Transforming Markets for Commercial Building Façades

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ABSTRACT

The facade is the linchpin of building performance, impacting operational and embodied carbon related to energy use, grid demand, and resilience. It also provides valuable benefits such as occupant comfort, view, health and wellbeing, and iconic imagery. Yet the performance of façades using business-as-usual (BAU) design and construction methods remains poor relative to what could be achieved if proven product technology and high-quality installation processes were fully utilized with optimal design.

These gaps between performance potential and market reality can only be closed with 1) a clearer understanding of technical and market barriers and 2) strategic, programmatic action that implements needed change. In 2024, we completed a research study for the U.S. DOE which laid out the complex, interconnected barriers to adoption of high-performance façade systems in North American new and existing non-residential and multi-family buildings. It identified strategies to address gaps across seven classes of barriers and pinpointed states and cities where adoption of high-performance facades is accelerating, along with key drivers enabling broader market adoption. One of the key barriers to adoption was the lack of a definition for, and verification of, high-performance façades.

We now present new research results outlining the key requirements of an above-code façade-specific program that, when combined with financial incentives, has the potential to accelerate adoption of high-performance façades, transforming BAU façade performance. A framework for such an above-code program is described, with recommendations on scope, and guidelines to support adoption by design teams and jurisdictions. Success requires engagement with partners in AEC community, utilities, NGOs, government, financial institutions, education, and business beyond the façade community.

Introduction

Today, it is impossible to create a high-performance building without a high-performance façade for virtually all building types. The façade impacts a broad range of performance outcomes in the building – from annual energy usage and peak demand loads to building service life, to human impacts such as thermal resilience, occupant comfort, health, productivity, learning and wellbeing. However, there is a large gap between the performance of the current BAU façades installed in most non-residential and multi-family new buildings today and what is technically possible if commercially available high-performance fenestration and façade assemblies were used alongside best practice installation and operating processes. There is also an enormous opportunity to improve the performance of building façades in our existing building stock, where the performance gap is even larger.

Windows and façades are responsible for about 25% of U.S. building HVAC energy use or about 10% of total U.S. building energy consumption [1]. Fluorescent lighting, and later LEDs, plus powerful HVAC systems have made it possible to condition virtually any building design in the hottest or coldest climates, as long as one could afford the associated utility bills. However, occupants are often still thermally and visually uncomfortable on the building perimeter.

Progress has been made in developing thermally improved fenestration technology and enhanced management of solar heat gain, with the resulting potential commercial sector wide savings documented in several R&D studies [2, 3, 4]. However, the overall net deployed market impact on new and existing non-residential and multi-family building stock remains far below these technical savings potentials because the market share of the highest performance fenestration products remains small.

In addition, thermal bridging in opaque areas, such as spandrel and rainscreen panel attachments and at assembly transitions, and air-leakage, continue to be either ignored or ineffectively managed. These two issues have been identified as significant detractors from energy performance [5, 6] and significant contributors to the energy gap – that is, the gap between as-designed and as-built performance [7, 8]. The performance of the opaque areas of the façade has been systematically over-estimated because thermal bridging has been ignored. Only recently has thermal bridging been mentioned in the U.S. model codes [9], and even now the requirements for mitigation are minimal.

The combination of concerns about carbon emissions from energy use and overall sustainable design, have driven above-code rating and certification programs, such as U.S. Green Building Council's LEED program. These programs primarily target building design, but some have recently expanded to include measured building operations, rather than predicted assessments alone. Building performance standards [10], enacted by local jurisdictions, such as New York's local law 97, require building owners to report and subsequently reduce operational energy consumption, thus increasing the focus on delivering measured impacts.

Research shows that shifting from incremental savings to a net zero-building performance perspective requires a different approach than in the past, when tweaking lower U-factor and solar heat gain coefficient (SHGC) to minimize winter heating and summer cooling loads was the focus [11]. The new conceptual framework for the next generation of highly efficient buildings is developed around a three step, "envelope first" approach, that is tuned to local climate, site conditions, and occupancy:

1. Minimize winter thermal heat loss and summer thermal heat gain
2. Operate dynamic solar control solutions that minimize summer cooling energy and manage load shape, but also capture the value of heating season solar gain [12];
3. Use daylight to offset electric lighting energy use and manage load shape, through automatic dimming controls for electric lighting, while improving occupant health and visual comfort.

At the 2006 ACEEE Summer Study, Arasteh et al. [11] demonstrated that such integrated façade design strategies with dynamic solar control can convert windows in the U.S. commercial building stock that caused a net annual energy cost of ~$20B (1.5 Quads) to then provide an annual savings exceeding 1 Quad, providing a cost benefit of $15B annually (Fig. 1).

While simulation studies show the performance potential of these highly efficient, responsive façade technologies and design strategies [11], real-world practice lags the simulated results, despite the commercial availability, and operational track-record of many of these high-performance façade and fenestration assemblies. This is due to extensive market barriers which have been identified and explored in our prior study [13]. The high-level barriers are highlighted below and in figure 2.

Reducing those barriers to market transformation is critical to accelerating adoption of available technologies and delivering the façade performance needed to create climate resilient, energy efficient, and human supportive building environments. One promising approach, which has shown significant benefit for driving residential window performance, is the creation of an above-code program (Energy Star® for windows) that is often coupled with third-party financial incentive programs, e.g. from utilities. This paper describes the logic behind an initial road map for the development of an above-code program for high-performance façades in commercial buildings.

