge of installation and benefits of new systems; Barrier 1.1.1 – Lack of local knowledge causing slow state adoption of model codes (policy makers); Barrier 7.1 – Lack of understanding of fenestration & façade performance at architects/consultants; Barrier 7.2 – Insufficient qualified consultants; Barrier 6.3 – Code officials have insufficient training and time to enforce fenestration requirements; Barrier 2.5 – Lack of knowledge of non-energy benefits (owner/developer); Barrier 3.3 – lack of knowledge of new / different products & benefits by architects and contractors.

⁷⁶ <https://www.ashrae.org/professional-development/ashrae-certification/certification-types/bemp-building-energy-modeling-professional-certification>

⁷⁷ <https://ibpsa.org/>

⁷⁸ The State of Facades Education in Academic Institutions: U.S.-Based Perspectives, Façade Tectonics Institute, May 2023. <https://www.facadetectonics.org/publications/collection/publications>

⁷⁹ <https://ibpsa.org/>

This concept addresses the knowledge gaps across the entire ecosystem (figure 24). Solutions for some of the education gaps have been proposed in other concepts such as (1) Marketing program for building occupants and owners in #3, (2) the façade engineer certification program (#5) and (3) the installer training program (#4), so they will not be discussed at length here. Each participant group requires its own targeted training and deployment program.

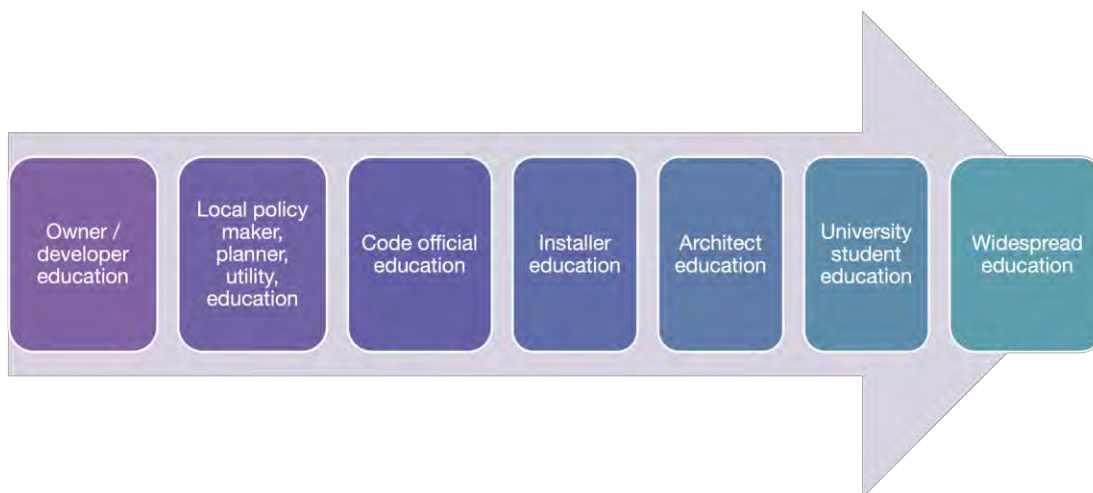


Figure 24: Concept 6 summary – Increase education and knowledge of high-performance fenestration and façade systems across the value chain.

6.1 Owner/developer:

See Concept #3, focusing the message on the importance of the building envelope especially on durability, passive survivability, resilience, daylighting, comfort, productivity, health, lease rates, perimeter heat/cooling system offsets, rentable space, and how to quantify it alongside energy savings and upfront cost.

Who: Partner with organizations such as the Building Owners and Managers Association (BOMA)⁸⁰ who have a keen interest in these topics.

6.2 Local policy-makers, planning committees and utilities:

Policy makers choose to adopt model codes and/or incentive programs at the state and city level. Utilities are also included in this demographic since they enact energy efficiency incentive programs. Education programs directed at those policy-makers are needed to build knowledge and confidence in adopting newer model codes and developing appropriate incentive structures to build capacity in the market.

Local planners and planning committees need to be educated on the issues related to retrofits versus demolition and reconstruction, to support more informed policy related to retrofits and disincentivizing demolition.

There is a gap in understanding the impact of façades by the utilities who develop incentive programs for reducing energy consumption in buildings, and the lack of fenestration or façade related incentive programs underscore this. Educating this segment of stakeholders could increase the awareness of the importance of façade system, thereby increasing the number of façade- and/or window-focused incentives for non-residential buildings.

⁸⁰ <https://www.boma.org/>

The insurance (and finance) industry has the potential to play a large role in supporting risk mitigation for new products and systems that deliver climate adaptation and mitigation (see concept 7.3). They could also be included in the target for education.

Who: Organizations such as the IMT⁸¹ and the New Buildings Institute⁸² are already working at the local level and would be great partners for this work as would the Regional Energy Efficiency Alliances, such as the Northwest Energy Efficiency Alliance (NEEA)⁸³, the Midwest Energy Efficiency Alliance (MEEA)⁸⁴ and the Southeast Energy Efficiency Alliance (SEEA)⁸⁵. FTI could support developing the façade related education.

6.3 Code official education and capacity building:

Increasing both the knowledge and the number of code officials focused on energy code enforcement is critical to improving code compliance. An education and awareness program is needed, that would include, for example: the impact of high-performance façades, how to identify thermal bridges, the NFRC non-residential certification requirements, how to review façade details for compliance, new model code requirements and how to enforce them, etc.

Finding alternative ways to fund state and city code offices, mirroring that of the City of Seattle or alternative structures, could also significantly increase their capacity to adopt and amend the newest model codes and to effectively enforce them.

Who: The National Labs could coordinate a group of organizations, including NFRC, FTI and its members, and the certifying body(ies) for code officials who already deliver training to code officials, to develop and deploy this training.

6.4 Installer and contractor education:

See concept #4. Develop advanced training for installers to support installing high-performance systems. In addition to the certification route described in #4, another route for supporting installer education could be modeled on British Columbia's approach, where a vocational college, the BC institute of Technology, drove practical education by offering courses and used a building performance laboratory to train builders, tailored to different building types.

Additionally, training needs to give glazing subcontractors and their fenestration fabricator suppliers the competence to calculate thermal bridges associated with the interfaces between fenestration and walls and within their systems. The syllabus for consultant training could be adapted for glazing sub-contractors and fabricators.

Who: DOE could support the development of vocational courses, partnering with local vocational schools around the country, and installer certification programs such as AGMCC, and with industry partners to develop the vocational programs. DOE or local entities (utilities, states, cities) could subsidize the provision of such courses to lower the barrier to education.

6.5 Professional architect continuing education:

Develop and widely deploy educational programs to ensure architects achieve a much better understanding of how façades are built (basic level), the performance of fenestration and wall systems, and specific education on high-performance strategies such as those of Passive House or net-zero designs. The first steps would be scoping the education program and engaging with AIA

⁸¹ <https://imt.org/>

⁸² <https://newbuildings.org/>

⁸³ <https://neea.org/>

⁸⁴ <https://www.mwalliance.org/>

⁸⁵ <https://www.seealliance.org/>

and other similar organizations (BEC, CSI etc.) to scope out collaboration and deployment opportunities.

Who: FTI could coordinate the development of a façade education series (starting with a basics series and building from there) engaging their diverse membership and other experts, and collaborate with AIA and other professional organizations, as appropriate, to drive to widest audience and access the smaller architectural firms. Funding from DOE would be needed to support both development and deployment.

6.6 Architecture student education:

A relatively small number of architecture schools in the U.S. have in depth teaching and training resources to teach the complexities of the field outlined in this document. The next generation of designers must be prepared to understand façade design and construction. We recommend developing standard syllabi covering building science, and its practical application in façade design, constructability, materials and assemblies, the non-energy benefits of high-performance façades, etc. The courses should include interaction with practicing design and construction professionals, to provide practical insights. New architects need to be taught skills that will allow them to analyze new materials and façade systems that they will encounter in their professional lives.

Syllabi should also include how to design buildings that achieve an 80% or greater reduction in whole life carbon so that a basic literacy in ultra-high-performance façades (and buildings) is established. Passive House Designer certification offers a technically rigorous introduction, either through PHI⁸⁶ or PHIUS⁸⁷. This training can then be adapted and extended to all climate zones as needed.

This course work needs to be integrated into undergraduate education, not just elective courses in post-graduate architectural education. A good benchmark for façade related undergraduate and graduate education can be found in the U.K. and Europe.

Who: FTI sits at the nexus of practitioners and educators and has connections with U.S. architectural schools and Canadian and European entities with façade related education and could coordinate syllabus development with support from DOE. DOE could encourage educational institutions to adopt the syllabus by offering appropriate funding or other support.

Concept 7: Create façade incentive programs

Barriers addressed: Incentive programs, if designed appropriately, could be used drive the needed changes to effectively to address many of the barriers identified. For example, strategies, such as funding incentives for state code adoption, grants for high-performance façade projects, prizes for new product innovation, can be used to reduce the upfront cost (barrier 1), thus improving the ROI (barrier 2). Incentives could be strategically used to reduce financial risk to new and different technologies (barrier 3), to encourage more effective project delivery methods (barrier 4), for façade experts to be brought to the table early (barrier 5), and for sufficient time and resources to be allocated for façade design (barrier 7).

Through this research we have identified several different targets for incentive programs to reduce risk or to improve the financial ROI. To reduce the actual or perceived risk and cost in adopting new or different façade materials, assemblies, or products to achieve higher above-code performance, it is important to focus on incentivizing and reducing risk for all participants, not just building owners. Figure 25 identifies the main target behaviors that need to be incentivized plus concepts for incentives that could drive those behaviors.

⁸⁶ <https://cms.passivehouse.com/en/training/certificates/designer-consultant/>

⁸⁷ <https://www.phius.org/certifications>

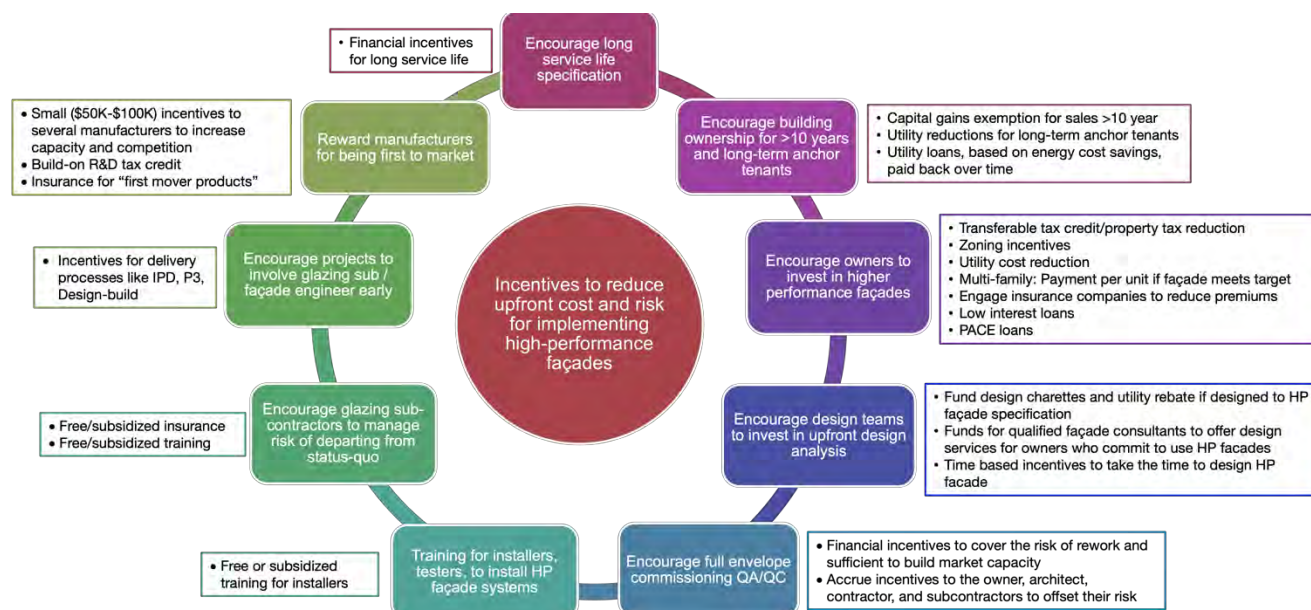


Figure 25: Summary of the incentive ideas (Concept 7) to reduce upfront cost and risk for implementing high-performance façade and fenestration systems.

7.1 The importance of a façade performance standard

If our goal is to encourage façade improvement over HVAC improvement it is critical to move away from incentives based only on whole building performance and towards incentive programs referencing façade specific performance. Many incentive ideas are predicated on having a definition for high-performance (HP) façades or façade assemblies to which to tie the incentive. **Actualizing the ideas in concept #1 are therefore foundational to many incentive ideas.**

In addition, incentives which encourage a **service life specification** and/or a commitment to quality through for example specifying ISO 15686-1:2011 or the Canadian durability Standard CSA S478-2019 are more likely to emphasis envelope performance.

