Dynamic Glass and Canadian Energy Codes:

Impact for Toronto Green Standard, BC Energy Step Code and Passive House Certification | Project R-22596.000

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1 Introduction

Building code updates and the growing popularity of voluntary certification programs are increasing the energy performance standards of buildings across Canada. As such, builders and developers are using more creative solutions to meet energy targets. This project evaluates how electrochromic glass can help builders and developers comply with new energy codes in Canada, as well as certification requirements such as Passive House. Specifically, the following building energy codes and certification programs are of interest:

- → Compliance with Toronto Green Standard
- → Compliance with BC Energy Step Code
- → Meeting Passive House (PHI) requirements

Based on these modeling and performance criteria, this study also identified how the use of electrochromic glass could offset the need for certain other energy conservation measures (ECMs).

1.1 Technology

Electrochromic glass, also referred to as dynamic glass, allows the glass to tint on demand or automatically to ensure that occupants stay comfortable year-round. The technology improves energy consumption in buildings by decreasing unwanted solar heat gains during warm periods and allowing solar heat gains during cold periods, decreasing the demand for mechanical space conditioning. Electrochromic glass can be used for windows, skylights and curtain walls.

1.2 Project Overview

This project evaluates the impact of dynamic glazing on energy code compliance in Toronto (Ontario) and Metro Vancouver (British Columbia), and certification to the Passive House Standard. This analysis is based around the properties of SageGlass dynamic glazing. The jurisdictional energy performance requirements in this evaluation vary depending on region, i.e. Toronto Green Standard in Toronto and BC Energy Step Code in the Metro Vancouver area, whereas Passive House targets are consistent in both regions. Two archetypes were selected for the evaluation of dynamic glazing, an Office Building in Toronto and Metro Vancouver, and a Multifamily Residential Building in Metro Vancouver.

This project also evaluates how the use of dynamic glazing can offset the need for certain other energy conservation measures (ECMs). General commentary is provided discussing the implementation considerations, e.g. pros and cons, of the trade-offs to meet targets with the product versus other measures.

2 Methodology

The methodology for the evaluation of dynamic glazing includes determining and adjusting whole-building baseline energy models to represent current design practices and market sectors for the study. These whole building energy models are used to quantify the impact of dynamic glazing. The models are also used to evaluate potential trade-offs to meet targets with dynamic glass products versus other measures.

2.1 Building Types and Energy Targets

Two building types were selected for the evaluation of dynamic glazing, an Office Building in Toronto and Metro Vancouver, and a Multifamily Residential Building in Metro Vancouver.

Table 2.1 provides an overview of the building types, locations, and energy targets for the evaluation of dynamic glazing. The energy performance targets and building characteristics for the six (6) scenarios are further detailed below. The Multifamily Residential Building was not modeled in Toronto.

TABLE 2.1 OVERVIEW OF BUILDING TYPES, LOCATIONS, AND ENERGY TARGETS

Location	**Energy Targets**	
	Office Building	Multifamily Residential Building
Toronto	→ Passive House International Classic → Tier 3 in 2020 (equivalent to Tier 1 in 2026) of the Toronto Green Standard (TGS)	N/A
Metro Vancouver	→ Passive House International Classic → Step 3[1)] of the BC Energy Step Code (BC ESC)	→ Passive House International Classic → Step 3[1)] of the BC Energy Step Code (BC ESC)

1) Note that the Step 3 criteria differ for Office and Residential buildings. The criteria are detailed further below.

2.1.1 Building Types

The characteristics of the buildings are dependent on their location and energy target, the key characteristics of the Office and Multifamily Residential Building archetypes for each energy standard is summarized below. In this study, previously created baseline models were used; modifications were made as required to meet the different energy targets.

Office Building

Two different Office Building archetypes were modified to reflect the Passive House and the BC ESC/TGS targets, respectively, with some additional variations between the BC ESC and TGS characteristics. The Passive House Office archetype, as well as the BC ESC and TGS Office archetypes are mechanically cooled since the Office archetype was primarily selected to demonstrate the effect of dynamic glazing on buildings with high cooling loads.

Table 2.2 summarizes the key characteristics of the Passive House, the BC ESC, and TGS Office archetypes. A detailed summary of the modeling inputs is provided in Appendix A.