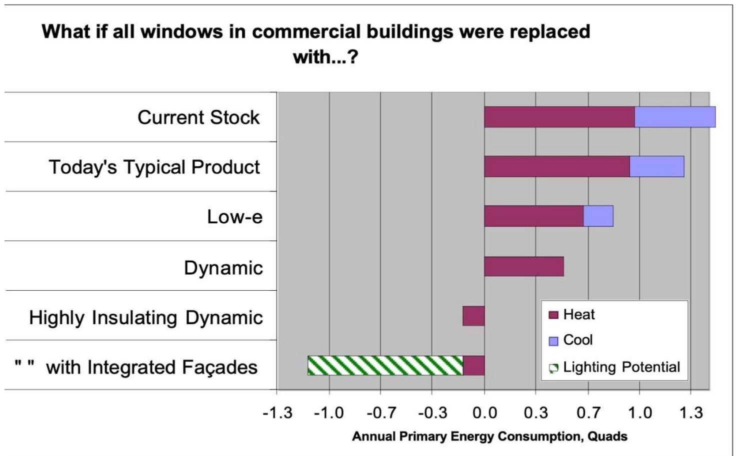

Figure 1: Impact on annual energy usage from building stock if all fenestration was replaced with higher performance assemblies [11]

As the nation focuses on the goal of lowering the energy impact of the overall building stock, we need a renewed focus on the building envelope to drive adoption of high-performance façade assemblies, systems and installation methods. Greater market demand will increase manufacturing economies of scale, expand design and installation capacity, spur investments in new technologies and lead to lower market costs and thus further market adoption.

The broad outlines of an “envelope first” above-code program for building design and retrofit are outlined here. However, the specific implementation pathways and new program actions will require further detailed thought, development, and testing.

In the following sections we summarize results of our 2024 study of the barriers to high performance facades [13] and the initial results of a new ongoing effort to catalyze and launch an above-code façade program for new and existing commercial buildings that could support market transformation. We hope by sharing our current “high-performance façade planning” with the broader ACEEE “energy efficiency” community, they can provide our project team with new insights and market connections.

Phase 1 Results: A Market Assessment and a Blueprint for Market Transformation

In 2024, the Façade Tectonics Institute (FTI) published a research report [13] detailing the many diverse and interconnected barriers to the market adoption of high-performance façades in non-residential and multi-family buildings. It also identified further barriers to retrofitting the façades of existing buildings. A summary of the seven high-level barriers can be seen in Fig. 2. Each of the seven high-level barriers has many underlying and interconnected root causes which are detailed in the prior study’s report. For example, one of the key reasons why there is an increased cost to implement a higher performance façade over a BAU façade, is that base energy codes set the cost base line. Model codes are not close to the highest performance nor best practice, they often allow the envelope performance to be downgraded via tradeoffs in return for higher HVAC, lighting and hot water system efficiencies, and the adoption by states is very slow. The report further laid out a 10-point blue-print of initiatives (Fig. 3), which if all implemented, could drive market transformation to higher installed façade performance. The cornerstone of the blueprint is the creation of an above-code program for non-residential and multi-family façades.

Typically, the model for market transformation is to use above code programs in

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 2: Map of the barriers to the adoption of high-performance façades in non-residential and multi-family buildings [13]. Credit: FTI

Blueprint for market transformation: Façades	
Concept 1	Develop an above code certification program for high-performance facades (and foundational systems)
Concept 2	Create tools and programs that improve the ability to communicate the overall economic value of high-performance facades to owners
Concept 3	Make windows the next “Marble Countertop” – a must have for owners and tenants alike
Concept 4	Ensure a sufficient number of high-performance window wall and curtain wall systems and trained installers available for a competitive market.
Concept 5	Create / identify certification programs for practitioners to verify competency, build capacity & improve façade simulation, design and execution.
Concept 6	Increase façade knowledge and education across the entire value chain
Concept 7	Create façade-focused incentive programs (to connect with above-code program)
Concept 8	Deploy code structure and deployment recommendations
Concept 9	Implement strategies to solve the retrofit challenge
Concept 10	Enhance domestic supply chain competitiveness

Figure 3: 10-point blueprint for change that FTI recommended to overcome the many barriers to adoption of high-performance façades [13]. Credit: FTI

combination with financial incentives to pull the top end of the market to higher performance (Fig.4). Early adopters use these programs to build better, and in doing so, new higher performing products and processes are vetted out and market capacity built. This results in reduced adoption risk and lower cost of high-performance solutions. It also supports investment by industry in new product development. Once the cost of high-performance comes down sufficiently, it can be adopted by the minimum mandatory codes, lifting the bottom of the market. This creates a virtuous cycle of regular increases in stringency and further energy and carbon savings.