7.2 Subsidized training offerings

Some of the targets for incentives have already been identified in some of the previous concepts, such as **free or subsidized training** for glazing sub-contractors and façade commissioning, and incentives for developing new fenestration products (curtain wall, window wall) to increase market capacity and competition, and reduce the risk of doing something new and/or different. The following are examples of current incentive programs in North America that stakeholders identified that offer training courses at low or no cost:

- NYSERDA⁸⁸ covers 50% of the cost of professional training courses for Passive House certification for consultants. It also offers free and low-cost training to code officials, architects, engineers, building energy professionals, and installers.
- MASS SAVE⁸⁹ in Massachusetts covers 100% of training and focuses on a wide range of audiences including training for workforce development, code officials and other professionals.
- PG&E in California⁹⁰ also offers funding for professional training.

⁸⁸ <https://www.nyscrda.ny.gov/All-Programs/Clean-Resilient-Building-Codes/State-Energy-Code-Training-and-Resources#:~:text=NYSERDA%20offers%20free%20and%20low,of%20the%20State%20Energy%20Code.>

⁸⁹ <https://www.masssave.com/>

⁹⁰ <https://investor.pgecorp.com/news-events/press-releases/press-release-details/2022/PGEs-Energy-Training-Centers-Offer-Free-Educational-Resources/default.aspx>

- Tri-county renewable energy network (3C-REN)⁹¹ covers 100% of Passive House training in California, supporting municipalities such as Ventura and San Luis Obispo. The Bay Area Regional Energy Network (BAYREN)⁹² also offers subsidized training.

7.3 Insurance to manage risk

Several incentive ideas focus on providing low-cost insurance products to reduce the risk of new/different or reduce the cost of ownership of buildings with high-performance façades:

- **Reduced building insurance premiums for owners** of buildings with high-performance façades to reward buildings that have longer service lives, greater durability and resilience.
- **Insurance for glazing sub-contractors and/or general contractors** to help them manage their risk around schedule, product performance and durability risk. This could be expanded to other parties in the project as appropriate.
- **Insurance attached to “first mover” products** that insure the manufacturer and/or the downstream purchasers for product warranty, liability, inability to meet project schedules etc. Product manufacturers can buy insurance for extended warranties, so it may be possible to insure new products with sufficient testing and validation.

The French technology assessment model: The French model could be developed in the U.S. to allow insurance companies and building owners better assess risk of new products and systems. It could support the provision of lower cost insurance coverage (perhaps subsidized by DOE or other incentive programs). In France, new building products go through what is called an “avis technique”⁹³ or a technical evaluation by a government entity – The Scientific and Technical Center for Building (CSTB). The CSTB undertakes a structured review of the product, sometimes identifying additional testing requirements, and assesses the suitability of the products for the application. These assessments are designed to provide “an informed opinion regarding the predictable behavior of structures built using the relevant systems and products, in order to allow participants to make their decisions and assume their responsibilities with full knowledge of the facts.” This assessment is often the gateway to use new products on construction projects in France, and is often needed by insurers, and gives owners and contractors comfort in a robust third-party evaluation.

The DOE and partners such as the National Laboratories for advanced testing and evaluation, and GSA through its Green Proving Ground program, could develop a program to fully analyze and vet new systems, and ensure they are fully tested to support lower risk adoption and insurance programs as listed above. LBNL has two large outdoor test facilities that might contribute to such a program. The Advanced Facades Testbed, with three side-by-side test offices, each about 10-15', facing south, can be occupied by test subjects for some studies, and have fully replaceable facade systems up to a 100% fully glazed wall. FLEXLAB is a series of four larger side-by-side pairs of test rooms, each about 15-ft x 30-ft in size, with fully replaceable facades up to 100% fully glazed wall; one of the testbeds can rotate to any solar orientation. Each of the test beds has sponsored multiple field tests of advanced facades and could be used in a variety of ways for the programs outlined here to vet new facade solutions.

Today, it is already possible for manufacturers to purchase insurance for extended product warranties. It may be worth exploring the possibility of combining the completion of a detailed technical evaluation with reduced cost or subsidized product insurance.

It would be instructive to engage with the insurance industry to understand their position on these concepts.

⁹¹ <https://www.3c-ren.org/>

⁹² <https://www.bayren.org/events-training>

⁹³ <https://www.ccfat.fr/doc/avis-techniques/procedure-atec-en.pdf>

7.4 Financial incentives to manage risk:

To complement insurance, direct financial incentives could be provided directly to manage risk such as:

- **Funding for projects which implement full envelope commissioning** to meet high-performance envelope standards. Funding would contribute to the cost of the commissioning, reducing risk and building capacity. will be important to ensure that the incentives accrue to all participants in the process to offset their risk.
- **Funding design charettes and technical support** that focus on high-performance façade design. This could be modeled on Enbridge Gas', "Savings by Design" program⁹⁴ in Canada, which provides help at the early stages of design by providing free design expertise which includes a free expert-led full-day design assistance workshop and free energy modeling to evaluate design choices, as well as monetary incentives to construct energy efficient buildings. Massachusetts' MASS SAVE offers free technical support to design teams⁹⁵. Since firms doing complex façades already do design charettes, the question needs to be addressed as to whether this type of program will result in meaningful change
- **Funding qualified façade consultants** to offer design services to owners who commit to using high-performance façades.

While it is noted that experienced architecture and engineering firms working for high-end clients already do many of the items we are recommending incentivizing, to drive to broader market adoption of high-performance façades such design needs to be extended to more buildings and more owners. It is important to expand expertise to more firms and support owners who want to do better. These funding efforts are intended to be short term and transitional until the underlying risk can be fully assessed and ameliorated, and market capacity increased, at which point they should not be needed. Other programs can provide longer term incentives and rebates to owners as desired to promote wider adoption of new technologies.

7.5 Incentives to improve owner ROI

To address the payback challenge with building a façade above code, several ideas have been pulled from the playbooks of jurisdictions which are already driving high-performance as well as the federal government and could be further explored:

- **Transferable tax credits** like the federal 179D, re-designed to focus on high-performance façades. It is important that these credits are transferable from the owner in case they are a non-profit organization which does not pay taxes. Such owners are often the ones more likely to want to drive to higher performance as they are typically universities, colleges, hospitals, museums etc. Allowing the incentive to be transferred to the architect and/or contractor will reduce the overall cost of the project. It will be important to be able to demonstrate that this incentive demonstrates additionality – that is, it does not just benefit those who would have built well anyway. A solution for this was provided through the "direct pay" system introduced in the Inflation Reduction Act of 2022, which allowed non-profits to be paid directly from the IRS⁹⁶.
- **Property tax reductions** for buildings with high-performance façades
- **Zoning incentives** such as increased height or reduced setbacks have been used successfully in jurisdictions. Vancouver allowed higher buildings or less stringent setbacks for passive house designs. Vancouver also allowed developers to do a zoning reclassification to make more lucrative conversion from commercial to mixed use. Expedited permitting has also been utilized as one of a group of incentives in various jurisdictions. The zoning incentives in New York City

⁹⁴ <https://www.enbridgegas.com/en/business-industrial/incentives-conservation/programs-and-incentives/new-construction/savings-by-design>

⁹⁵ <https://www.masssave.com/en/business/programs-and-services/new-construction-and-major-renovations>

⁹⁶ <https://www.whitehouse.gov/cleanenergy/directpay/>

that grew out of Zone Green⁹⁷ offers a Floor Area bonus for walls that are substantially more efficient than the existing NYC energy code, which is seen as valuable. The incentive states “up to eight inches of additional wall thickness could be exempted from floor area (*calculation*), encouraging high-performance buildings without changing the amount of usable space in the building.”

- **Utility rate reductions** for high-performance façade implementation. This would accrue to the tenant in developer buildings.
- **Low interest loans for qualified projects.** There are several precedents for this type of program. The Bank of Canada has a green loan program for affordable multi-family housing retrofits⁹⁸. It funds energy audits, energy modeling studies, building condition assessment reports prior to retrofit, and 100% of retrofit costs in a mix of low interest repayable and forgivable loans, up to a maximum limit. This could be part of a solution to address the large barriers to façade retrofit. The regional climate agency created by the City of Toronto (TAF)⁹⁹ also provides low-cost green construction loans for energy efficient projects. “Green loans” are also issued by the World Bank¹⁰⁰ and the European Union’s investment bank (the European Investment Bank, EIB) issues green loans for affordable “climate friendly” housing, sustainably designed schools, hospitals, and other buildings¹⁰¹.
- **Property Assessed Clean Energy (PACE) financing**¹⁰² could be used or modified by local jurisdictions to allow the property owner to finance the upfront cost of the higher façade performance investment and pay back the costs over time through a property assessment, added to the regular property tax. The unique part is that the assessment follows the property, not the owner and allows the upfront investment to be paid back in 20-30 years. According to the DOE, “more than 37 states plus the District of Columbia have commercial PACE enabling legislation.”
- **Financial payment per unit in a multi-family development** could be made if the façade meets a specific target façade performance. Massachusetts through its Mass Save program provides \$1500/unit for multi-family buildings constructed to passive house standards.
- **Financial incentives to the developer** sufficient to fully or partially offset the increase in project design time (say 3 months) which extends the time to cash flow if the project takes the time to design (and implement) a high-performance façade. Funds could also be provided for design charrettes or for qualified façade consultants to provide the upfront design services. There should be a requirement for building owners to retain accurate records of the as-built construction to facilitate upgrading at a later time.

These incentive and financing programs vary widely in their target markets, the financial rewards involved, and the duration of the programs. In general, they are designed to be transitional and limited to overcoming barriers so that once performance is well documented, the supply chain delivers well-priced high-performance products and the industry has the skills to specify, install and operate them. At that point the various payment programs are no longer needed.

ACEEE has a database¹⁰³, albeit dated, of incentives that have been enacted in local jurisdictions that may be a useful source of additional ideas that can be aligned with higher performance facades (rather than whole building performance).

⁹⁷ https://www.nyc.gov/assets/planning/download/pdf/plans/zone-green/zone_green.pdf

⁹⁸ <https://www.cmhc-schl.gc.ca/professionals/project-funding-and-mortgage-financing/funding-programs/all-funding-programs/canada-greener-affordable-housing-program>

⁹⁹ <https://taf.ca/green-construction-loans/>

¹⁰⁰ <https://www.worldbank.org/en/news/feature/2021/10/04/what-you-need-to-know-about-green-loans>

¹⁰¹ <https://www.eib.org/en/projects/topics/climate-action/explained>

¹⁰² <https://www.energy.gov/scep/slsc/property-assessed-clean-energy-programs>

¹⁰³ <https://database.aceee.org/city/requirements-incentives>

7.6 Creative funding mechanism: Carbon credits

There are carbon offset programs that provide financing for creating solar farms, planting trees and similar initiatives that reduce carbon emissions. Companies and individuals invest in these projects which reduce carbon emissions, by buying carbon offsets, to balance out their own carbon emissions. Would it be possible to create carbon offsets for improved façade systems?

Aureus Earth, a spin off from the Rocky Mountain Institute (RMI), offers incentives to accelerate decarbonization of the construction industry, addressing the green premium between traditional materials and low-carbon and/or carbon storing alternatives, in particular mass timber, but also low carbon concrete, bamboo, and carbon-storing steel¹⁰⁴. It quantifies the carbon savings from these materials and offers them as carbon offsets for sale to fund the specific construction project. According to Paul Schwer, of PAE Engineering, the University of Washington's Foster School of Business¹⁰⁵ invested in a mass timber building and sold \$125,000 of carbon credits to fund it.

For a similar system for high-performance façade systems to work, the construction project would need to calculate (estimate) the carbon saved relative to a code-compliant construction, the carbon would be valued and "sold" as offsets to fund the added cost of constructing a higher performance façade. This funding mechanism could be used for retrofits as well as new construction. There are challenges with quantifying operational carbon emission reduction over time without full knowledge of grid decarbonization, so this would need to be addressed. The building would also need to ensure performance to the design, to confirm that the appropriate carbon offset is earned. This may be a program to evaluate as part of phase 2 of this work.

7.7 Incentivizing the long-term ownership and tenant model

As demonstrated by PAE Engineering in their first developer led Living Building Challenge office building¹⁰⁶, if the developers are (1) willing to hold a building for at least 10 years, (2) have an anchor tenant signing a long-term (15 year) lease, to give them guaranteed income for over 10 years, and (3) that tenant is willing to pay a 10% premium for the performance delivered, they can see an ROI. Creating a program in which no capital gains tax would be paid for buildings with high-performance façades, held for over 10 years, would be a way to incentivize this behavior. Utility rate reductions or other tax incentives accruing to the tenant, as well as the quantified validated benefits of occupying a higher performance building, could be used to encourage them to sign long leases.