TABLE 2.2 KEY CHARACTERISTICS OF THE OFFICE ARCHETYPES

	Passive House		**BC Energy Step Code**	**Toronto Green Standard**
Energy Target	Passive House Classic		Step 3	Tier 3
Location	Metro Vancouver	Toronto	Metro Vancouver	Toronto
Above Grade Floor Area, m^2 (ft^2)	12,200 m^2 (129,000 ft^2)		17,500 m^2 (189,000 ft^2 ft^2)	
# of Storeys	9-storey office tower		17-storey office tower on a 2-storey commercial space podium	
Above Grade Wall Thermal Performance, ft^2-hr-°F/Btu	R-20	R-40	R-6	R-15
Fenestration	SageGlass dynamic triple glazed punched windows		SageGlass dynamic triple glazed curtain wall	SageGlass dynamic triple glazed curtain wall
Window U-value, Btu/ ft^2-hr-°F	Ug-0.12 (centre of glass)	U-0.12 (centre of glass)	U-0.32 (installed[2)])	U-0.27 (installed[2)])
Window SHGC/g-value	Low g-value: 0.03 High g-value: 0.36		Low SHGC: 0.07 High SHGC: 0.36	
Window to Wall Ratio	55%	40%	60%	50%
Exterior Shading[1)]	No	No	No	No
HVAC	Central air source heat pump providing heating and cooling. Central dedicated outdoor air system with heat recovery providing ventilation		Central air source heat pump providing heating and cooling. Central dedicated outdoor air system with heat recovery providing ventilation	

1) Shading from balconies and other building features is captured in the model if applicable.
2) U-value includes glass and frame, and install thermal bridging

Multifamily Residential Building

Two different multifamily building archetypes were modified to reflect Passive House and BC ESC targets in Metro Vancouver. Table 2.3 summarizes the key characteristics of the Multifamily Residential Building archetypes. A detailed summary of the modeling inputs is provided in Appendix A.

The Passive House Multifamily Residential Building archetype has partial mechanical cooling through the ventilation system. The BC ESC Multifamily Residential Building archetype does not include mechanical cooling, and therefore the impact of dynamic glass on mitigating overheating is assessed, instead of the impact on energy consumption for mechanical cooling.

TABLE 2.3 KEY CHARACTERSTICS OF THE MULTIFAMILY RESIDENTIAL BUILDING		
	Passive House	**BC Energy Step Code**
Energy Target	Passive House Classic	Step 3
Location	Metro Vancouver	
Above Grade Floor Area, m^2 (ft^2)	7,900 m^2 (85,000 ft^2)	5,220 m^2 (56,000 ft^2)
# of storeys	6-storey residential building	5-storey residential building
Above Grade Wall Thermal Performance, ft^2-hr-°F/Btu	R-30	R-21
Fenestration	SageGlass dynamic triple glazed punched windows	SageGlass dynamic double glazed punched windows
Window U-value, Btu/ ft^2-hr-°F	Ug-0.13 (centre of glass)	Fixed: U-0.29 (installed[2]) Operable: U-0.32 (installed[2])
Window SHGC/g-value	Low g-value: 0.03 High g-value: 0.36	Low SHGC: 0.07 High SHGC: 0.36
Window to Wall Ratio	40%	20%
Exterior Shading[1)]	No	No
HVAC	Central ventilation system with heat recovery, DX heating and cooling coil to temper supply air. Electric baseboards in suites.	Electric baseboards. In-suite HRVs providing ventilation. No mechanical cooling.

1) Shading from balconies and other building features is captured in the model if applicable.
2) U-value includes glass and frame, and install thermal bridging

2.1.2 Energy Performance Standards

The archetypes were used to evaluate how dynamic glazing may be used to meet energy performance targets. The jurisdictional energy performance requirements to evaluate vary depending on region, i.e. Toronto Green Standard in Toronto and BC Energy Step Code in the Metro Vancouver, whereas Passive House targets are consistent in both regions.

Passive House

Table 2.4 summarizes the International Passive House Institute (PHI) Classic criteria for the Office Building and Multifamily Residential Building.

TABLE 2.4 PASSIVE HOUSE CLASSIC CRITERIA FOR OFFICE AND MULTIFAMILY RESIDENTIAL BUDILINGS		
	Criteria	Unit
Heating Demand or	≤ 15 or	$kWh/(m^2_{TFA}/yr)$ W/m^2_{TFA}

TABLE 2.4 PASSIVE HOUSE CLASSIC CRITERIA FOR OFFICE AND MULTIFAMILY RESIDENTIAL BUDILINGS		
Heating Load	≤ 10	
Cooling Demand or Cooling Load	≤ 15 or ≤ 10	$kWh/(m^2_{TFA}/yr)$ W/m^2_{TFA}
Airtightness test result n50	≤ 0.6	1/h
Primary Energy Renewable (PER)1)	602)	$kWh/(m^2_{TFA}/yr)$
Frequency of overheating	< 10%	%

1) Primary Energy Renewable, PER, considers the total energy requirements of the building evaluated in the scenario of a world where solely renewable energy sources are used. It includes PER factors to account for losses in the power generation chain of the potential renewable energy sources and storage. PER factors are maintained by the Passive House Institute.
2) The PER criteria for multifamily residential buildings is calculated using the Passive House Institute PER calculator. The calculated PER criteria is specific to the project and may be higher than the standard criteria of 60 $kWh/m^2/yr$ due to higher occupancy density.