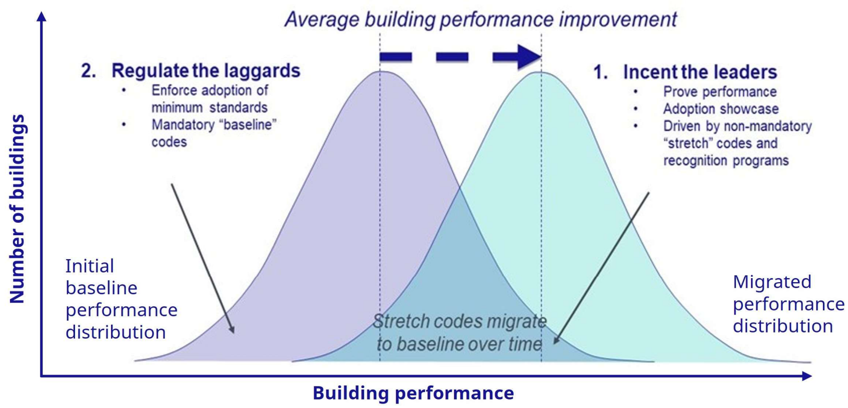

Figure 4: Virtuous cycle of high-performance adoption. Credit: Technoform

This phenomenon has been illustrated by the Energy Star program for residential windows (Fig. 5). The combination of a 30% homeowner federal tax credit, implemented by the American Recovery and Reinvestment Act of 2009 (ARRA), tied to the purchase of Energy Star windows, drove adoption of Energy Star windows to over 80% [14]. More importantly, after each cycle of stringency increase in the Energy Star program, the previous Energy Star performance requirements were adopted by the model codes, thus raising the floor.

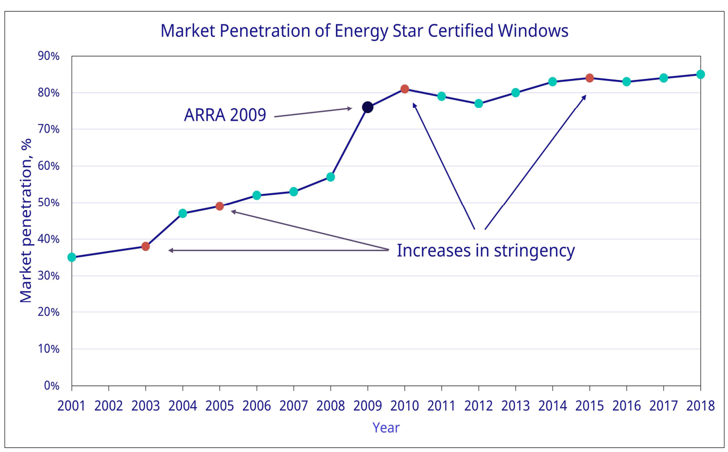

Figure 5: The market penetration of above-code Energy Star certified residential windows correlated to federal homeowner tax credits. Data: US EPA.

This provided meaningful increases in performance of installed windows in the low-rise residential market that has not been mirrored in the non-residential and high-rise multi-family market. It is believed that key to the success was that the Energy Star performance requirements, while more stringent than baseline codes, did not over-stretch the industry's capability to deliver products at prices acceptable for market adoption when considered alongside the financial incentives. Higher performance should cost more than code minimum compliance, but when coupled with financial incentives and demonstrated energy and cost savings over time, the result should ideally be close to cost neutral.

The lack of a standard definition for a high-performance façade, and a formal above-code program to certify performance against it, is an important missing element for commercial façade market transformation. This appears to be a mostly U.S. phenomenon because of the low stringency of the base codes and their lack of an envelope performance focus.

In much of Europe, base building codes, because of their structure and stringency, already drive a more envelope-first approach. In London, the above-code whole building performance program, NABERS (National Australian Built Environmental Rating Scheme), adopted from Australia, drives envelope-first design and construction without focusing on facades alone, because it rewards as-built and operated energy efficiency and occupant comfort performance. The key is as-built and operated performance – it is hard to deliver both without a focus on façade performance.

While there are building level above-code programs such as Energy Star or USGBC's LEED in the U.S., these programs focus on building level energy use intensity. In many cases, energy efficiency is achieved by using high-efficiency internal service systems such as lighting, HVAC and hot water heating. These often are used to compensate for the thermal losses and solar gains through a less efficient envelope. And since many programs are based on model energy codes, thermal bridge mitigation and air-leakage reduction and verification are minimal or entirely lacking. A façade's stand-alone performance in isolation from the HVAC system is critical for:

- **Delivering thermal resilience:** It is the only barrier protecting occupants from outside climate extremes in the aftermath of power outages.
- **Long-term in-service energy performance**: Any gap in envelope performance is carried with the building throughout its life since envelope replacement is not common, whereas HVAC systems are upgraded or replaced on a much shorter life-cycle.
- **Reducing risk of missing as-built energy performance expectations**: While energy simulations may indicate that trading off envelope performance for increased HVAC performance results in the same overall energy use intensity, in practice, it is likely not an equivalent trade off. For example, on the building's perimeter, a poor envelope will deliver poor occupant thermal comfort. Occupants will tend to adjust the thermostat to make the space warmer or cooler, increasing energy use over that predicted.
- **Electric grid load management**: Reducing peak heating and cooling loads are critical to proper HVAC system sizing and enabling grid decarbonization. With electrification of heating, grid loads are increasing and peak loads are moving to the early morning before sunrise in the winter. This becomes increasingly challenging as grids are powered from renewable sources.

It is important to note that we believe that while an above code program for high-performance non-residential façades is a key component of a broader market transformation strategy, it will not on its own be sufficient. Other strategies laid out in the market transformation road map will also be needed.