7.8 Incentivizing early involvement of the glazing sub-contractor / façade engineers

The single largest lever we have seen that gets façade expertise to the table in early design is when codes have become significantly more stringent and focused on building envelope performance, such as in Massachusetts and Vancouver.

In lieu of more stringent codes, an incentive strategy that may tangentially help, is to reward project delivery methods such as Public Private Partnerships (P3)¹⁰⁷ and Integrated Project Delivery (IPD)¹⁰⁸, or Design-Build (DB)¹⁰⁹. While it isn't clear that sub-contractors will always be at these tables, these project delivery methods are more likely to deliver a higher performance, higher quality outcome, and reduce risk. According to the Canadian Council for Public-Private Partnerships, "when design services are integrated into a P3 contract, the consortium's architects and contractors plan the project together." They note that P3 projects "leads to design innovations and better-quality

¹⁰⁴ <https://aureusearth.com/>

¹⁰⁵ <https://aureusearth.com/projects/>

¹⁰⁶ <https://www.amazon.com/PAE-Living-Building-Developer-Led-Nature-Inspired/dp/1736212907>

¹⁰⁷ <https://www.pppcouncil.ca/why-p3s/how-p3s-work#:~:text=A%20P3%20project%20agreement%20outlines,the%20availability%20of%20sub%20trades>

¹⁰⁸ <https://leanconstruction.org/lean-topics/integrated-project-delivery->

<ipd/#:~:text=What%20is%20IPD%3F,together%20under%20a%20single%20agreement.>

¹⁰⁹ <https://dbia.org/what-is-design-build/>

equipment and materials that improve an asset's performance and prolong its life". According to the Lean Construction Institute, in IPD projects, "key parties involved in the design, fabrication and construction aspects of a project are joined together under a single agreement"¹¹⁰. The impact of better collaboration and communication is a reduction in time wasted, material waste, increase in efficiency and improved project outcomes.

7.9 Integrated incentive programs to benchmark

The following incentive programs have been identified as good models to use for comparison. They contain multiple components (some of which are highlighted above), such as training programs offered at no- or low-cost, funding for design expertise, design competitions and more. Incentive packages used could be adapted to be more façade focused.

- **New York State's New Construction and Renovation Program and Incentives**¹¹¹: The buildings of Excellence program¹¹² is a competitive program that celebrates exemplary projects and requires a submission to get funding of up to \$1M. New York replicated the programs in Brussels which promoted an exemplary building program. Passive House projects tend to be successful. According to stakeholder feedback, the full NYSEDA incentive program for high performance buildings is somewhat piecemeal, with components that could be better connected. "The basic components are there; the goal line is not so clear."
- **Massachusetts' MASS SAVE Program**: This program iterates on the New York Buildings of Excellence program. It is competitive to a certain extent (not everyone gets funding), but incentives are reportedly more straightforward to achieve. According to stakeholder feedback, "it is a well thought through incentive program, which is well connected with vertical and horizontal integration."

Concept 8: Deploy code related recommendations

Barrier(s) addressed: Barrier 1.1 – Codes set the baseline cost and don't require better fenestration / façade performance.

Codes can be both a pathway to encourage innovation and progress, but also an obstacle to progress and a preserver of the status quo. The feedback from the stakeholders in this research has overwhelmingly pointed to lagging energy codes as a key reason for the lack of progress in implementing high-performance façade systems. Many stakeholders, particularly architects and façade consultants / engineers, felt that the only way to make meaningful change quickly is to address the barriers presented by the current state of energy code stringency, structure, and adoption. They felt it is a way to level the playing field for all building owners and developers and to ultimately help encourage progress toward more aggressive future net zero performance goals.

The barriers to high-performance facades driven by energy codes can be grouped into two categories: (1) Structural challenges in the way the codes are written, adopted, and enforced, and (2) a lack of focus on envelope performance. U.S. model codes do not take a "fabric first" approach¹¹³. Both affect the ability to increase envelope related code stringency and the former also seeks to address the enforcement gap.

¹¹⁰ <https://leanconstruction.org/lean-topics/integrated-project-delivery-ipd/#:~:text=What%20is%20IPD%3F,together%20under%20a%20single%20agreement.>

¹¹¹ <https://www.nyserda.ny.gov/PutEnergyToWork/Energy-Program-and-Incentives/New-Construction-and-Renovations-Programs-and-Incentives>

¹¹² <https://www.nyserda.ny.gov/All-Programs/Multifamily-Buildings-of-Excellence>

¹¹³ <https://www.be-st.build/news/how-to-build-fabric-first/#:~:text=Fabric%20first%20means%20optimising%20the,further%20systems%20such%20as%20heating>

8.1 Addressing model code structural challenges

Figure 26 depicts a set of ideas to address code structural challenges to increase façade performance.

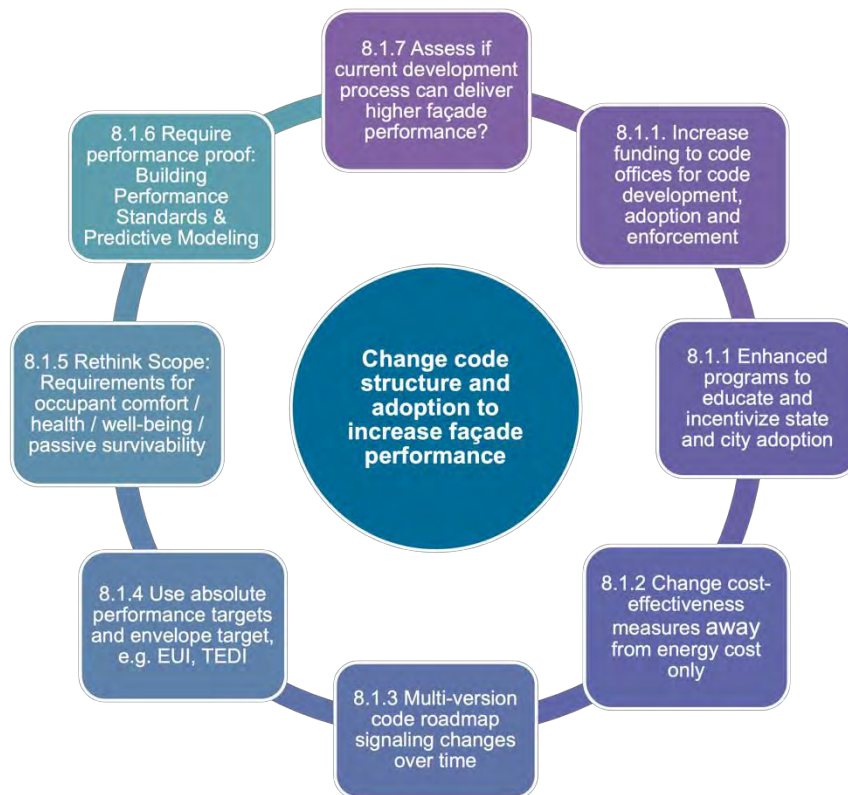


Figure 26: Summary of concepts (8.1) to change the model code structure to increase façade performance.

8.1.1 Funding and training for local jurisdictions

The first two concepts are connected: (1) An increase of funding and/or change in funding structure for local code offices and (2) the deployment of enhanced programs to educate and incentivize local jurisdictions to adopt the most recent model code. The first can enable the second. While neither directly address façade performance, in general, more recent model codes increase the stringency of the envelope requirements, by including, for example, air-barrier testing and leakage limits, thermal bridge mitigation, and incrementally better fenestration U-factors.

It has been clear when talking to jurisdictions who are leading the way that they not only have political will, but they adequately fund their code enforcement and development activities. Funding structures like the City of Seattle, which do not rely on building permit revenue, and which provide sufficient capacity for code review, adoption and enforcement could make a significant impact on adoption and enforcement.

Training code officials to identify thermal bridges on plan documents and assess fenestration performance through NFRC certification documentation would be significant in improving compliance. Another suggested effective method is to require submittal documents to clearly demonstrate compliance in a manner that the plan examiner can evaluate quickly and easily. Requiring drawing reviews, testing reports, commissioning data and proof of fenestration performance through NFRC label certificates to be provided to the code official to validate what's getting built could have a significant impact. New York City has a requirement for final fabrication

drawings for fenestration and opaque assemblies to be submitted for a final code review to ensure compliance. All these activities require a well-trained and well-funded staff.

NEEP made several recommendations in their report:

- Provide economic incentives for implementation and enforcement.
- Diversify stakeholder engagement and outreach in the code adoption process to be more inclusive.
- Develop and fund education and training (see recommendations in concept #6 above)

Charging an additional, higher permit fee for buildings which elect to use the performance compliance path could be a way to fund a professional review of the energy model to ensure appropriate modeling and assumptions have been used.

8.1.2 Change cost-effectiveness requirements

Cost-effectiveness assessments need to be more sophisticated to capture more than energy cost savings. Several approaches have been implemented in the case studies, and others identified as potential options to evaluate:

- Evaluate cost effectiveness of envelope stringency increases holistically by considering the cost savings of downsizing of HVAC systems as well as accrued energy cost savings (as Massachusetts has done).
- Use the social cost of carbon to assess payback rather than energy cost only (2024-IECC developed a method that could be used for measure analysis, but for information only).
- Demonstrate that any increased stringency measure is the most cost-effective available means of achieving the performance (Washington State), rather than imposing a specific cost-effectiveness requirement.

Changing the cost-effectiveness metrics will accelerate increases in code stringency.

8.1.3 Create a code evolution roadmap

As British Columbia has done, create a multiyear roadmap for code stringency changes. This allows manufacturers to plan product development with confidence, aligning product availability with the timing of new code enactments. Developing a multi-step code roadmap to get to net-zero would be effective in building capacity over time. Practitioners and installers also have time to plan and increase capacity. It would also provide a way to tie incentives to higher steps to encourage market movement, just as has occurred in British Columbia and the City of Vancouver.

8.1.4 Change to absolute performance targets

Use absolute performance targets, such as energy use intensity (EUI) and an envelope metric such as TEDI for cold climates and a cooling climate option, rather than relative performance targets. Absolute performance targets prevent design teams from playing games by making the base-case model as bad as possible to make their design comply. DOE could support creating model pathways or guidelines to support achieving the targets.

A word of caution from designers: The use of TEDI as a metric alone does not give a full picture of performance, especially because it is impacted by ventilation rate, and can lead to dark, sealed buildings.

8.1.5 Rethink energy code scope

It is time to have a mindset shift around energy codes and rethink how façade performance impacts carbon emissions, life safety, human well-being, passive survivability, resilience and durability as well as energy usage. There can be a tension between energy efficiency and glazing area, as often the route to achieving an energy target with the lowest upfront cost is to increase the opaque area at the

expense of transparent area. As building scientist Joe Lstiburek has asserted¹¹⁴ we are expecting windows to do a lot more than doors (like provide daylight and views, while controlling heat gain, heat loss and glare in addition to other major functions), so it stands to reason that they should cost more. It is important to avoid negative unintended consequences because of a singular narrow focus on energy cost. If the goal is to achieve low-carbon, comfortably daylit buildings, that both support human wellness and address climate change, we need to either broaden the scope of energy codes or align them with other regulations concerning human health and well-being.

The building codes, often focused on managing acute safety requirements such as fire protection and structural stability, could serve as a vehicle for measures related to human health and well-being since a scope change may not be necessary. For example, the widely adopted International Building Code (IBC) states that its purpose is to “provide a reasonable level of safety, public health and general welfare” and mentions “adequate light” as one of the mechanisms for achieving this. Currently it does not differentiate between daylight and electric light. Adding provisions for daylight and views in the IBC would be consistent with its scope and purpose, and an argument could also be made for adding requirements for thermal resilience in certain building types.

There are precedents for minimum daylight requirements in other countries. In France, for example, there have been policy initiatives to prevent low window areas in residential buildings caused by increasingly stringent energy codes. Since their 2012 code, new residential buildings must have a **minimum** glazed area of no less than one-sixth of the habitable floor area: The “one-sixth rule”. More recently, France’s code (RE2020) while maintaining the one-sixth rule also includes an option to meet two requirements from the European daylighting standard EN17037¹¹⁵ *Daylight in Buildings* related to daylight provision and views provision. Other countries in Europe have adopted this standard. In 2019, the U.S. National Institutes of Health issued a bulletin¹¹⁶ describing EN17037 and suggesting the U.S. may follow this lead.

Additionally, many jurisdictions are facing an insurance crisis (in addition to a climate crisis) and some buildings/areas may become uninsurable if codes do not start requiring greater resiliency.