Metro Vancouver

Several jurisdictions in the Lower Mainland have adopted the BC ESC[1] and currently require new construction to comply with the lower steps and rezoning to comply with the upper steps. The intent of the BC ESC is to provide a clear path to performance improvement and to make the requirements more stringent with time.

In this study the baseline models have been adjusted to meet Step 3 with dynamic glazing for both the Office and Multifamily Residential Buildings in Metro Vancouver as Step 3 captures the greatest market share of buildings in these early-adopting jurisdictions as well as future market of other jurisdictions. Step 3 is also currently required as a minimum energy target for BC Housing projects[2] and aligns with the City of Vancouver's rezoning requirements[3]. This also provides a variety in building performance to be assessed since it is not the most stringent Step Code tier and thus avoids overlap with the Passive House scenarios.

Note that for non-mechanically cooled buildings, Step Code buildings are required to demonstrate that all conditioned spaces meet the thermal comfort criteria described in the City of Vancouver Energy Modelling Guidelines (v2.0)[4]. The thermal comfort criteria is used to evaluate the benefits of dynamic glazing in the Metro Vancouver market where mechanical cooling is less common in multifamily buildings.

[1] Jurisdictions that have adopted the BC Energy Step Code; https://energystepcode.ca/implementation_updates/
[2] BC Housing, Design Guidelines and Construction Standards, 2019
[3] Green Buildings Policy for Rezoning – Process and Requirements, July 22 2010
[4] City of Vancouver, Energy Modelling Guidelines version 2.0, July 11, 2018

Table 2.5 summarizes the BC ESC targets for Office and Multifamily Residential Buildings.

TABLE 2.5 BC ENERGY STEP CODE CRITERIA FOR OFFICE AND MULTIFAMILY RESIDENTIAL BUILDINGS				
	Office Building		**Multifamily Residential Building**	
	TEUI[1)] (kWh/m²/yr)	TEDI[2)] (kWh/m²/yr)	TEUI[1)] (kWh/m²/yr)	TEDI[2)] (kWh/m²/yr)
Step 1	Conform to Part 8 of the NECB			
Step 2	130	30	130	45
Step 3	100	20	120	30
Step 4	-	-	100	15

1) TEUI, Total Energy Use Intensity, is the annual energy use on site, including heating, cooling, ventilation, service water heating, pumps, auxiliary HVAC equipment, lighting and plug load energy.
2) TEDI, Thermal Energy Demand Intensity, is the annual heating energy demand for the space conditioning and conditioning of ventilation air. TEDI does not account for heating system efficiency.

Toronto

The TGS was modelled for archetypes in Toronto instead of the BC ESC. Our understanding is that Tier 1 represents the largest market share for Office buildings in the Toronto area, though the Tier 1 target is constantly evolving. Table 5 summarizes the TGS criteria for Office buildings, including the evolution of the Tiers from 2020 to 2030. The energy and greenhouse gas intensity (GHGI) targets for Tier 1 of the TGS are planned to gradually become more stringent over the next 10 years. To align the energy targets for the Toronto Office Building with the Vancouver Office Building, and to capture a large future market share, the baseline models have been adjusted to meet Tier 3 in 2020, which will be equivalent to Tier 1 in 2026.

Since most buildings have mechanical cooling in Toronto, the analysis of dynamic glazing system in Toronto will have a focus on cooling demand and cooling equipment sizing/design.

TABLE 2.6 TORONTO GREEN STANDARD CRITERIA FOR OFFICE BUILDINGS (2020)				
	Tier 1	Tier 2 (Tier 1 in 2022)	Tier 3 (Tier 1 in 2026)	Tier 4 (Tier 1 in 2030)
TEUI[1)] (kWh/m²/yr)	175	130	100	65
TEDI[2)] (kWh/m²/yr)	70	30	22	14
GHGI[3)] ($kgCO_2e/m^2/yr$)	20	15	8	4

1) TEUI, Total Energy Use Intensity, is the annual energy use on site, including heating, cooling, ventilation, service water heating, pumps, auxiliary HVAC equipment, lighting and plug load energy.
2) TEDI, Thermal Energy Demand Intensity, is the annual heating energy demand for the space conditioning and conditioning of ventilation air. TEDI does not account for heating system efficiency.
3) GHGI, Greenhouse Gas Intensity, is the total greenhouse gas emissions associated with the use of all energy utilities on site.

2.2 Summary of Energy and Thermal Comfort Metrics

Table 2.7 summarizes the energy and thermal comfort metrics that are reported on in this study, as applicable for BC ESC, TGS, and Passive House International. The criteria and definitions of the metrics required by the energy standards are summarized above.

Although cooling energy consumption is accounted for in the TEUI metric, there is currently no criteria for cooling energy included in the BC ESC or TGS. To further understand the impact of dynamic glazing on the archetypes' cooling energy, we are reporting on additional metrics, as described in Table 2.7. Note that these metrics are not included in the BC ESC or TGS, and therefore there is no criteria that needs to be met to comply with either of the energy standards.