Objective & methodology: Outlining an above code program for façades

The objective of this study is to create options and outlines for possible structures of an above code program for façades used in non-residential and multi-family buildings. The first phase, described herein, does not aim to fully design a program, but rather to (i) identify the appropriate breadth of scope, (ii) outline important criteria and guidance for a program that the design and construction community, as well as policy makers, can effectively adopt, (iii) identify potential challenges, (iv) identify specific potential industry partners to co-develop such programs and (v) provide possible outline structures, along with advantages and disadvantages. This is an ambitious sector-wide undertaking, requiring time and persistent effort, particularly given the multi-year commercial building design-build-occupancy cycle.

Given this market reality, there is also a desire to identify potential "low hanging fruit" – concepts for a limited program which could be easier and/or faster to implement and which could be a beach head strategy for building a broader-scoped program. Such limited scope could include a program for fenestration only or one that is façade-focused, but only on energy efficiency, or a building occupancy focus, e.g. on schools or offices. Full program design will be the goal of a subsequent second phase, based on the road map generated from this study.

The main inputs for this study were gained through a series of stakeholder focus groups and one-on-one conversations involving over 50 participants from across the value chain. Stakeholders included architects (Walter P Moore, NBBJ, Techne, Adrian Smith+Gordon Gill), façade engineers (ARUP, SGH, WSP, Heintges, Socotec, Green Façades, WJE, Salient Engineering, Transolar), building scientists (RDH, Stantec), academics and national laboratories (University of Toronto, UC Berkeley, University of Loughborough, LBNL, NLR, ORNL), façade contractors, fabricators and suppliers (Enclos, Harmon, Kawneer, Pilkington/NSG, Vitro, Apogee) , non-governmental organizations involved in certification and incentive program development (NFRC, ACEEE, Stewards of Affordable Housing for the Future, Phius, Passive House California, 2050 Partners), and policy-makers from jurisdictions which have been focused on increasing stringency of envelopes (City of Seattle, Commonwealth of Massachusetts).

Experts in daylight metrics and thermal comfort were interviewed to understand best practice in these areas. Practitioners working in both heating and cooling dominated climates were interviewed, including those in Europe, to assess best-practice for solar heat management.

Participants were initially asked:

- What are the most important performance criteria for a high-performance façade against which every façade should be measured? Are there any secondary criteria that may be important for some building types, but not for others?
- What are the most important categories to differentiate façades, e.g. climate zone, orientation, window-to-wall ratio (WWR), building or load type, fenestration type or wall type used?
- Are there any building types that you believe would be a good first / more simple focus?
- What is the potential for using fenestration as a simple first step?

After concepts were elucidated and developed from the initial conversations, we asked for feedback on these specific program structure ideas in subsequent stakeholder meetings to build on, and understand the potential advantages and pitfalls, of each concept. Subject-specific conversations were completed with some stakeholders, especially related to thermal and visual comfort and daylighting to understand current best practices and standards and how they may be adopted.

Stakeholder engagement, while diverse, was weighted towards practitioners working on more sophisticated construction projects. By their very nature, façade consultants are brought in on more sophisticated façades, and so skew to larger, more complex, higher performance projects. That said, because of the challenges in understanding and complying with the new stretch code, façade consultants are being engaged on most projects in Massachusetts. Because the most stringent codes are in heating dominated climates, our stakeholders were initially aligned with solutions in those climate zones, but the stakeholder group was then broadened to account for issues more prevalent in cooling dominated climate zones.

Outcomes: Program Scope

The overwhelming feedback from practitioners that came through from focus groups' notes and transcripts and one-on-one conversations is that a high-performance façade is more than just high energy efficiency – any façade program must be also based on durability, occupant comfort and wellness and passive survivability. It is important that higher ratings in such a program should correlate to greater asset value, since economics is a key market driver. One of the ways to deliver increased asset value is to have greater certainty that the expected performance is delivered. Programs like LEED, where certification is often given based on predicted rather than actual performance, have been criticized because they struggle to consistently add asset value because of the gap between as-modeled and as-built performance. Energy simulations are notoriously poor building performance predictors and are typically most useful for comparisons.

Stakeholders felt that as-built verification measurements are critical for a program to reliably deliver increased asset value, and that those measurements should be made when initially occupied and regularly during a building's service life in order to maintain compliance with the program. While increasing asset value is a challenge with design-based programs, it has been shown to be possible with programs that demonstrate as-delivered performance. A clear example is the impact of the NABERS program in the UK and Australia. It measures and rates a building's actual as-operated energy performance and has been attributed to increasing competition in the real-estate market, with an associated increase in value for higher performing buildings in that program. Reports show higher NABERS ratings are associated with incrementally higher rents, better occupancy and higher valuation premiums [15,16,17]. Value premiums increase by 9% for NABERS 5-star assets. References of this impact come from market studies from building owner groups such as JLL and CBRE as well as peer reviewed technical studies.

There are many factors – some conflicting – that stakeholders felt should be considered together to provide a façade with balanced high-performance. The primary performance priorities identified by practitioners through interviews and stakeholder roundtables are:

- Thermal resilience (passive survivability)
- Façade-related energy load (e.g. using a Thermal Energy Demand Intensity (TEDI)-like metric measuring heating and cooling load caused by the façade), and peak energy loads to support grid resilience.
- Service life (including water management, condensation resistance, upgradability, design for disassembly, maintainability)
- Occupant thermal comfort
- Comfortable, glare-free sufficient daylight
- Quality views
- Lifecycle / embodied carbon

Thermal resilience, energy performance and occupant thermal comfort are very much linked. One could argue that specifying sufficient passive survivability (length of time during which a human survivable temperature is maintained during a power outage) should deliver high levels of occupant thermal comfort and energy efficiency. This performance linkage should be evaluated further, and to ensure that there are no unintended consequences relating to, for example, design for daylighting and views or other design priorities, which are very much building type specific.