It is recommended that the following be included in energy codes or building codes as appropriate:

- Targets for **operational carbon** (not just energy)
- Targets for **daylight admission and views** to ensure adequate occupant wellness and encourage the use of high-performance glazing in building occupancies such as schools, day care centers, offices, and residential occupancies. There are existing standards to determine adequacy of daylight and views, such as in ASHRAE Standard 189.1/IgCC, LEED v4 and EN17073 that could be utilized as performance standards. Simpler prescriptive approaches, such as the one sixth rule, or minimum glazing areas could be taken. A simple measure was proposed (and subsequently defeated) for the last IBC revision which would have required windows in classrooms and daycare centers.
- A requirement to achieve an appropriate level of **thermal comfort adjacent to the façade** (such as the Passive House standard).
- A target for **thermal resiliency to support passive survivability**. Such requirements have been tested out in USGBC’s LEED v4.1 program that could be used as a model¹¹⁷. Ted Kesik’s thermal resilience design guide¹¹⁸ also can act as a model. PNNL recently published a study¹¹⁹ of the impact of implementing building envelopes with the performance of the most recent model energy code and

¹¹⁴ <https://basc.pnnl.gov/videos/distinguished-lecturer-series-building-science-adventures-building-science>

¹¹⁵ <https://standards.iteh.ai/catalog/standards/cen/1b0ef311-7fc5-4e72-9f64-f670cde0b05f/en-17037-2018a1-2021>

¹¹⁶ https://orf.od.nih.gov/TechnicalResources/Documents/Technical%20Bulletins/19TB/Daylighting%20%E2%80%93%20European%20Standard%20EN%2017037%20October%202019-Technical%20Bulletin_508.pdf

¹¹⁷ <https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-data-47?return=/credits/New%20Construction/v4.1>

¹¹⁸ https://pbs.daniels.utoronto.ca/faculty/kesik_t/PBS/Kesik-Resources/Thermal-Resilience-Guide-v1.0-May2019.pdf

¹¹⁹ https://www.pnnl.gov/sites/default/files/media/file/ResiliencyIssuesBuildingEnergyCodes_BECEWG_Aug2023.pdf

Passive House, demonstrating the impact on number of lives saved during power outages in severe hot or cold climate events.

- Targets for ensuring **adequate condensation resistance** to maintain indoor air-quality and durability of the façade.
- Targets for **embodied carbon**, once there is sufficient structure and data validation in the market. The Environmental Protection Agency is driving hard to increase data robustness and uniformity for environmental product declarations in construction materials through funding through the Inflation Reduction Act¹²⁰.

8.1.6 Require performance proof: Drive Building Performance Standards & Predictive Modeling

Building performance standards, which set emission limits for existing buildings are de facto outcome based codes for new construction, since new buildings become existing buildings as soon as they are given a certificate of occupancy. While relatively low in stringency compared to the expected performance of new buildings, they are effective at improving the performance of existing low-performing buildings. However, the presence of emissions targets which ratchet up over time is expected to drive design teams to future-proof their building designs, by making sure that they are sufficiently energy efficient and ensure that what they designed was what is built using inspection, measurement, and commissioning through the construction process. BPS have the potential for driving new-construction performance above energy code requirements if emissions limits are set accordingly, but this would require effective predictive energy modeling and a lot of experience in closing the performance gap. The industry is not ready for this yet.

Investing in **better predictive building performance modeling** is a significant need. This would facilitate BPS by future proofing new buildings and reduce the risk that as-built will not match as-designed performance. DOE could fund work to improve predictive modeling, and as a first step carry out an extensive study comparing modeled energy use with actual energy use to understand the typical gap and their root causes.

BPS can also have a positive impact on incentivizing envelope renovation. Refer to Concept 9.1 below where a more detailed overview of the work that IMT and the federal government is currently doing to support and promulgate BPS and additional recommendations.

8.1.7 Code development process: Will what got us here, get us there?

It is not clear that the process by which our current codes are developed is capable of implementing any of the concepts laid out above to get the building envelope (or whole building performance for that matter) where it needs to be in time to meet national and global climate targets.

This has been demonstrated by the recent 2024-IECC appeals process¹²¹, in which special interest groups were successful in overturning decarbonization provisions as they were deemed by the ICC board of directors to be out of scope, even though the converse had been communicated throughout the code development process. The provisions were moved to a non-mandatory appendix.

Given that the model codes are developed by independent organizations, with a strong influence of industry special interests, it is not clear that the structural changes laid out here could feasibly be implemented, at least on the time frame necessary. An analysis of the capability of our current code development process in supporting needed changes is recommended.

¹²⁰ <https://www.epa.gov/greenerproducts/reducing-embodied-carbon-construction-materials-through-inflation-reduction-act>

¹²¹ <https://www.iccsafe.org/about/periodicals-and-newsroom/icc-pulse/the-international-code-council-board-of-directors-makes-final-decision-on-2024-iecc-appeals-and-addresses-preemption-challenges/>

8.2 Increase codes' focus on the building envelope

Figure 27 below summarizes the concepts identified that, if implemented in energy codes, would increase the performance of the building envelope by taking a more fabric first approach. They are discussed in turn below. This approach would drive a focus on load reduction first, before considering the mechanical requirements, supporting design and simulation approaches like PAE's (see case study).

8.2.1 Envelope testing and commissioning

Increasing the mandatory requirements for testing of building envelope performance during and after installation is a critical step in assuring quality and reducing the performance gap between as-designed and as-built¹²². Air leakage is one of the largest degraders of building performance and is a problem in both hot and cold climates. Reducing the allowable air-leakage and broadening the requirement for air-leakage testing to more buildings and more climate zones is important.

We heard that it was also important to develop better methods for air-leakage testing in larger buildings, which could be a development activity that DOE supports.

Controlling the quality of the continuous insulation and ensuring that thermal bridging strategies are implemented through inspection during installation and commissioning is also important. Infra-red thermography coupled with drone technology is also available for evaluating thermal performance of building envelopes and is often used to identify issues on existing buildings¹²³. This technique could be evaluated as a requirement as a final check of quality, identifying any issues and facilitating remediation prior building handover.



Figure 27: Concepts (8.2) for modifying model codes that increase the focus on building envelope performance.

¹²² <https://pure.psu.edu/en/publications/a-review-of-the-energy-performance-gap-between-predicted-and-actu>

¹²³ <https://iibec.org/wp-content/uploads/2007-07-brooks.pdf>

8.2.2 Account for thermal bridging

Thermal bridging through slab edges, opaque cladding attachment, balconies, window-wall interfaces, parapets and structural columns are major heat loss paths in the building envelope. Until very recently, thermal bridging has been completely ignored in model codes. This makes it challenging for higher performing buildings that do address thermal bridging to show higher performance than the baseline, since the baseline is considered “perfect”. The 2024-IECC and ASHRAE 90.1-2022 have taken first steps to acknowledge and reduce these performance degraders, but there is a lot of scope for further improvement. Approaches like that of British Columbia and Massachusetts, which reference the Thermal Bridging Guide¹²⁴ are good benchmarks for others to build on.

Ensure that performance de-rating, reporting and identification of all thermal bridges are required on code compliance submittals and used in performance simulations.

8.2.3 Require a minimum façade performance

Currently, model codes allow increases in internal system efficiencies – lighting and HVAC – to be traded off against lower performance façades when using the performance compliance path. This is typically the lowest cost route but reduces investment in the long-lived façade while increasing investment in shorter-lifetime internal systems. A minimum envelope thermal performance would limit the amount to which this trade-off could be made. As noted previously, in recognition of this issue, several jurisdictions (Washington, City of Seattle, Massachusetts, New York City) have already implemented such limits, and even the latest version of ASHRAE 90.1 (2022) has implemented an envelope backstop.

The precedents offer several different options to evaluate and refine: Area-weighted U-factor limits compared to the prescriptive requirements, the more complex ASHRAE 90.1 and New York City approaches or thermal energy demand intensity (TEDI) limit. In colder climates, where the TEDI metric is used, it is also important to guard against overheating. There is also a need to evaluate alternative envelope metrics to TEDI for cooling dominated climates.

Recommendation: Undertake a thorough evaluation of existing precedents and their consequences – intended and unintended – and other concepts to set envelope targets in performance compliance paths and make a recommendation of a minimum performance target. FTI could manage this activity, in collaboration with stakeholders from local governments and institute members from the AEC community which are familiar with design and construction using the precedents.

8.2.4 Quality control for performance path compliance

Require a standard simulation method to be used, and qualified simulators to carry out simulations, for performance path compliance. As mentioned previously, British Columbia has already implemented a simulation guideline, so there is good precedent for implementing a standard procedure to be followed. This would improve the quality and consistency of building energy simulations, especially as they relate to façade systems, ideally more accurately representing its performance. This strategy would be facilitated by the implementation of [Concept #5 – create certification programs for practitioners](#).

8.2.5 Require opaque assembly thermal performance validation

Require design teams to prove opaque wall assembly thermal performance with appropriate thermal modeling, in a manner similar to that used for fenestration. Wall assemblies’ thermal performance is often reduced significantly because of thermal bridging edge effects related to attachments. Also, as noted previously, the thermal performance of spandrel assemblies is routinely over-estimated by the current simulation tools and procedures. More effective performance assessment needs to be

¹²⁴ <https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/power-smart/builders-developers/building-envelope-thermal-bridging-guide-v1-6.pdf>

developed and required by code. The current work by the Pankow Foundation¹²⁵ should inform requirements and provide some of the currently missing tools and guidance. Completing two of the ideas in Concept 1, “3-D modeling tool for accurate simulation of assemblies” and “more accurate NFRC ratings for spandrel” would facilitate incorporation into model codes.

8.2.6 Provide alternative compliance pathways

Allowing alternative compliance pathways using third-party building certifications, such as Passive House, that deliver a performance higher than the current code, is a way of rewarding higher performance without making it harder to construct them. According to the Passive House Network’s ‘Policies We Want’ brief, *“Removing the requirement to develop two separate energy models is a foundational move that can be done prior to implementing any incentive or reach code. It allows project design teams to reduce cost and complexity, and avoids conflicting directions generated by two differing modeling programs”*¹²⁶. There are several precedents: Massachusetts allows Passive House certification to be an alternative compliance pathway for all building types. Washington State provides Passive House alternative pathway for single family residential. Denver allows Passive House as an alternative compliance pathway for residential and non-residential buildings¹²⁷.

8.2.7 Require a long service life commitment

Requiring a building service life commitment of say 100 years (see ISO 15686-1:2011) or even a quality commitment will have the effect of driving improvements in the quality of the envelope, because that is a driver of building service life.

ISO 15686-1:2011¹²⁸ Buildings and Constructed Assets Service Life planning provides a framework. Canada has also developed a building service life standard, CSA S478-Guideline on Durability in Buildings¹²⁹ that, if adopted in the U.S., could drive higher performance in façades. This standard has already been adopted into the Canadian National Building Code and the Ontario Building Code. Its scope states ‘this Standard provides criteria and requirements for the design of a durable building and its building elements and includes provisions for cost analysis and management and for a quality management program for the design, construction, operation, maintenance, repair, and renovation of a building and its building elements.’ Like ISO 15686, it provides some guidance on estimating service life of assemblies and components.

According to those in the Toronto market, while “a core group of conscious designers / architects go above and beyond the standard already and do not need to be reminded that durability matters in order to act, having the standard means that the topic is getting more visibility, which is a positive step.”

¹²⁵ <https://www.pankowfoundation.org/our-work/research-grants/exterior-wall-systems/sustainability/thermal-performance-of-spandrel-assemblies-in-glazing-systems-research-roadmap-phase-1/>

¹²⁶ “The Policies We Want”, Passive House Network, 2023: <https://passivehousenetwork.org/wp-content/uploads/2023/09/2023-Policies-We-Want-Brief.pdf>

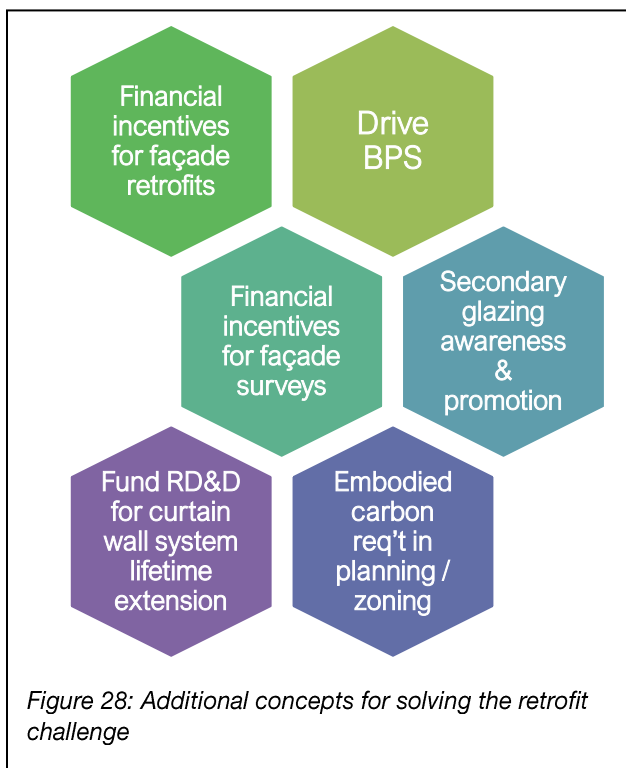
¹²⁷ <https://passivehousenetwork.org/codes/>

¹²⁸ <https://www.iso.org/standard/45798.html>

¹²⁹ <https://www.csagroup.org/store/product/CSA%20S478:19/>

Concept 9: Implement strategies to solve the retrofit challenge

Barrier(s) addressed: Reducing the cost, disruption, and the risk for upgrades of glazed walls.