The TEUI metric used in the BC ESC and TGS and the PER metric use in the Passive House certification standard are both representative of total energy use. However, PER considers the total energy requirement (based on source energy) of the building evaluated in a future scenario where only renewable energy sources are used to generate power. PER includes factors that account for end-use served and losses in the power generation chain (including storage) of the potential renewable energy sources. PER factors are maintained by the Passive House Institute.

TABLE 2.7 SUMMARY OF ENERGY AND THERMAL COMFORT METRICS				
Metric	Unit	Required per Energy Standard	Applicability	
			Office Archetype	Multifamily Residential Building
Passive House International				
Heating Demand or Heating Load	$kWh/m^2/yr$ W/m^2	Yes	✓	✓
Cooling and Dehumid. Demand or Cooling Load	$kWh/m^2/yr$ W/m^2	Yes[1)]	✓	✓
PER	$kWh/m^2/yr$	Yes	✓	✓
Frequency of overheating	%	Yes[1)]	n/a	n/a
BC Energy Step Code				
TEUI	$kWh/m^2/yr$	Yes	✓	✓
TEDI	$kWh/m^2/yr$	Yes	✓	✓
# of overheated hours	#	Yes[2)]	n/a	✓
Cooling Energy Demand[3)]	$kWh/m^2/yr$	No	✓	n/a
Peak Cooling Load[4)]	W/m^2	No	✓	n/a
Toronto Green Standard				
TEUI	$kWh/m^2/yr$	Yes	✓	-
TEDI	$kWh/m^2/yr$	Yes	✓	-
GHGI	$kgCO_2e/m^2/yr$	Yes	✓	-
Cooling Energy Demand[3)]	$kWh/m^2/yr$	No	✓	-
Peak Cooling Load[4)]	W/m^2	No	✓	-

1) It is required per the Passive House Standard to report on Cooling and Dehumidification Demand and Cooling Load if the building has mechanical cooling, and Frequency of overheating if the building is not mechanically cooled.
2) It is required per BC ESC to report on # of overheated hours if the building is not mechanically cooled.
3) Cooling energy demand is the annual cooling energy demand for space conditioning and conditioning of ventilation air. This metric does not account for system efficiencies.
4) Peak cooling load is the maximum cooling required for space conditioning and conditioning of ventilation air. This metric does not account for system efficiencies.

2.3 Modeling Workflows

As part of this study, a modeling workflow of the dynamic glazing was developed for compliance with the Passive House certification programs as maintained by the International Passive House Institute (PHI) and the Passive House Institute US (PHIUS). Specifically, how to model electrochromic glass in the Passive House Planning Package (PHPP) and WUFI-Passive.

The full workflow is provided in Appendix B. It should be noted that this protocol must be reviewed by PHI and PHIUS before it can be accepted for projects seeking certification. As the two Passive House certification standards use different modeling tools, workflows are presented for each modeling tool.

2.4 Evaluation of Energy Performance and Trade-offs

The baseline models were set up to meet the energy targets for the six (6) scenarios listed in Table 2.1, using dynamic glazing as a measure to meet the targets. The dynamic glazing energy modeling protocol for hourly modeling tools was provided by SageGlass, while the modeling protocol for PHPP was developed as described in Section 2.2 and in Appendix B. Modeling was carried out in the hourly energy modeling tool eQuest (v.3.65) for the BC ESC and TGS archetypes, and in PHPP (v.9.6a) for the Passive House archetypes.

The dynamic glazing was then removed from the compliant energy model and replaced with non-dynamic window of the same U-value and a typical SHGC to quantify the energy impacts and thermal comfort benefits of using dynamic glass. To assess what measures may be offset by the use of dynamic glass, alternative energy conservation measures (trade-offs) were then implemented to again meet the energy and/or thermal comfort metrics. The considered trade-off measures are summarized in Table 2.8, together with the anticipated qualitative impact on heating and cooling demand, and which archetype each trade-off is applicable to. Up to two trade-offs were selected per archetype and location, if applicable one mechanical and one enclosure focused trade-offs were modeled.

The trade-offs were primarily selected depending on the limiting metric(s). In cases where multiple trade-offs are applicable, or where trade-offs have to be bundled to meet the energy/thermal comfort criteria, the trade-offs were selected using a design-team approach based on industry experience. The trade-offs may come with drawbacks that could be avoided by using dynamic glazing, and such drawbacks are discussed in the Results section.

Operable shading devices were not modeled for the office archetypes; this is because fixed shading (overhangs/fins) is currently a more common shading strategy as overhangs and fins do not need to be manually controlled and require less maintenance.

The enclosure thermal performance and HRV efficiency is at the practical upper limit for the Toronto Office TGS and Toronto Passive House Office archetype, and therefore the improved enclosure thermal performance and improved HRV efficiency trade-offs are not applicable for these archetypes.