Any program must deliver outcomes across these primary performance priorities. However, there were also some secondary performance outcomes identified that are important for some buildings, but not all and depend mostly on a building's location and potentially on occupancy type: *Acoustic performance, natural ventilation, wind load resistance, wind borne debris resistance, seismic resistance, wildfire resistance, integration with building systems, adaptability*.

Some of these building-specific requirements are safety requirements already addressed by building code, so they may not need to be part of an above-code program. Others likely could be listed as optional requirements for certain building types or locations. Note also that the relative importance and impact of all the variables noted above will further vary with ownership model, building type and occupancy, new versus retrofit, and climate type.

Results: Overall program design guidance

The following overall program design guidance was received from the stakeholders in interviews and roundtables:

Don't reinvent the wheel:

It is important to stakeholders that, wherever possible, the program should use standards and metrics that have already been developed and are already known to, and being used by, practitioners. For example, the daylighting and views requirements from USGBC's LEED program or the International Well Building Institute's (IWBI) WELL standard were recommended, as were the thermal comfort calculation methodology laid out in ASHRAE Standard 55, modified for façade proximity. Practitioners mentioned the following existing programs that energy provisions could be borrowed from:

- **Massachusetts Stretch Energy Code** envelope requirements, which have stringent thermal bridging and air-leakage requirements and do not allow envelope U-factor performance to be traded off with internal mechanical, electrical and plumbing (MEP) systems. The component trade off compliance path is recommended by Massachusetts' practitioners.
- **ASHRAE 90.1 Appendix C's** envelope credits, which provide additional prescriptive measures above the base code which further increase energy efficiency performance.
- **USGBC's LEED** certification program,
- **California's Green Code**
- T**he City of Seattle's envelope requirements**. These are based on the 2021 version of the International Energy Conservation code (2021-IECC) with modifications that tighten envelope stringency, including thermal bridge mitigation and tighter air-leakage requirements. It also limits the ability to trade off envelope and MEP system performance. In the performance path, the envelope U-factor performance (weighted by area) can only be 10% worse than the prescriptive baseline.
- The **British Columbia Step Code and NABERS building performance program** reviewed above were also referenced.

If utilizing the provisions of any of these existing energy-focused programs, different thermal and solar control performance requirements would likely be needed across the range of climate zones (see outcome versus simplified strategies below). In addition, evaluation of a the pros and cons of standalone program versus creating a façade-specific add-on to an existing broad-based whole building program should be completed.

Minimize the cost and complexity:

This is a key issue for jurisdictions, owners and design teams. This is tied to the first concern of not reinventing the wheel. Minimizing the introduction of new methods or tools, where building on existing systems may suffice, will minimize additional design costs and risks.

Jurisdictions must have a simple way of determining compliance – this could be through an independent third-party certification, like USGBC's LEED, IWBI's WELL, or Energy Star for Buildings. This suggests that third-party certification and verification be part of the above code program. As noted above, performance verification is critical, rather than just design verification.

Deliver jurisdictional and incentive program needs:

Jurisdictions need a nationally known or brand recognized program that provides credibility to connect to incentives. In some forward-looking jurisdictions, some of the easy, low-cost incentives, such as additional allowable height and footprint (bulk) may already be spoken for. For example, incentives might be the ability to add more floors or extend closer to the lot lines outside of normal zoning rules, in return for delivering higher building energy efficiency are low-cost incentives that jurisdictions often already offer. If those have already been assigned, there may not be many low-cost incentives to offer façade performance improvements, leaving only direct financial incentives available.

Incentives also need to be affordable for the jurisdiction. This typically means incentives can be neither too generous nor too long-lived. The structure of the incentive programs should be considered carefully to ensure it drives market transformation that delivers higher performance as BAU. Jurisdictions are also interested in ensuring that they have "grid friendly" façades. That means any program design should focus on minimizing peak heating and peak cooling loads.

Deliver an "asset rating" for the building on a lifecycle basis:

That is, provide value from the program through the life of the building. The value of building should reflect the rating given by the above-code system. This would be financially desirable for building owners and their willingness to build to the above-code program. One of the criticisms leveled at LEED is that it doesn't deliver outcomes to owners. Disclosure of performance will be important to deliver asset value. As reviewed above, a correlation to asset value has been demonstrated by the NABERS program in the U.K. where building values and desirability appear to be correlated to the as-built and operated performance assessment and certification. Verification tied to the rating is the key.

Include thermal bridge mitigation and air-leakage control and verification:

Many practitioners underscored the importance of requiring substantial thermal bridge mitigation, including assembly derating, and stringent air-leakage and verification requirements, like in Massachusetts and British Columbia, and as used in Passive House design (PHI and Phius certifications), across all climate zones. According to Paul Ormond, Commonwealth of Massachusetts, because of the adoption of the Massachusetts Stretch Code [18] across much of the state, new buildings in Massachusetts no longer have perimeter heating. This is because of the implementation of these practices, alongside good thermal insulation requirements for fenestration. Practitioners note that it is often easier to comply with the stretch code using the Passive House certification alternative pathway, indicating the stretch code's stringency.