Retrofit and renovation of the existing building stock, and specifically the building envelope, is becoming an increasingly important element of most long-term energy and carbon emissions planning. To solve the retrofit challenge, much of the work described above for new construction will be needed, but also additional solutions to overcome the other, quite significant, retrofit specific hurdles, will be needed. This includes the following (see figure 28 for a summary):

9.1 Drive adoption of building performance standards

While building performance standards (BPS) drive the reduction in energy use of the whole building, façade improvements typically will be required once the annual emissions targets are ratcheted down sufficiently, and the low hanging fruit of lighting and HVAC retrofits have been harvested. So, driving the adoption of BPS at the state and local level can be a catalyst to drive façade renovation, assuming of course that the penalties of non-compliance have sufficient teeth. Some

participants have suggested that the leading BPS, Local Law 97 in New York City, is not yet strong enough to incentivize action on the building envelope, and that they are concerned that many owners will pass on the cost of the fine as lease increases to tenants.

There is already a significant push for building energy benchmarking and performance standards from government and the non-profit sector. The federal government has launched a federal building performance standard¹³⁰ in 2022 which requires federal agencies to cut energy use to achieve zero scope 1 emissions in 30 percent of the floor area in buildings owned by the federal government¹³¹. The U.S. EPA is supporting whole-building data availability, a definition for net-zero emissions buildings and improved tools to support BPS¹³². IMT is championing widespread adoption of building performance requirements across the country, by collaborating in the design of local and state policy change, engaging with utilities, and advocating for federal action and improved construction standards and policies¹³³. The map below (figure 29) shows the current state of U.S. BPS for existing buildings from IMT. In addition to these jurisdictions, there is also a pipeline of cities and states who have implemented energy benchmarking, which is a precursor to BPS.

¹³⁰ <https://www.sustainability.gov/pdfs/federal-building-performance-standard.pdf>

¹³¹ <https://www.sustainability.gov/federalbuildingstandard.html>

¹³² <https://www.energystar.gov/buildings/resources-topic/what-are-building-performance-standards/blog-building-performance-policy>

¹³³ <https://imt.org/about/our-strategy/>

We recommend financial support for driving the adoption of BPS and for the organizations such as IMT supporting design and deployment. It is critical to ensure that BPS programs are designed with sufficient financial teeth for façade and fenestration retrofits to make sense. An evaluation of the scale of penalties required to incentivize façade retrofits would be useful to do.

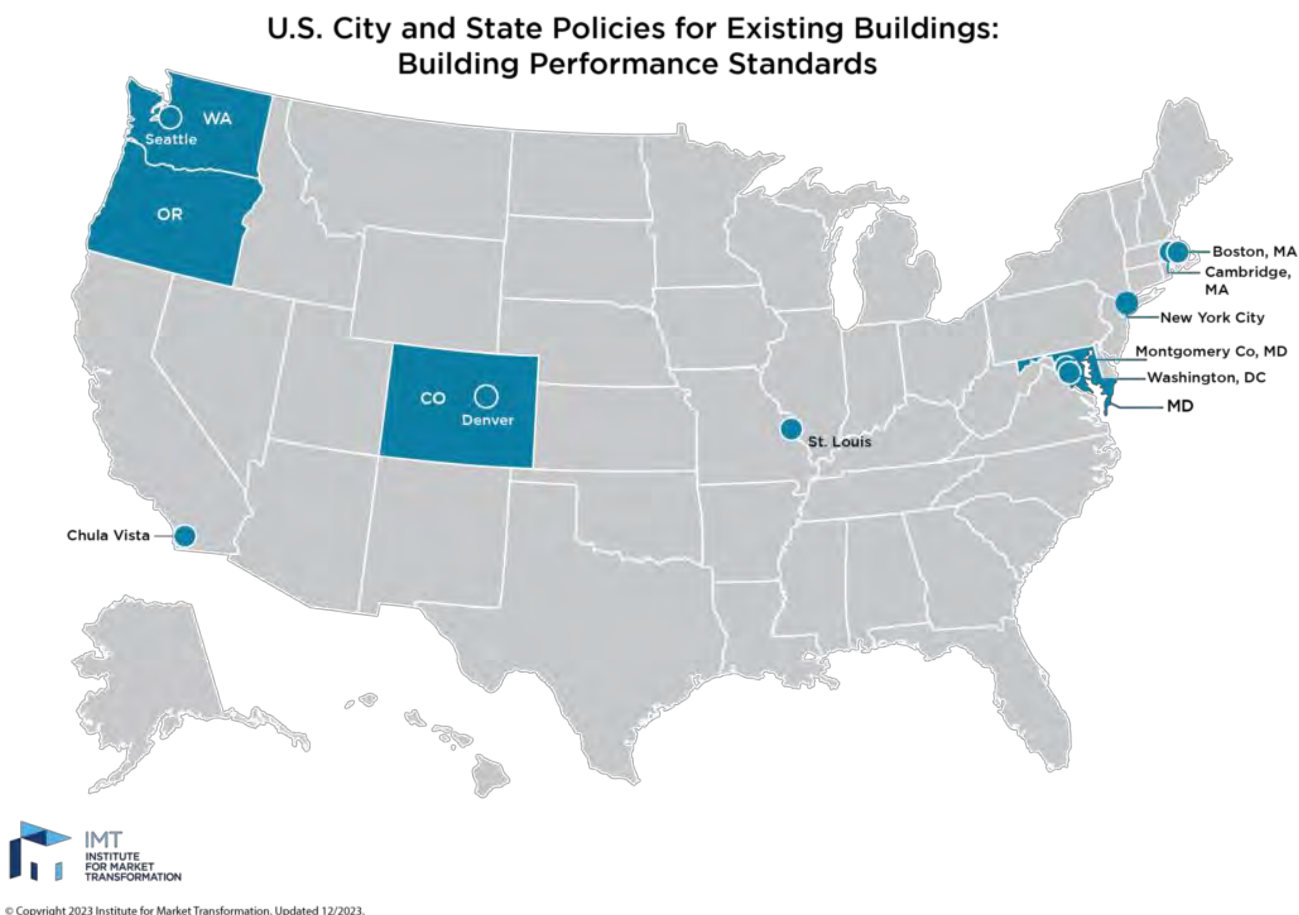


Figure 29: Jurisdictions that have adopted building performance standards as of May 2024. Source: IMT

Also, alongside tightening BPS penalties, having funding for capacity building for façade renovation in local markets is key, as are incentives to support façade surveys (see below) to reduce risk. According to feedback, the timing of availability of funding for, and availability of, training for capacity building relative to the implementation of BPS emission targets is very important. If capacity for façade renovation is not available before the BPS compliance is required, the market cannot move and severe challenges relative to compliance with the regulations may occur

9.2 Financial incentives for façade surveys to assess retrofit feasibility

As noted in the barrier section, there is a significant risk of the unknown due to unquantified conditions in existing renovating façade systems. One strategy to reduce this risk is to provide financial incentives such as grants for façade surveys which can identify the full scope of potential façade retrofits. Free technical support for such surveys and solution development could also be effective. Mass Save's program includes retrofit surveys and technical support for buildings, including façades. Its effectiveness relative to encouraging façade retrofits would be good to analyze in order to optimize a federal program.

9.3 Financial incentives for fenestration / façade retrofits to improve the ROI

Even with a survey completed, the cost of renovation can still be too high for a commercially viable payback (in the absence of BPS emission penalties), depending upon whether some of the non-energy benefits are valued by owners. Financial incentives, such as grants, or low interest loans could be effective in closing the payback gap. An analysis could be undertaken to establish the amount and type of financial incentive that would effectively close that gap for a range of fenestration and/or façade renovations to support incentive program design.

There is a keen interest nationally in decarbonizing buildings by replacing gas heating systems with heat pumps in older buildings. Many of these buildings have thermally poor single glazed, leaky fenestration. Facade retrofits should reduce the heating loads, thus saving money on the downsized heat pump systems and any grid services that need to be upgraded as well. Façade upgrades facilitate more extensive and more cost-effective building electrification.

9.4 Secondary glazing improvement awareness and promotion

The federal government is placing a lot of emphasis on secondary glazing solutions – for good reason, since they are an easy to install, cost-effective means of improving fenestration performance. These are typically faster, cheaper and less disruptive to the workplace than a conventional facade replacement. Anecdotally, the energy service companies (ESCOs), who are engaged by owners to create efficiency improvement strategies for their buildings do not appear to be aware of these solutions. An awareness campaign amongst ESCOs and other building owner organizations could be effective at increasing awareness of secondary glazing alternatives as cost-effective solutions. Additionally, as some product solutions thermally improve the glass area only, whereas other products improve the full window system (glass plus frame), assessment guidelines and tools to evaluate and distinguish between these alternatives are needed to optimize energy savings and overall performance.

GSA has funded several demonstration projects that show the value of well-planned secondary glazing systems and DOE recently announced a new 2-year program with a \$2M prize for companies to develop improved affordable secondary glazing solutions with high thermal performance. While the primary target has been improved thermal properties in cold climates, buildings in all climates have significant cooling and thermal comfort challenges with existing single, clear glazing and require solutions with enhanced solar control (static or dynamic) to improve occupant comfort while managing peak loads, minimizing cooling and enhancing resilience.

Who: DOE could fund an information and marketing program to ESCOs and building owners to promote adoption of these solutions. Ratings to distinguish energy efficiency performance between solutions should also be supported.

9.5 Fund research, development & deployment for curtain wall systems that are readily serviceable, upgradeable, and adaptable to extend lifetime

One of the reasons that curtain wall systems are hard to renovate is that they are not currently designed to be easy to replace, service, upgrade or adapt. If curtain wall design is not changed now, we are destined to build in the same barriers for the next generation of retrofits. To change this paradigm, the DOE could fund a competition and/or prizes for manufacturers to design serviceable and upgradeable curtain wall designs. This could be combined with the proposed prize program for higher performance curtain wall and window wall designs, so they are designed to meet serviceability, circularity, and thermal performance requirements. This could start the industry thinking about designing for sustainability.

The Europeans have also explored a different business model for long-term investing in new high-performance solutions, Facade as a Service (FaaS). Following the model of software and other

leased services, a company designs, deploys, operates and then services the building facade for a lease fee from the owner. The system delivers an agreed upon level of thermal and visual comfort to the occupants; minimizing the energy operating cost is now to the advantage of the lessor, as is high quality maintenance to prevent premature failure, ensuring a longer life. The underlying facade elements can be designed to be updated and replaced over time as needed, thus minimizing energy use and carbon emissions but maximizing comfort and related services. It would be useful to explore this model in more detail to better understand how or if it might become a viable commercial offering.

9.6 Advocacy for embodied carbon considerations in planning and zoning to disincentivize demolition and re-build.

Making it less easy to knock down and rebuild will drive a focus on renovation and reuse, including the building envelope. Adopting embodied carbon considerations for the treatment of existing buildings in planning and zoning regulations would have the benefit of reducing demolition and increasing renovation of existing buildings. In doing so, façade renovation could be more justifiable, since there isn't an easy, lower cost demolition route. Financial incentives, such as those described above, could then be used to subsidize the cost of renovations.

This is likely to be a heavy lift since planning and zoning is under the jurisdiction of cities and states, but a set of model rules could be developed for adoption. Organizations such as IMT or the New Buildings Institute (NBI), who are already working at the local level and creating model regulations in adjacent areas, could collaborate with subject matter experts on embodied carbon and façades.

Concept 10: Enhance domestic supply chain competitiveness

A challenge that needs to be considered when developing policy to drive high-performance façade implementation is how to develop capability and reduce cost in local supply chains to assure local production capacity is available to support widespread decarbonization across the country.

With increased construction costs and the current challenging financing conditions, developers are increasingly looking outside of the U.S. to more developed international markets, like Europe and China, and to even developing markets like India and South America, to provide the needed higher performance products at lower cost. The European market has already achieved the economies of scale for high-performance fenestration products, including those that meet Passive House performance standards, and this performance has become business-as-usual along with mass-market pricing.

Project teams report that the international fenestration market currently offers developers significant opportunity for cost savings while still meeting the demand for high-performance. One participant cited a recent award of a large, unitized curtain wall contract to a company with an international supply chain for which all material will be sourced and fabricated overseas. No company with a North American sourced supply chain or fabrication facilities could come close to competing on price for the same performance.

Supporting this experience, according to data published by the U.S. Census Bureau (figure 30), imports of insulating glass from Europe to the U.S. has increased by 57% in just two years from 2021 to 2023¹³⁴. Vinyl window imports have increased by 71% over the same time. Aluminum window imports have increased by 50% compared with pre-pandemic levels. While there is some inflation baked into these numbers, inflation does not account for all this increase.