TABLE 2.8 THE IMPACT AND APPLICABILITY OF THE CONSIDERED TRADE-OFFS								
Trade-offs	Impact		Applicability					
	Heating Demand	Cooling Demand	Office				Multifamily Residential Building	
			Toronto		Metro Vancouver		Metro Vancouver	
			Passive House	TGS	Passive House	BC ESC	Passive House	BC ESC
Reduced window-to- wall ratio	Decrease	Decrease	✓	✓	✓	✓	✓	✓
Exterior operable shading	No/small impact	Decrease	n/a	n/a	n/a	n/a	✓	✓
Exterior fixed shading (overhangs/ fins)	Increase	Decrease	✓	✓	✓	✓	✓	✓
Increased solar heat gain coefficient	Decrease	Increase	✓	✓	✓	✓	✓	✓
Improved enclosure thermal performance (walls/roofs)	Decrease	No/small impact	n/a	n/a	✓	✓	✓	✓
Increased HRV efficiency	Decrease	No/small impact	✓	n/a	✓	✓	✓	✓

3 Results

The whole building energy models were used to evaluate dynamic glazing to meet energy targets in Toronto and in Metro Vancouver for two different building types, Office Building and Multifamily Residential Building. The results are presented by location, below.

3.1 Toronto

This section summarizes the results of the Passive House and Toronto Green Standard Office archetypes located in Toronto. The Multifamily Residential Building archetype was not modeled in Toronto.

3.1.1 Office Building

The energy modeling results for meeting Passive House targets and TGS targets are presented below for the Office archetype, including potential trade-off options.

Passive House

Table 3.1 summarizes the results for the Passive House Office archetype with dynamic glazing, together with the results for the archetype when dynamic glazing is removed (Standard Glazing), and the selected trade-offs.

The heating demand and PER both exceed the Passive House criteria when the dynamic glazing is removed. Although the heating demand and PER exceed the threshold, the greatest difference is shown in the cooling energy metrics. However, the cooling energy metrics do not exceed the Passive House criteria and therefore the trade-offs are selected to reduce the heating demand and PER.

A potential mechanical trade-off is to improve the HRV efficiency, to reduce both the heating demand of the space and the total energy consumption (PER). The enclosure thermal performance is at the practical upper limit for this type of building; therefore, the selected enclosure trade-off is focused on increasing the g-value of the glazing in combination with reducing the window-to-wall-ratio. The following trade-offs were implemented independently to create two potential alternate compliance paths:

→ **Improved HRV Efficiency:** HRVs upgraded from 84% to 91% efficient.

→ **Increased g-value + Reduced WWR:** Increased g-value from 0.27 to 0.36 and reduced window-to-wall-ratio from 40% to 30%.

TABLE 3.1 PASSIVE HOUSE OFFICE ARCHETYPE LOCATED IN TORONTO						
Metric	Unit	Criteria	Sage Glass	Standard Glazing[1)]	Improved HRV Eff.[1)]	Increased g-value + Reduced WWR[1)]
Passive House Metrics[2)]						
Heating Demand Or Heating Load	$kWh/m^2_{TFA}/yr$ W/m^2_{TFA}	*15* *10*	15 14	17 14	15 13	14 13
Cooling & Dehum. Demand Or Cooling Load	$kWh/m^2_{TFA}/yr$ W/m^2_{TFA}	*15* *10*	6 4	12 8	12 8	13 8
PER	$kWh/m^2_{TFA}/yr$	*60*	58	62	58	60

1) Modeled g-value of 0.27, U-value unchanged.
2) The red font indicates that the criteria is exceeded.

The HRV system efficiency needed to reduce the heating demand and PER below the threshold is higher than common practice for this type of building, though feasible with a high performance unit and well thought out mechanical design.

Reducing the window-to-wall-ratio may not be associated with a cost penalty (depending on window and wall assembly), however, for some projects a reduced window-to-wall-ratio may restrict the building from achieving architectural and marketability objectives. The use of dynamic glass can allow for a higher window-to-wall-ratio while still meeting the Passive House energy targets.

Although the trade-offs bring the metrics down to meet the heating demand and PER requirements for Passive House, the cooling energy demand is still significantly higher than the archetype with dynamic glazing. This indicates that the use of dynamic glazing may enable the use of smaller capacity cooling equipment, though this would need to be confirmed by the mechanical engineer. Alternatively, additional measures would be required to reduce the cooling energy demand back down to the same level as with dynamic glazing.

Toronto Green Standard

Table 3.2 summarizes the Tier 3 TGS Office archetype results (equivalent to Tier 1 targets in 2026). In addition to the TGS metrics, the table includes cooling energy demand and peak cooling load (as defined in Table 2.7). Although there are currently no criteria for cooling energy demand or peak cooling load included in the TGS, these metrics are included to further understand the impact of dynamic glazing on the archetype's cooling energy.