Stakeholders asserted that the U-factor of the envelope should never be degraded in return for increased efficiency of building HVAC, lighting or hot water heating systems. This is typically what happens when design teams use the performance compliance paths of the model codes and is a key reason why BAU building envelopes remain poorer than they need to be. Duane Jonlin, City of Seattle, noted that the only reason design teams use the code's performance path is to degrade the performance of the envelope. Since implementing the limited envelope trade off, the City of Seattle has seen a significant reduction in use of the performance compliance path, and more use of the envelope component trade-off approach. Verification of air-leakage and thermal bridge mitigation is important. Strategies have been developed in Massachusetts, British Columbia and Seattle on how to verify performance, and what corrective actions can be taken if the targets are missed.

A new approach to solar heat gain control is needed:

From a performance perspective, the overall thermal load on the cooling system caused by the façade should be limited. Massachusetts has introduced a TEDI-cooling metric in its Stretch Code to manage cooling loads caused by the facade.

From a prescriptive standpoint, setting performance is more challenging. Generally, (with perhaps some exceptions and ability to manage overheating), the lower the façade's U-factor, the better. This is independent of façade orientation. There is not such a simple correlation for specifying solar heat gain coefficient (SHGC). The optimum SHGC for a façade depends on the sunlight impingement, which, at a given latitude, is a function of orientation, location, adjacent buildings, and season. Lower SHGC is not always better, as some gains can be helpful in heating dominated climates. Continuing the trend in SHGC reduction as is happening incrementally in model codes is not a pathway to net-zero energy performance, especially in the northern and mixed climate zones, and cannot continue without negatively impacting energy performance.

Additionally, because half the sun's energy is in the visible light range, achieving very low solar heat gain coefficients in fenestration reduces visible light transmission, which can be counterproductive for daylighting and view quality.

An optimum annual average SHGC can be calculated that minimizes annual energy use based on the building, its orientation and location. However, using this single figure average leaves a lot of energy efficiency potential on the table and does not consider peak load management. The average SHGC is too low in winter, when more heat gain may be desirable, and it is too high in summer or with direct sun, when less heat gain is desirable. This is why dynamic solar control is promoted as being the optimum, net zero solution.

In Massachusetts and Seattle, prescriptive code development leaders identify the need to bring in exterior shading requirements to support solar heat gain control as a next step in the progression of their already stringent energy codes.

Input from practitioners working in cooling dominated climate zones on high-performance buildings has been gathered to benchmark strategies which are currently being implemented to deliver the highest performance solar control.

In southern Europe, double skin façades with automated shading in the closed cavities were the go-to for high-performance ten years ago but have not lived up to expectations. This is because of higher energy costs from the air-circulation in the cavity, higher than expected maintenance costs and higher upfront costs due to the additional components and weight. In the past 5 years, the southern European solutions have been focused on using solar control glass (triple silver low-e coatings), thermally broken frames and external static shading devices. Typically, horizontal or vertical (generally fixed) shading, as appropriate, will be added to the south, east and west elevations. The west typically has a different shading configuration, and often the vertical and horizontal layouts are also used as a design aesthetic (Fig. 6).

While practitioners like the idea of moveable exterior shading systems, they prefer not to use them because of the need for a 50-year service life. Maintenance has been noted as a long-term problem, with a responsibility gap arising during occupancy such that maintenance is just not done properly over time. Yet maintenance for other building systems, like elevators, is already done well and systematized. The difference is that elevator maintenance is required by law as a life safety requirement. Façade shade maintenance is typically not a life safety requirement.

Figure 6: Example of static exterior shading: (a) exterior decorative vertical shading, (b) recessed windows, (c) horizontal shading. Credit: H. Sanders.

Practitioners have noted that a prescriptive requirement for solar control in a cooling dominated climate should include a limit on the window-to-wall ratio. Owners and developers often want fully glazed buildings, but occupants in these buildings all ultimately put up their own shading devices to make themselves comfortable, often leaving them in place long after the direct sun has gone. Mixed mode buildings – natural ventilation and HVAC – may also have a potential for supporting high-performance façades.

Lifecycle planning is important:

Maintenance and renovation planning should be a key requirement of the program, with a desire to verify performance throughout the building's service life to maintain certification.

Verification of performance must be included:

This is critical to closing the performance gap between as-built and as-designed. According to stakeholders, demanding performance verification changes contractor behavior, driving actual performance closer to simulation over time. Simulations can be completed initially for system and product selection, but as-built measurements must be made for performance verification. Measurements before occupancy should include air-leakage testing and thermal scanning to identify thermal bridging / air-leakage hotspots and assess overall U-factor.

But post-occupancy performance measurements should also be made to ensure performance is achieved across all the primary categories once the impact of occupants is known. TEDI – the energy load from the façade and ventilation – can be measured separately, but it means that the HVAC system must be separately sub-metered from other energy loads. For new construction that can be easily managed. For existing buildings this could be more challenging. Verification solutions for other outcomes such as daylight, comfort, service life will be needed.

Recertification at regular points (e.g. every 3 to 5 years) during the life of the building was requested, to ensure initial performance is maintained over the service life. It would also ensure that the building maintenance plan is implemented and assembly / design choices are made with long-term performance in mind.