¹³⁴ <https://usatrade.census.gov/index.php?do=login>

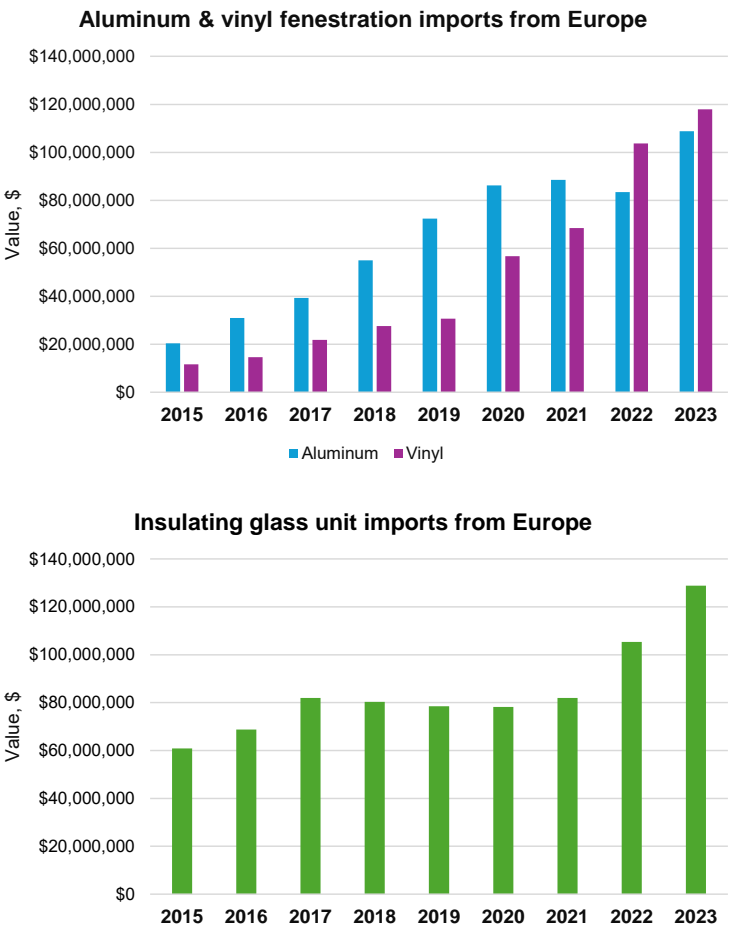


Figure 30: Import data for aluminum and vinyl fenestration and insulating glass into the U.S. from Europe. Source: U.S. Census Bureau.

Digging further into the import data at the state level, it is even more illuminating. Insulating glass unit imports from Europe into Massachusetts have doubled since 2019, presumably because of the drive to triple-pane insulating glass which is by many accounts up to 30% less expensive than when sourced domestically. Likewise, vinyl window imports to New York and Massachusetts have almost doubled and tripled respectively, since 2021. These jurisdictions are driving Passive House type performance in multi-family residential buildings.

Until the local domestic capabilities can compete with international markets to deliver the same high-performance at competitive cost, there is a significant risk that domestic market supply capabilities will be driven down and be unable to invest in R&D and the production capability, creating an even higher barrier to achieving building decarbonization goals. It is critical that there is a domestic market ready and able to meet the demands of high-performance façades required to move rapidly towards decarbonization goals.

Conclusions and recommendations

This research has shown that there are many barriers to the widespread adoption of high-performance fenestration and façade systems, many of which are interconnected and part of cascading causal relationships which create a complex web of interactions and interconnected dynamics. Transforming the market is not simple because of this complexity and legacy structures and processes, some of which are challenging to influence. Of course, if it was easy, the solution would have been found by now.

There is no one single silver bullet that will accelerate market deployment of high-performance fenestration and façade systems – even sweeping nationwide adoption of the newest model codes (unlikely though that may be) needs capacity building, tools, and enforcement. A coordination of multiple approaches including tools, training, standards, codes, innovation, and incentives is needed. The success of such a coordinated approach has been seen in Vancouver, BC. A piecemeal approach will not be effective.

An extensive blueprint for action has been proposed for both new construction and to drive façade renovation. Many of the concepts need further vetting to explore technical and implementation feasibility, such as, for example, the development of a non-residential façade Energy Star® program.

Some ideas need less vetting for feasibility and can be considered basic foundations for market transformation. Ideas that could be considered in this category are, for example, the promulgation of the new NFRC non-residential fenestration rating program, improvement and broadening of NFRC rating systems, a guideline or standard for high-performance façades, strategically targeted financial incentives that foster key innovation and deployment program gaps, and broad-based training programs. Cross-cutting education and training programs are clear needs and could be initiated with a scoping activity to identify the key learning outcomes for each constituency.

While developing new policies and programs to drive high-performance façades in new construction and retrofit, it will be important to identify ways to support capacity development and competitiveness in domestic supply chains to ensure the domestic industry is positioned to support expected growing decarbonization needs across the country in future decades and prevent unintended market supply consequences.

The following are recommendations for the next steps:

1. **Initiate work on the foundation activities of Concept 1 – above code program for high-performance facades**, up to and including developing standards for façade performance that are sensitive to building type, size, ownership and climate. The standard for façade performance is key to using incentives to drive façade performance. Once the standard is complete, an evaluation of a certification program could occur.
2. Initiate scoping and evaluation work for **Concept 2 – tools and programs to communicate economic value to owners including both energy/carbon benefits as well as non-energy benefits**.
 - What demonstration programs are currently available that can be modified or used to demonstrate the triple bottom line?
 - Outline a guide for assessing the financial impact of IEQ benefits, identifying information or research gaps to be addressed.
 - Scope out the suggested tools. What are the market needs? What data and tools are already available?
3. Initiate **research on the existing San Francisco Bay eco-system of high-performance non-residential buildings** to understand the drivers on both the supply and demand side. Use this as a first step towards developing and launching a broader targeted market awareness campaign on “why windows matter” (Concept 3).

4. Initiate **research to determine detailed market requirements for high-performance curtain wall and window wall**, including long-term serviceability requirements. Define and support any new fundamental R&D needs and develop a prize program to incentivize near term commercialization of new products from multiple manufacturers (Concept 4).
5. Scope an **installer training program for high-performance fenestration** collaborating with AGMCC (Concept 4).
6. Evaluate and scope a **façade engineering certification program** (Concept 5), gaining feedback from façade professionals on the benefits and potential challenges and experience from similar programs in Europe.
7. Scope and outline **a cross-cutting educational program** (Concept 6) on façades. Identify the learning objectives and outcomes for each stakeholder group, key content requirements, partners for deployment, risks and challenges, relevant international experience, etc. Include an education and marketing program targeting ESCOs for secondary glazing solutions for retrofit (see #11).
8. Engage **the insurance industry to explore opportunities** for using insurance vehicles to de-risk new façade products for manufacturers, installers, owners, etc.
9. Evaluate **façade carbon credits** to drive adoption of high-performance facades by providing new funding opportunities associated with deployment of low carbon design solutions.
10. **Enhance the impact of codes on high performance façade solutions**– it is likely that “what got us here may not get there” – that is get us to our nation’s 2035 and 2050 decarbonization targets. How can we enhance the existing role that DOE plays working with partners at the local, state and national level in changing the structure of building codes and aligning more with envelope performance issues and opportunities? Adding thermal resilience and daylight and views requirements to the codes would prevent unintended consequences and provide better balance. Indeed, simply including thermal resilience requirements would drive an envelope first design approach without having to change the structure or stringency of the model energy codes. In fact, it has been argued that a simple recipe for change is to require (1) appropriate thermal resilience performance, (2) good quality control of construction through commissioning and air-leakage testing, and (3) effective training of professionals on how to simulate, design and construct façades.
11. **Develop an awareness campaign** for energy service companies (ESCOs)¹³⁵ and building owners for **secondary glazing system retrofits**. Energy service companies develop, design, build and arrange financing for projects that save energy and reduce energy costs. Their compensation is typically linked to the energy savings achieved. Typically, window and façade retrofits are not proposed because of their expense, complexity, and long payback period. If professionals driving energy retrofit solutions in existing buildings were more aware of the products and performance of secondary glazing systems, there would likely be a higher uptake of the technology and concomitant energy and carbon savings.

¹³⁵ <https://www.energy.gov/femp/energy-service-companies>

Appendix A: Data generation methodology

The premise of this project is that there are examples of well-designed, high-performance fenestration and/or façades in place today, but they are uncommon - they are the exception but not the rule. Since the technology, systems, tools and knowledge base seem to be available to some to execute such projects, the research question was why do we not see more high-performance façades implemented on a more routine basis?

Since the challenges seemed to lie mostly in deployment, the research methodology focused on seeking feedback from a wide range of professionals working across the entire non-residential and multi-family building design and construction value chain. The goal was to understand where and why each sector of the supply chain encounter challenges to using high-performance façades and fenestration, and how these challenges differ depending on building and owner type, location, and other factors.

The very nature of this research means that somewhat subjective data is generated because it depends on an individual's personal experience and viewpoint. In cases where there are differences in experiences and / or opinion both contrasting viewpoints are given.

The Façade Tectonics Institute (FTI) is fortunate to have a diverse membership that spans all the key stakeholder groups that needed to be engaged by this project. Many of the FTI members are also deeply engaged with numerous other public and private entities, industry associations, trade groups, standards organizations etc., not only in the U.S. but globally, which was very useful in understanding best practice and contrast business-as-usual globally.

Stakeholders engaged

The general categories of stakeholders engaged in this research are listed below and a list of more than 100 individuals who contributed in various ways are provided in participants list, along with their company affiliation and specialty.

- Non-residential architects from small (local, 1-2 offices), medium (regional, 2-5 office locations), and large (national and/or international) architectural firms.
- Consultants and engineers, including envelope consultants, façade engineers, energy engineers, building scientists operating at both the national and local/regional level.
- Cutting edge project teams that are engaging in, for example, net-zero energy, Passive House, and Living Building Challenge projects.
- Building owners and/or their project managers
- General contractors operating at the regional and national level
- Glazing contractors from medium (regional) and large (national/international) size firms
- Non-residential fenestration fabricators (windows, curtainwall, window wall)
- Non-residential glass fabricators (IGUs)
- Material suppliers such as for flat glass, sealants, thermal barrier materials, interlayers etc.
- Educators and academics
- Code / local officials responsible for developing and enforcing energy codes

Ensuring geographic and climate diversification in the data collection was also a focus. Participants were sampled from locations with more forward moving codes such as Seattle, WA, Vancouver BC, Toronto ON, Massachusetts, and New York City as well as participants working in locations where business-as-usual fenestration performance is limited.

Gathering Input

With a group this large and diverse, and the very broad subject matter of “high performance facades”, the initial goal was to explore the range of subjective responses and from these build a framework to effectively organize and summarize the complexity of responses.

A series of face-to-face and virtual meetings were completed with groups of 5 to 25 participants to explore the topic. The initial moderated discussions revolved around a series of three broad questions:

- **What are the barriers** you have encountered to the use of high-performance fenestration in new and existing buildings?
- **Under what market conditions** (economic incentives, public policy, mandatory codes, owner approach, market dynamic, etc.) have you experienced high-performance fenestration to be successfully installed on the building?
- **If you had a magic wand**, what combinations of carrots (incentives), sticks (codes/regulations), software tools, market conditions, etc., would you wish for that you believe would drive more extensive use of higher performance fenestration?

Written surveys containing these questions were also conducted at several FTI forum events to broaden yet further the feedback.

Some underlying issues that were represented in the responses as given were clarified and teased out through additional lines of question and engagement with additional stakeholders. While there was broad agreement on many issues, there were also some divergent views expressed. This was not unexpected given the range of participants’ roles in the design and construction process and the different markets explored. The report preserves, and in some cases highlights, those differing views as they represent a market reality that must be addressed.

The feedback from the first several round table discussions was organized and assembled into a list of seven high level barriers, and their accompanying, often cascading root causes. Those results were then tested with some of the later groups to explore agreement, disagreement, and identify missing items or interconnections. The final summary of barriers is illustrated conceptually in Figures 4 and 5 and described in more detail in the Barriers section. Some high-level barriers like “significant first cost increase over BAU” stood out as key obstacles and were explored further with a deeper dive into the cost issues in Figure 6.

Once the barriers were fully explored, discussions were refocused on identifying successful solutions to overcome the barriers and on exploring jurisdictions and organizations which appear to be effectively overcoming these barriers. The latter research, which involved interviewing participants with first-hand experience, generated six case studies in this report: Vancouver, BC; Seattle, WA; Massachusetts; London, UK; Passive House development; A developer led Living Building Challenge certified office building.