Replacing the dynamic glazing with a non-dynamic window of the same U-value results in an increase in both heating and cooling energy demand, and the total energy use intensity (TEUI) exceeds the threshold for Tier 3 TGS. To meet the Tier 3 TGS targets with dynamic glazing, the archetype already includes a high performance enclosure, HRVs, and heating and cooling system equipment. Therefore, there are limited alternative energy conservation measures (ECMs) to replace dynamic glazing as trade-offs.

The greatest increase in energy metric is for the cooling energy demand, so the trade-offs were focused on reducing the cooling energy. For this archetype, only one of the modeled trade-off combinations reduced TEUI below the threshold. The following trade-off combination was implemented for the Toronto TGS Office archetype:

→ **Fixed Shading + Reduced WWR:** Fixed exterior overhangs (3 ft deep) on all elevations and reduced window-to-wall ratio from 50% to 25%.

TABLE 3.2 TORONTO GREEN STANDARD OFFICE ARCHEYTPE LOCATED IN TORONTO

Metric	Unit	Criteria (Tier 3)	SageGlass	Standard Glazing[1]	Fixed Shading + Reduced WWR[1]
Toronto Green Standard Metrics[2]					
TEUI	kWh/m²/yr	*100*	100	113	100
TEDI	kWh/m²/yr	*22*	15	19	17
GHGI	kgCO_2e/m²/yr	*8*	5	6	5
Non-Toronto Green Standard Metrics					
Cooling Energy Demand	kWh/m²/yr	*n/a*	36	53	34
Peak Cooling Load	W/m²	*n/a*	32	54	34

1) Modeled SHGC of 0.31, U-value unchanged.
2) The red font indicates that the criteria is exceeded.

Office buildings generally have high plug loads and lighting energy consumption. For the upper tiers of building performance this means that a smaller fraction of TEUI can be associated with heating, cooling, and ventilation compared to the lower tiers. It is particularly hard to achieve low TEUI targets in climates such as Toronto's, which has both cold winters and hot summers, and therefore significant heating and cooling loads. The Toronto Office archetype in this study already includes high performance enclosure, HRVs, and cooling and heating equipment so adding additional ECMs as trade-off measures to SageGlass is challenging. The results indicate that Office archetypes with high window-to-wall-ratio in Toronto may especially benefit from the use of dynamic glazing.

3.2 Metro Vancouver

This section summarizes the results of the Passive House and BC ESC Office and Multifamily Residential Building archetypes located in Metro Vancouver.

3.2.1 Office Building

The energy modeling results for meeting Passive House targets and BC ESC targets are presented below for the Office archetype in Metro Vancouver, including potential trade-off options.

Passive House

Table 3.3 summarizes the results for the Passive House Office archetype with dynamic glass together with the results for the archetype when the dynamic glass is removed (Standard Glazing), and the selected trade-offs.

Similar to the Toronto Passive House Office archetype, the heating demand and PER exceed the target when the dynamic glazing is replaced with a non-dynamic window of the same U-value.

The following mechanical and enclosure upgrade trade-offs were implemented to reduce the heating demand and PER to meet Passive House targets without dynamic glazing:

- **Improved HRV Efficiency:** HRVs upgraded from 80% to 87% efficient.
- **Increased g-value + Reduced WWR:** Increased g-value from 0.27 to 0.36 and reduced window-to-wall-ratio from 55% to 45%.

TABLE 3.3 PASSIVE HOUSE OFFICE ARCHETYPE LOCATED IN METRO VANCOUVER						
Metric	Unit	Criteria	Sage Glass	Standard Glazing[1]	Improved HRV Eff. [1]	Increased g-value + Reduced WWR
Passive House Metrics[2]						
Heating Demand Or Heating Load	$kWh/m^2_{TFA}/yr$ W/m^2_{TFA}	*15* *10*	15 14	17 14	15 13	14 13
Cooling & Dehum. Demand Or Cooling Load	$kWh/m^2_{TFA}/yr$ W/m^2_{TFA}	*15* *10*	1 0	6 6	6 6	7 8
PER	$kWh/m^2_{TFA}/yr$	*60*	59	62	59	60

1) Modeled g-value of 0.27, U-value unchanged.
2) The red font indicates that the criteria is exceeded.

Similar to the Toronto Passive House Office archetype, the HRV system efficiency that was implemented as a trade-off to reduce the heating demand and PER below the threshold is higher than common practice for this type of building, though feasible with a high performance unit and well thought out mechanical design.

The enclosure focused trade-off includes reduced window-to-wall ratio in combination with increased g-value of the glazing, similar to the Toronto archetype. Due to the milder climate in Metro Vancouver, compared to Toronto, the Metro Vancouver archetype can achieve Passive House standard with a higher window-to-wall-ratio than the Toronto archetype. However, the reduction in window-to-wall-ratio required to meet the Passive House criteria after removing the dynamic glazing is similar for the two archetypes and locations.