Façade performance must be tied into internal systems:

It is important that the envelope be coordinated well with the HVAC and lighting systems. As noted above, integrated façades use dimmable lighting to harvest daylight are critical to getting to net zero. But also critical is that the HVAC system is designed to leverage the façade performance. The façade must show coordination with building systems to ensure actual façade performance is used in the mechanical system design, there is an effective ventilation strategy, and managed overheating risk.

New construction and retrofits should be considered separately and have separate performance requirements because of the significantly different challenges in meeting the same performance requirements. There is strong interest in increasing the scope of façade retrofits, since demolition of existing buildings and reconstruction often carries a deep embodied carbon penalty.

Results: Initial program structure guidance

The following guidance on the structure of an above-code program has been provided and should be incorporated into any above-code program:

Tiered rating system: A tiered system of good - better - best like that of other rating programs, such as LEED, was desired to give some flexibility in compliance. It is also important as it gives design teams a range of above-code performance levels to choose from to align with budgets, owner needs and local energy codes. This will allow the virtuous cycle observed with Energy Star residential windows, where the standard was higher than the code baseline, but not so high as to be economically unattainable.

Set a minimum standard in each primary performance category: It will be important to set minimum standards in each primary performance category, and identify which practices should be avoided, to ensure balanced performance is achieved, limiting the risk of façades that prioritize one performance category above all others. A façade that prioritizes energy efficiency, at the expense of daylight admission by severely limiting window area, should not be considered high-performance.

Normalization of ratings or scores across categories is critical: Given the need for multiple performance categories, such as energy, daylight admission, thermal comfort, service life, etc., normalizing performance across these different categories will be important. For example, a point given for daylighting performance should be as impactful as a point given for thermal resilience or energy efficiency. A criticism once leveled at LEED was that adding a bike rack delivered as many points as achieving more complex energy or daylighting measures.

Qualification should occur by hitting at least the minimum requirements in each mandatory category and any secondary category appropriate for the building.

Results: Program approaches

Two diverse approaches came to light during the stakeholder meetings, each with benefits and drawbacks (Fig. 7). Both approaches start with a focus on performance outcomes:

An outcome-based approach, which would define façade performance based on measurable performance outcomes in all the primary categories identified above – measured as-built and post-occupancy as appropriate. Full qualification to the program would only be given after outcome verification. For example, good-better-best targets would be set for TEDI heating and cooling and verified through physical measurement. Similar targets would be developed for occupant thermal comfort, daylight admission, visual comfort, quality views, passive survivability, lifecycle carbon and service life.

This approach would not prescribe how to achieve the outcome-based targets, thus providing a lot of design freedom. Simulations to assess daylight admission, visual comfort, thermal comfort, TEDI and calculations for lifecycle carbon would have to be carried out during design phases, but with actual as-built verification.

This approach would be more elegant and simpler in program structure, since it would be independent of climate zone and building type. The only variant would be retrofit versus new construction that would likely have different outcome targets because of the different challenges and approaches to retrofits. Yet compliance would require more sophistication and capability in the design team to complete the necessary simulations and analyses.

Because of the known challenges with energy simulations matching as-built performance, the program should include provisions for collection of design phase performance projections, verification test results and actual energy data to support energy simulation refinement and calibration and identification of systematic performance gaps.

This compliance route would likely be more costly to use than a more simplified compliance path. It also presupposes that the required metrics and evaluation tools are available or could be developed without extensive time and effort. Assessing and verifying service life is a challenge.

A simplified, more prescriptive approach, which could define parameters like area-weighted U-factor and SHGC, minimum and maximum window area, air-leakage, thermal bridge mitigation, and implemented in a similar way to the component trade off method in model energy codes (but with more stringent targets). It would likely need different performance requirements for different climate zones. Although there was a suggestion of a "universal façade" which is climate independent, such an approach can miss the extremes.

Simplified methods for daylight admission, thermal and visual comfort, lifecycle and embodied carbon, and service life will have to be developed, and where possible, drawn from other standards. Prescriptive equivalencies to the outcome-based targets could be developed by creating shoe-box perimeter zone models of a range of façades that meet the desired outcome-based performance levels. View requirements are already typically quite prescriptive.

This relatively simple approach would have wider accessibility to design teams, offering lower compliance costs. However, it would be more complex and costly to develop because of variations of prescriptive level performance across building type and climate zone, and potentially elevation. Challenges identified in this approach are how to more simply specify more stringent solar heat gain management and glare control, as one needs to consider active versus passive solutions. Simply lowering the solar heat gain coefficient of the fenestration is not sufficient to lower energy usage and peak demand sufficiently to achieve the highest performance. Doing so could negatively impact daylight admission as visible light transmittance is reduced when achieving the lowest solar heat gain coefficients in fenestration.

Implications: It is entirely possible that a single program with both an outcome-based and simplified compliance pathways could be developed. More sophisticated design teams may choose the simulation-based option for greater design flexibility, whereas others may choose the simpler compliance approach. The LEED program, for example, allows various means of meeting daylighting requirements from a more sophisticated simulation route to simple physical measurements of light intensity at certain days during the year.

The advantages and disadvantages of a completely new standalone "façade approach" versus adding some elements to existing prescriptive and performance-based whole building programs, such as LEED, WELL, BREEAM, etc. are also being considered.