Based on participants’ identification of barriers and their ideas for solutions to address, plus the strategies that appear to be successful in the case study examples, a series of nine recommendations were developed to address those barriers. Some of these are standalone topics and others might be elements of a larger program to more aggressively address the needs, gaps and barriers outlined above. Collectively they represent key elements that might be expanded upon by DOE and other interested partners to advance the marketplace for high performance facades. A tenth recommendation is made to address a potential unintended consequence on the domestic supply chain of driving to high-performance façades.

Appendix B: Glossary

Airtightness or air-leakage – is the measure of the amount of air that transfers across the building envelope. Heat and moisture transfers with the air, which is why air-leakage can be a large contributor to the poor performance of building envelopes. A ‘tight’ enclosure according to the ASHRAE Book of Fundamentals is less than 0.10 cfm/sq.ft. @ 75 Pa (0.3” of water). Most curtain walls can achieve an air-leakage of 0.06 cfm/sq.ft. at 75 Pa but achieving 0.10 cfm/sf at 75 Pa on a whole building level can be a challenge. In the PHIUS system, 0.040 cfm/sf at 50 Pa is the maximum leakage permitted for certification.

Business-as-usual (BAU) – Currently the typical designs, materials, assemblies and construction methods used to construct building façades.

Curtain wall – A non-load bearing exterior wall cladding which typically span floor-to-floor and is built outside of (or hung on) the floor slab edges. There are two main types: Unitized or stick-built. Unitized systems are built as pre-glazed multi-opening units in a factory, shipped to site for fast installation. Stick-built systems have framed openings built on-site and the insulating glass and any other components are then installed.

Energy performance gap – the often-large difference between the performance the building energy model predicts during design phases and the performance realized during occupancy as confirmed by utility bills¹³⁶. Measured energy consumption after occupancy can be higher and sometimes much higher than design predictions

Façade – the vertical exterior walls of a building that includes opaque and transparent elements.

Fenestration: Any transparent opening in a building envelope using glass (or other transparent material) designed to admit sunlight/daylight, air or people, such as windows, curtain wall, window wall, storefront, skylights, glazed doors (e.g. patio doors).

Glazed wall: A glazing system such as a curtain wall or window wall with opaque spandrel areas.

Greenhouse gas (GHG) – as defined by IPCC’s Sixth Assessment Report, the IPCC describes greenhouse gases (GHGs) as “gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths, within the spectrum of radiation emitted by the Earth’s surface, by the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapor (H₂O), carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄) and ozone (O₃) are the primary GHGs in the Earth’s atmosphere. Humanmade GHGs include sulphur hexafluoride (SF₆), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs)”¹³⁷. Collectively these gases contribute to global warming.

Non-energy benefits: Benefits that include, for example, reduced carbon emissions, increased occupant comfort, health, wellness and productivity, electrical grid resilience, passive survivability.

PACE loan – Property Assessed Clean Energy loan for improving energy performance. They are attached to the property, not the current owner. Certain lenders like Freddie Mac and Fannie Mae do not support them.

Passive House Design – Design principles focused on a fabric first approach, in which the envelope is well insulated and extremely air-tight with continuous insulation minimizing thermal bridging, with highly insulating fenestration sized and placed appropriately to manage solar gains. Heat recovery ventilation is used to provide excellent air-quality energy efficiently¹³⁸.

¹³⁶ Li, J., Iulo, L. D., & Poerschke, U. (2023). A Review of the Energy Performance Gap between Predicted and Actual Use in Buildings. *Building Simulation Conference Proceedings*, 18, 1973-1980. <https://doi.org/10.26868/25222708.2023.1430>

¹³⁷ <https://www.ipcc.ch/help/frequently-asked-questions/#:~:text=The%20IPCC%20describes%20greenhouse%20gases,atmosphere%20itself%2C%20and%20by%20clouds.>

¹³⁸ <https://www.phius.org/passive-building/what-passive-building>

PHIUS – U.S.-based Passive House certification program.

PHI – Passive House Institute, Darmstadt, Germany, is an independent research institute which developed and defines their internationally applicable certification program..

Reference service life – The period of time after installation during which a building, or its part, meets or exceeds the performance requirements¹³⁹.

Spandrel – Spandrel panels are opaque areas of curtain wall or window wall located between the transparent vision areas. They are typically opaque so as to hide ducting and other mechanical, electrical and plumbing systems between the floors of buildings. They are typically an integral part of a continuous vertical curtain wall, providing a continuous vertical surface.

Sustainable building – a new building or retrofit which has reduced its whole life carbon by at least 80% over its estimated service life based on a 2005 baseline for a given occupancy type, construction type and climate zone. This included embodied carbon. Based on IPCC recommendations, at least 80% is required to level off the accumulation of anthropogenic GHGs. Sustainable buildings also adequately support human health and well-being.

Sustainable façade – a façade that contributes to the realization of a sustainable building as defined above. Its assembly U-factors, SHGCs, WWR, and compactness will vary by climate zone, occupancy group etc.

Thermal bridge – An element on a building envelope that has higher thermal conductivity than the surrounding materials, which creates a path of least resistance for heat transfer.

Ultra-high-performance enclosure – in this paper, meeting or exceeding the performance guidelines according to PHIUS¹⁴⁰, which are specific to climate zones in the U.S.

Whole life carbon – the total embodied and operational greenhouse gas emissions accumulated during the service life of a building including material manufacture, building construction, use, demolition, recycling and disposal. Embodied carbon is determined by the impacts of manufacturing and sourcing materials and components assembled on site to complete construction; operational carbon includes all carbon emitted over the life of an operating building.

Window – An operable or non-operable assembly that is installed in an opening in an exterior wall (or roof) intended to provide view and admit sunlight/daylight or air into a building. It is typically framed and glazed with glass. Sometimes window is used as a group term instead of fenestration, to also include other types of fenestration.

Window-to-wall ratio (WWR) – The ratio of the transparent area of a vertical façade to the total area of vertical façade. For a glazed wall, where the spandrel covers the ceiling to floor area (~3-4 ft), floor-to-ceiling glass (~10 ft) would constitute a 70-75% window-to-wall ratio.

Window wall – In contrast to curtain walls, window walls sit on the floor slabs, spanning between slabs, floor to floor. They are also non-load bearing and typically are pre-fabricated as floor-to-floor units, coming to the project ready to install.

¹³⁹BSI, [BCIS](#). 2008. PD 156865. Standardized Method of [Life Cycle Costing](#) for [Construction Procurement](#). s.l. : BSi, 2008.

¹⁴⁰https://ssccust1.spreadsheethosting.com/1/bc/830791e0e82174/Phius%20CORE%20Prescriptive%202021_Snapshot_v3/Phius%20CORE%20Prescriptive%202021_Snapshot_v3.htm

Appendix C: Detailed list of solution ideas

Below is a list of ideas to address the barriers to adoption that were gathered from the round tables and interviews, sorted by type: Incentive targets, strategies, and types; tools, metrics and criteria development, policies; programs and policy; education, training and capacity building; energy codes and compliance; innovation.

Incentives	
Incentive Targets	Incentive Strategies/types
<p>Encourage owners to invest in higher performance fenestration/facades (note: For non-profit owners which are typically the ones doing better and who don't pay tax, need to make sure that the incentives make sense to them)</p>	<p>Taxes: Lower property tax rates, income tax credits (transferable)</p>
	<p>Valuable zoning: floor area ratio (FAR), building height, setbacks (Vancouver), expedited permitting, zoning reclassification (BC) Replicate the zoning incentives in NYC that grew out of Zone Green - it offers a Floor Area Ratio bonus for better performance per inch of wall thickness.</p>
	<p>Create “prescriptive compliance” incentives for high-performance assemblies</p>
	<p>Holistic incentives which look at energy and carbon</p>
	<p>Time-based incentives that can allow developers to take 2-3 months more to evaluate façade options (delay the time to revenue generation & offset the carrying cost).</p>
	<p>Utility cost reductions for owners/developers who own their buildings</p>
	<p>Provide payment per unit if multi-family building is constructed to meet higher level targets (ref. MA)</p>
	<p>Insurance credits for buildings meeting an identified building envelope performance target</p>
	<p>Funding mechanism: Create carbon offsets for improved façade systems (rather than giving offsets to solar farms). Demonstrate the carbon saved and sell those offsets to fund the added cost. This could be used for retrofits as well as new construction. There are challenges with quantifying operational carbon emission reduction over time. Opportunity to evaluate further in phase 2?</p>
	<p>Funding mechanism: Provide low-interest loans as an incentive - Investigate green financing and green infrastructure bank in Canada as models</p>
	<p>Funding mechanism: Engage insurance companies to reduce coverage costs for high-performance façades with a long service life (durability standard, resilience, passive survivability, service life)</p>
	<p>Require the appraisal process to include energy performance as a criterion.</p>
<p>Encourage (1) developers to hold a building for 10 years and (2) long-term anchor tenants to sign long-term (15 year) leases to guarantee income for developer for a building with a high-performance façade</p>	<p>A capital gains tax exemption for developers who keep their properties which have high-performance façades for 10 years or more (opportunity zone expansion)</p>
	<p>Utility cost reductions for tenants/owners</p>
	<p>Utility loans for tenants/owners – a model where the cost of energy savings that will be made later (over time) can be deducted upfront in a loan format and repaid later in energy savings.</p>

<p>Encourage façade improvements over HVAC improvements – less whole building focus, more façade focus – when designing incentive programs.</p>	<p>Create a federal tax incentive, like the current electrochromic incentive in the Inflation Reduction Act, but much broader to be façade or fenestration performance-based and referenced to a performance standard.</p>
	<p>Fund free façade design charrettes and provide utility rebates if built as high-performance (Enbridge Utility, “Savings by Design” Canada)</p>
	<p>Provide funds for (qualified) façade consultants to offer services to owners that commit to building higher performance facades on specific projects and to have the façade consultants involved in the early stages of the design</p>
<p>Encourage upfront design analysis work on the design side. This may be more scalable or have more leverage in decision making than a direct rebate as there may not be sufficient dollars.</p>	<ul style="list-style-type: none"> • Fund free façade design charrettes and provide utility rebates if built as high-performance (Enbridge Utility, “Savings by Design” Canada) or • Provide funds for (qualified) façade consultants to offer services to owners that commit to building higher performance facades on specific projects and to have the façade consultants involved in the early stages of the design
<p>Encourage service life specification/commitment to quality through specifying e.g. ISO15686-1:2011 or Canadian Durability standard CSA S478-2019 and commissioning (see below)</p>	<ul style="list-style-type: none"> • Financial incentives for requiring a service life/durability commitment
<p>Encourage full envelope commissioning (air leakage, thermal bridging, plus validation of wall and fenestration assembly performance against specification/code) to demonstrate as-built quality/performance.</p>	<ul style="list-style-type: none"> • Financial incentives for full envelope commissioning to cover the risk of rework and sufficient to build capacity in commissioning services/quality installers, including planning, during installation inspection, air leakage testing, thermal bridge management, fenestration verification. Incentives should accrue to the owner, architect, contractor, and subcontractors to offset their risk
<p>Encourage installer, inspector, testers to become trained/proficient to prepare for commissioning requirements</p>	<p>Free or subsidized training for installation and quality control and commissioning professionals in combination with commissioning incentives</p>
<p>Reduce risk for all participants in the team – architect, GC, glazier etc. (not just incentive to owner) by spreading incentives across several parties for adopting high-performance systems or for proving performance after construction (commissioning)</p>	<p>Subsidize/pay for professional training/certification for installers and designers/consultants to support move to commissioning/outcome-based targets</p>
	<p>Free/low-cost insurance for schedule, performance and durability risk to de-risk use of new products/designs – for all parties in the project.</p>
<p>Encourage glazing sub-contractors to manage the risk of departing from the status-quo (and not baking risk into the cost of high-performance).</p>	<p>Subsidize/pay for professional training/certification for installers for high-performance products/systems</p>
	<p>Insurance schemes to reduce schedule, durability and performance risk of new products/installations</p>
<p>Encourage façade retrofits by making them more financially viable</p>	<p>Financial incentives for the owner through 179D tax credits and other local funding vehicles</p>
	<p>Fund the initial condition survey to de-risk it</p>
<p>Encourage contract models/delivery processes such as IPR, design build or construction management with design assist rather than design-bid-build.</p>	<p>Rebates/incentives for P3/design-build/IPR process that brings all stakeholders to the table early.</p>
<p>Encourage design teams to have glazing subcontractor/façade consultant at the design table early – as early as the HVAC contractor/consultants.</p>	<p>Rebates/incentives for P3/design-build/IPR process that brings all stakeholders to the table early.</p>
	<p>Keep the R&D tax credit to support innovation. Perhaps build on it for façade related innovation?</p>

Reward manufacturers for bringing new technologies to the market. Don't let them have to wait for competitors to catch up	Fund many small (\$50K-\$100K) incentives to fenestration manufacturers to develop higher performance systems in targeted areas, e.g. spandrel, window wall, etc. to increase capacity and competition. (Reference BC Mining incentive for windows)
Encourage business model change to “ renting of façades ” – to reframe cost from upfront capital cost to monthly operational cost.	Provide funding incentives/finance models where their risk of upfront cost is lowered by having long-term contracts from owners (reference TU Delft)