As shown for the Toronto archetype, the trade-offs in the Metro Vancouver scenario bring the metrics down below the threshold, however, the cooling energy demand and cooling load are still significantly higher compared to the archetype with dynamic glazing. Although the cooling load is small for the Passive House Office archetype , dynamic glazing can not fully eliminate the need for cooling. However, the use of dynamic glazing may enable smaller cooling equipment, though this should be confirmed by the mechanical engineer.

BC Energy Step Code

Table 3.4 summarizes the Step 3 BC ESC Office archetype results. Note that the table includes cooling energy demand and cooling load (as defined in Table 2.7). Although there are currently no criteria for cooling energy demand or peak cooling load included in the TGS, these metrics are included to further understand the impact of dynamic glazing on the archetype's cooling energy.

Replacing the dynamic glazing with non-dynamic windows of the same U-value results in an increase in both heating and cooling energy demand, and both the TEUI and TEDI metrics exceed the Step 3 threshold.

Similar to the TGS Office archetype, this archetype already includes high performance HRVs and heating and cooling system equipment, and therefore both trade-off options that were assessed are enclosure focused. To reduce both heating and cooling the following trade-offs were implemented to the BC ESC Office archetype:

→ **Fixed Shading + Improved Enclosure Performance**: Exterior fixed overhangs (3 ft deep) on all elevations. Improved wall thermal performance (spandrel & opaque wall) from R-6 overall to R-15 overall.

→ **Fixed Shading + Reduced WWR:** Exterior fixed overhangs (2ft deep) on all elevations. Reduced window-to-wall-ratio from 60% to 30%.

TABLE 3.4 BC ENERGY STEP CODE (STEP 3) OFFICE ARCHETYPE LOCATED IN METRO VANCOUVER

Metric	Unit	Criteria (Step 3)	Sage Glass	Standard Glazing[1]	Fixed Shading + Improved Enclosure Perf. [1]	Fixed Shading + Reduced WWR[1]
BC Energy Step Code Metrics[2]						
TEUI	kWh/m²/yr	*100*	96	108	100	100
TEDI	kWh/m²/yr	*20*	16	22	18	20
Non-BC Energy Step Code Metrics						
Cooling Energy Demand	kWh/m²/yr	*n/a*	26	39	32	25
Peak Cooling Load	W/m²	*n/a*	29	41	33	30

1) Modeled SHGC of 0.31, U-value unchanged.
2) The red font indicates that the criteria is exceeded.

Similar to the TGS Office archetype, extensive trade-offs had to be implemented to bring the metrics below the threshold. A wall thermal performance of R-15 is at the upper limit for a building of this type due to the window-wall assembly with spandrel panels. As such, to increase the wall thermal performance from R-6 to R-15 would require a spandrel panel system with very high thermal performance and details to minimize thermal bridging. This may be costly and hard to achieve depending on the building design, as well as cost and constructability objectives.

Fixed exterior overhangs were modeled rather than operable shading devices since it is currently a more common shading strategy for office buildings as overhangs do not need to be manually controlled and require less maintenance. However, fixed exterior overhangs greatly impact the aesthetic of the building and may not be desired for certain projects. The use of dynamic glass can offset the use of architectural exterior shading and additional ECMs to further reduce the heating demand, such as improved enclosure performance, or reduced window-to-wall-ratio.

3.2.2 Multifamily Residential Building

The energy modeling results for meeting Passive House targets and BC ESC targets are presented below for the Multifamily Residential Building in Metro Vancouver, including potential trade-off options.

Passive House

Table 3.5 summarizes the results for the Passive House Multifamily Residential Building archetype, together with the results for the archetype when dynamic glazing is replaced (Standard Glazing), and the selected trade-offs.

As shown in Table 3.5, the heating demand exceeds the Passive House threshold when the dynamic glazing is removed. Unlike the Office Passive House archetype, there is only a small increase in cooling demand for the Metro Vancouver Multifamily Residential Building Passive House archetype. This is likely due to a combination of the relatively mild Metro Vancouver climate, lower internal heat gains than the Office, and self-shading from articulation and balconies, which are not present in the Office. Since heating demand is the only metric that exceeds the Passive House criteria, the trade-offs were selected to reduce the heating demand for this building. Similar to the Office Passive House archetype, the mechanical trade-off is focused on improving the HRV efficiency to reduce the heating demand. The enclosure trade-off uses an increased g-value to reduce the heating demand.

Following trade-offs were implemented:

→ **Improved HRV Efficiency:** HRVs upgraded from an 85% efficient centralized system to an 89% decentralized (in-suite) system.

→ **Increased g-value:** Increased g-value from g-0.27 to 0.36.