Is a commercial fenestration-only program viable?

This was reviewed with several fenestration fabricators, most of whom thought that a fenestration-only approach would be very difficult to create without unintended consequences, especially because of the impact of the wall-window interface and the wide range of air-water-structural (AWS) characteristics windows must achieve depending on the building application.

The North American Fenestration Standard (NAFS) separates windows into four categories according to their AWS: Residential windows (RW), light commercial (LC), commercial windows (CW) and architectural windows (AW). The level of AWS performance often determines the window framing material – typically aluminum windows, because of their structural strength are used in the higher structural performance architectural applications – CW and AW – whereas residential style wood and vinyl windows are typically used in single family and low-rise multi-family residential buildings. It is easier to achieve a high thermal performance in a low-conductance frame like vinyl or wood compared to an aluminum frame. An above-code program that sets one value for U-factor across all fenestration categories may run into challenges with creating an uneven playing field.

One could argue that the model codes already set one minimum for U-factor and one for SHGC for all fenestration, so why not an above-code program? Model codes are the lowest level of performance allowable. If only small incremental improvements in performance above code are targeted, then perhaps this may be a viable route. However, when much higher performance than the model codes is required (e.g. for net zero performance), there could be some unintended consequences. At a minimum there may have to be consideration for thermal performance as a function of AWS performance. In both cases, by focusing on fenestration only, the broader issues of thermal bridging and air-leakage are ignored, which leaves a lot of performance on the table.

Conclusions and next steps

Creating an easy to adopt and use above-code program for façades that delivers added asset value to building owners will be critical in transforming the market and ensuring that BAU façades represent the performance of the best-available technology. The initial work described herein has provided a conceptual outline and guidance for an above-code program for façades. The outcome-based pathway is more elegant and simpler yet requires more sophistication from the project team. A more prescriptive pathway is likely more complex to develop, yet is simpler for design teams to comply, but with potential limitations on design freedom.

The must-haves for a high-performance façade, such as thermal bridge mitigation, air-infiltration control, and the verification of performance, have been identified. The full breadth of performance that should be measured is not just focused on reducing energy use, but also improving grid resilience, service life, climate change adaptation and mitigation and occupant comfort, health and wellbeing.

The next steps will involve building out the outcome and simplified pathways to identify where there are gaps in tools or prescriptive approaches. Evaluating the standalone façade-only program versus collaborating with existing whole building programs will be important, as will correlating outcomes to a range of prescriptive approaches. Identifying and collaborating with partners to evaluate incentive program structures will be needed, as will fully vetting the opportunities and limitations for an assembly-only (e.g. fenestration) approach.

Outcome-focused program		
	Outcome-based, performance path	**Simplified path, calibrated to deliver the desired outcomes**
Building Typology Variants	• New construction • Retrofit	• New construction • Retrofit • Climate zone • Building internal load type • Orientation
Verification	**Verification requirements** • Review of design & assumptions, • Review of simulations, • Review of assembly performance, including de-rating • Commissioning & testing (air-leakage, thermal imaging) • As-built and operated outcome validation	**Verification requirements** • Review of design vs prescriptive requirements, • Review of assembly performance (de-rated) • Verification that as-built / installed assemblies match prescribed requirements • Commissioning & testing (air-leakage, thermal imaging) • As-built and operated outcome validation
Energy	Minimum air-leakage requirements	Minimum air-leakage requirements + good-better-best targets
	Minimum thermal bridge mitigation requirements (psi and chi values)	Minimum thermal bridge mitigation requirements + good-better-best targets
	Modified TEDI-cooling and heating, or similar, targets	Simpler requirements for U-factor, SHGC – area weighting and trade-offs within envelope.
	Peak load targets	Prescriptive solar control provisions, e.g. orientation-based SHGC, shading, based on simulations delivering outcome targets.
	Alternative compliance options, e.g. Phius, PHI, MA stretch code.	Alternative compliance options e.g. Phius, PHI, MA stretch code.
Passive survivability	Simulation-based targets Alternative compliance options, e.g. Phius, PHI	Higher requirements for air-leakage, solar control, area-weighted U-factor, etc. Alternative compliance options, e.g. Phius, PHI
Thermal comfort	Target for occupant thermal comfort in the perimeter zone. Including physical verification. Alternative compliance pathway: Phius, PHI	Higher thermal / solar control needed to deliver comfort, e.g. operable windows, shading. Alternative compliance pathway: Phius, PHI.
Daylight and visual comfort	Minimum prescriptive requirements	Minimum prescriptive requirements
	Targets for daylight admission and glare, based on simulation, including outcome verification.	Prescriptive requirements, benchmarking existing standards, aligned with equivalent performance targets, including outcome verification.
Views	Typically, prescriptive in nature	Typically, prescriptive in nature
Service life | Water management	• Dynamic heat and moisture analysis to confirm no condensation. • Use Canadian standard CSA S478 – Durability in Buildings – to achieve & justify a defined service life.	• Prescriptive moisture management provisions • Service life as "outcome-based, performance path"
Lifecycle carbon	Requirements could include • Lifecycle carbon analysis of the façade across expected lifetime • Embodied carbon assessment, including reduction from downsizing HVAC	Requirements could include prescriptive measures such as quantifying and reducing the embodied carbon of the top sources in the façade.

Figure 7: Two distinctly different parallel paths for a broad-scoped above-code façade program.

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