Tools, metrics, criteria development

Create metrics for non-residential / multi-family residential fenestration and façade performance to allow quantification of high-performance. (Evaluate Thermal Energy Demand Intensity (TEDI) for cooling dominated climates and alternative options if not appropriate, review Ted Kesik's approach using a unified method including heating, cooling, embodied carbon). Include daylighting and comfort metrics to ensure a balanced approach, as well as embodied carbon. <i>This would be a recommended phase 2 activity.</i>	Create definition(s) of/criteria for high-performance fenestration and façades for incentive programs to reference using metrics above – these would change over time and must be a function of climate, building type, structural requirement etc. - include embodied carbon, daylighting, comfort, resilience - Could start with fenestration, or even a subset of fenestration (punched opening windows) and progress to all fenestration and then façades. However, by delaying the attention on façades, we are ignoring thermal bridging and air-leakage which are two large sources of performance degradation. <i>Developing such metrics could be a phase 2 activity.</i>
ROI/NPV tool: DOE create a credible, interactive, easy to use tool(s) to support communication and quantification of non-energy benefits of high-performance fenestration/façades. It would be easy to present to building owners/developers and tenants the ROI and NPV, including all aspects of a high-performance façade, including energy, HVAC size reduction, trade off with perimeter heat/cooling, estimate dollar value of productivity/retention based on thermal/visual comfort/IAQ, impact of durability, leasable space increase, lease rates etc. DOE create a credible interactive tool to support communication and quantification of the non-energy benefits.	Develop a schematic design façade analysis tool that can support doing quick analyses of envelope systems which outputs comfort, daylighting, energy/peak demand, HVAC size impacts, perimeter heating/cooling requirements, and the cost savings related to that. • A tool from the national labs that can quantify the impact of thermal/visual comfort & daylighting could support owner education and more sophisticated cost-benefit analyses. Create a process flow chart with tools that are available at each stage for analysis
Better building energy simulation tools: Ensure thermal bridging at interfaces can be accounted for and can work for Passive House projects, and don't underestimate enclosure performance. Require this for code compliance.	Create better/easier to use daylighting tools
A standard process for building energy simulation (see City of Vancouver). Ensure that thermal bridging at interfaces in simulation. Edit the ASHRAE handbook of fundamentals to say that modelers can't use the parallel path methodology for calculating thermal transmittance and need to model the linear interfaces and point bridges.	Integrate lifecycle carbon into façade analysis tools/metrics • Integrate lifecycle carbon analysis into metrics/requirements so that operational performance isn't driving unnecessarily high embodied carbon. • Standardized tools/data sources for determining embodied carbon A simple tool to support evaluating operational carbon versus embodied carbon – to be used at scale
THERM upgrades: Create easy-to-use 3-dimensional thermal modeling tool to replace 2-D therm. Include moisture transfer. Make THERM more user friendly taking clues from FLIXO.	NFRC standard/rating for fenestration installation (psi value of installation, like in Passive House).
NFRC: Recognize thermal bridging in spandrel performance	NFRC: Ensure new non-residential certification program is sufficiently easy for custom curtainwall
NFRC: Certify performance data for Passive House compliance	Improve predictive modeling to support BPS and outcome-based performance.

Programs/Policy	
Develop a non-residential Energy Star program for fenestration and/or façades that defines high-performance to combine with incentive programs (<i>use metrics and performance definitions noted in metrics section</i>). The scope could vary initially from simple punched opening windows in specific small building types to complex façade-based approach which considers holistic metrics (thermal, solar heat gain, daylighting, air-leakage, thermal bridging etc.) <i>A phase 2 activity.</i>	Fund more field studies (before/after) to demonstrate the triple bottom line advantages of high-performance façade systems. Data can feed into tool for NPV/ROI.
Modify or expand the Green Proving Ground program to minimize risk in a more scalable way than currently. Ask GSA if there is anything missing.	Fund programs that demonstrate what success looks like in high-performance façade design
Increase energy costs (without impacting most vulnerable populations). If we had to pay the full cost of energy, this would affect the way people think about payback on upfront costs.	Review GSA's design excellence program to see what attention there is to facades and make recommendations to adjust. In general, explore the effectiveness of award programs to drive adoption (Phase 2).
Create insurance programs that insure new products , covering the cost of replacement, delivery delays, lack of performance, and any other potential liabilities) until they are field proven to support contractor adoption. <ul style="list-style-type: none"> • Condo market could be a good market for this because of litigious history • Have a good Samaritan law where architects can't be sued in pursuit of higher performance. 	Develop a certified simulator program (aligned with standardized procedures) and require this certification for code compliance.
Develop a certified envelope commissioning agent program (aligned with standards) and require it for code compliance or recommend requirement in specifications.	Bring experience/case-studies from Europe to get the 10 years' experience requirement.
Emulate Buildings of excellence program (NYC, MASS SAVE) at a national scale with a focus on high-performance facades/fenestration.	Programs that support thinking of façade cost based on cost/month rather than upfront cost (like homes and cars)
Create guidebooks for retrofitting "typical" buildings (like the Philadelphia "rowhouse" manual)	Create carbon offsets for improved façade systems (rather than giving offsets to solar farms). Demonstrate the carbon saved and sell those offsets to fund the added cost. This could be used for retrofits as well as new construction. There are challenges with quantifying operational carbon emission reduction over time. Opportunity to evaluate further in phase 2?
Increase adoption of building energy labeling and performance standards	Integrate evaluation of retrofit vs rebuild in the building plan/code approval process (like London and Paris). Developers would need to be able to provide that it is more effective (on a carbon and other basis) than to retrofit.
Focus R&D investment on funding testing of products to reduce adoption risk	Marketing program – to consumers and building owners about benefits of high-performance windows
Change funding structure of state/local code enforcement/development offices to provide more capability for plan/simulation/envelope detail reviews and code development.	Take Back requirements – require enclosure contractors to take back their products at end-of-life and fully reuse or recycle them. Most glass is still landfilled.

Education and training – Capacity building	
<p>General: Drive education and practical training related to high-performance façades and components, their energy and non-energy benefits, design and installation in all silos. Tailor the education to each stakeholder group, including owners and developers.</p>	<p>Architect education – develop educational programs to ensure understanding of how façades get built (basic), the performance of fenestration and systems, and specific education on high-performance strategies (like Passive House, net zero).</p> <ul style="list-style-type: none"> Engage with AIA to educate smaller architectural firms <p>Create a basics of fenestration and façade education series (FTI could do this) and collaborate with AIA (may need \$\$) to drive to widest audience.</p>
<p>Local policy makers: These are the people in cities and states that choose to adopt model codes and/or incentive programs. Develop education programs for politicians, code departments, local utilities to build knowledge and confidence in adopting newer model codes and incentive structures.</p>	<p>Façade consultants – develop and deliver practical education that builds capacity in the industry to design, engineer, supervise installation, and commission high-performance façade systems.</p> <ul style="list-style-type: none"> Blower door testing capability Specific training for field testing and commissioning Energy simulation and thermal (THERM/WINDOW) modeling <p>Develop Façade Consultant Certification Program</p>
<p>Owner/developer: Focus on the importance of the building envelope, especially on durability, passive survivability, resilience, daylighting, comfort, productivity, health, lease rates, perimeter heat/cooling system offsets, rentable space, and how to quantify it alongside energy savings and upfront cost.</p>	<p>User/tenant education – educational programs focused on the benefits (non-energy and energy) of high-performance façade systems. Objective: Make occupants ask for high-performance façades instead of marble entryways, or to ask for floor to ceiling glass with appropriate comfort. “Find ways to encourage people to want their buildings to be as good as they want their phones to be!”</p> <p>Condo owners may be a good target, since high volumes of condos are being built at lowest performance possible with expected short façade life. Learn lessons from tech driven cities (like the Bay Area) where commercial tenants are driving performance and transfer to other cities</p> <p>Launch consumer marketing program for why windows/facades are important – turn windows/facades into the new “marble countertop” to drive market expectation/demand.</p>
<p>Building envelope commissioning: Create scalable training programs for installers/designers/engineers</p>	<p>University education – Prepare the next generation of designers by constructing syllabi that teach building science, practical application in façade, and non-energy benefits. Interaction with practicing professionals is key. Need to be able to teach skills to analyze new materials/systems.</p>
<p>Glazing/façade subcontractors: Develop advanced training for installers to support installing high-performance systems. [Collaborate with NACC who run the first contractor certification program].</p>	<p>Code officials – Education and awareness program on the impact of high-performance façades, how to identify thermal bridges, NFRC non-residential certification requirements, help in driving compliance related to fenestration performance, new code requirements.</p>
<p>Determine effective methods for air-leakage measurement in large buildings</p>	<p>Educate city/state planners/planning committees on the issue of retrofit vs demolition/rebuild</p>

Energy codes and compliance	
Incentivize states and cities to adopt the most recent model codes (or find a way of having a national energy code).	Restructure code development so that the code signals the requirements for the next iterations . In so doing, create a roadmap for the industry to work towards (like the BC Step Code)
Make national model codes more stringent – have larger leaps (reframe cost-effectiveness requirement to facilitate).	Create a national tiered stretch code . Each state can choose which tier/level to enforce.
Introduce carbon as a metric and targets in model codes (not just energy cost)	Use absolute performance targets (EUI and an envelope metric, e.g. TEDI/cooling climate option) rather than relative performance targets with examples of pathways to achieve (DOE could create guidelines and/or tools to support). Create daylighting targets to ensure adequate use of glazing.
Have specific minimum performance targets for the envelope , like TEDI for cold climates, or minimum area-weighted U-factor performance. Limit the performance trade-off that can be made with shorter lifetime internal systems (HVAC, lighting). Need: Evaluate alternatives for envelope metrics for cooling dominated climates, trade-offs with embodied carbon (Phase 2 activity).	<ul style="list-style-type: none"> Require buildings to be designed for 100 years (see ISO 15686-1:2011) or Require a service life commitment/commitment to quality (like ISO 15686-1:2011 or Canadian service life standard) Encourage service life specification/commitment to quality through specifying e.g. ISO15686-1:2011 or Canadian Durability standard CSA S478-Guideline on Durability in Buildings that could drive higher performance
Provide alternative compliance pathways in addition to standard pathways.	Adapt Canadian S478 durability standard for the U.S. and integrate it into model codes . Would require a maintenance/durability plan for the building envelope.
Simplify codes – pathway for performance needs to be well defined so that they are easily enforced. (Issue in Massachusetts).	Require proof of performance (NFRC label, drawing reviews vs. specification, testing, commissioning) to be provided to the code official to validate what's getting built. Have impactful negative consequences (more teeth) for non-compliance.
Code departments should require final fabrication drawings (e.g. fenestration, opaque assemblies) be submitted for a final code review to ensure energy code compliance (like NYC).	Require NFRC label certificates/labels for all fenestration be submitted to the code official for compliance verification.
Better educate code officials (increase capacity for enforcement)	Require thermal bridges to be identified on the documents submitted for code compliance.
Require thermal bridge mitigation in energy codes (recognize thermal bridging in opaque systems)	Require design teams to prove assembly's thermal performance – require thermal modeling – and if it doesn't work as designed then prevent use.
Train code officials to identify thermal bridges on plan documents and assess fenestration performance through NFRC certification documentation	Retrofits: Make Building Performance Standards more widespread and give them more teeth , so it is cost effective to do an envelope renovation/retrofit. This also impacts new construction decisions for future-proofing.
Require use of standard simulation procedure for performance path compliance (see city of Vancouver).	Mindset shift – rethink approach to energy codes in terms of how façade performance impacts life safety, human well-being, passive survivability, resilience and durability. Alternatively, require the building code to have a requirement for thermal resiliency, daylight and occupant comfort for appropriate building types in addition to acute safety requirements.
Require certified simulators to complete performance path simulations.	Design codes that are more attuned to surrounding ecosystems
Is there a similar path in non-residential construction for incentivizing triple pane vs adding more insulation as there is in CA residential?	Implement a whole life carbon code; recognize that this is a complex issue and hard to do.
Follow European model of high-cost (non-subsidized) energy and nationwide stringent codes (low probability)	Currently we design buildings for extremes – should we change this and expect people to put on a sweater in winter and wear short sleeves in summer?

Innovation	
Need faster evolution of curtainwall performance especially spandrel – it has fallen far behind and needs to match performance of opaque wall. Look to Europe where precast/GFRC/UHPC mega-panel approaches have displaced the traditional curtain wall.	Fund more in-house façade R&D at architects
In Europe there is an R&D collaborative – can we recreate this in the U.S.?	More cost-effective high-performance window wall.
Fund RD&D for increasing serviceability, upgradeability, etc. for glazed wall systems	