TABLE 3.5 PASSIVE HOUSE MULTIFAMILY RESIDENTIAL BUILDING ARCHETYPE LOCATED IN METRO VANCOUVER

Metric	Unit	Criteria	Sage Glass	Standard Glazing[1)]	Improved HRV Efficiency[1)]	Increased g-value[1)]
Passive House Metrics[2)]						
Heating Demand Or Heating Load	$kWh/m^2_{TFA}/yr$ W/m^2_{TFA}	*15* *10*	15 12	18 12	15 12	15 11
Cooling & Dehum. Demand Or Cooling Load	$kWh/m^2_{TFA}/yr$ W/m^2_{TFA}	*15* *10*	0 0	1 0	1 0	1 0
PER	$kWh/m^2_{TFA}/yr$	*77*[3)]	71	74	67	71

1) Modeled g-value of 0.27, U-value unchanged.
2) The red font indicates that the criteria is exceeded.
3) The PER criteria for Multifamily Residential Buildings is calculated using the Passive House Institute PER calculator. The calculated PER criteria is specific to the project and may be higher than the standard criteria of 60 $kWh/m^2/yr$ due to higher occupancy density.

An effective strategy to reduce the heating demand for an archetype with low cooling load is to increase the g-value. However, increasing the g-value may not be an option for non-mechanically cooled buildings, as it may increase the risk of overheating and result in need of mechanical cooling; though in the case of the archetype, this is feasible since the building is mechanically cooled.

The results indicate that multifamily residential buildings of similar design characteristics as this archetype and located in climates similar to Metro Vancouver may not benefit from the use of dynamic glazing as much as other archetypes that have been assessed. However, the benefit of dynamic glazing may be greater for multifamily residential buildings located in warmer climates, or multifamily residential buildings with higher window-to-wall-ratio, or for passively cooled multifamily residential buildings. An example of a passively cooled multifamily building is assessed below.

BC Energy Step Code

Table 3.6 summarizes the Step 3 BC ESC Multifamily Residential Building archetype results. This archetype is passively cooled and must therefore demonstrate that the operative temperature in conditioned spaces within the building does not exceed the ASHRAE 55-2010 80% acceptability upper temperature limit for more than 200 hours, as described in the City of Vancouver Energy Modelling Guidelines (v2.0)[5].

As shown in Table 3.6, when the dynamic glazing is removed, TEDI and the thermal comfort metric (# of overheated hours) exceed the threshold for BC ESC compliance. The dynamic glazing allows for a higher SHGC at its maximum range (SHGC of 0.41), and therefore the heating demand is increased slightly when the dynamic glazing is replaced with a non-dynamic glass with a SHGC of 0.31.

Potential trade-offs were selected to help reduce the TEDI metric back to compliance. Since TEDI is largely impacted by enclosure performance, the trade-off selection focused on improving the thermal performance of the opaque wall assemblies. Shading was also implemented to help balance the unwanted solar heat gains without dynamic glazing, which is important to reduce the number of overheated hours for BC ESC compliance. The following trade-offs were implemented to reduce the heating demand (TEDI) back to levels that would comply with the BC ESC, and reduce the risk of overheating (# of overheated hours):

- → **Operable Shading + Improved Enclosure Performance:** Exterior operable shades on all elevations, assumed to be controlled (manually) to optimize the reduction of unwanted solar heat gains. Improved wall thermal performance from R-21 to R-23.
- → **Fixed Shading + Improved Enclosure Performance:** Exterior fixed overhangs (3ft deep) on west- and south-facing façade, and exterior reveal shading (1.6 ft deep) on the west side of the window on the south- and west façade. Improved wall thermal performance from R-21 to R-28.

[5] City of Vancouver, Energy Modelling Guideliens version 2.0, July 11, 2018

TABLE 3.6 BC ENERGY STEP CODE (STEP 3) MULTIFAMILY RESIDENTIAL BUILDING ARCHETYPE LOCATED IN METRO VANCOUVER						
Metric	Unit	Criteria	Sage Glass	Standard Glazing 1)	Operable Shading + Improved Enclosure Perf. 1)	Fixed Shading + Improved Enclosure Perf. 1)
BC Energy Step Code Metrics 2)						
TEUI	kWh/m²/yr	*120*	104	106	106	106
TEDI	kWh/m²/yr	*30*	30	31	30	30
# of over-heated hours	#	*200*	199	303	107	200

1) Modeled SHGC of 0.31, U-value unchanged.
2) The red font indicates that the criteria is exceeded.

As mentioned, the high end of the SHGC range of dynamic glazing is higher than the SHGC of the non-dynamic glass, therefore there is a slight increase in heating demand when the dynamic glazing is removed. Energy conservation measures are implemented to reduce the heating demand, in combination with measures to reduce the risk of overheating. In this analysis, the wall thermal performance was improved to reduce the heating demand, instead of improving the thermal performance of the walls; the project team may choose a different approach, such as increasing window thermal performance, HRV efficiency, or the SHGC.

A common strategy to reduce the risk of overheating for non-mechanically cooled buildings is to add operable or fixed exterior shading. Fixed exterior shading (such as overhangs and reveal shading) are effective at reducing solar heat gains to the space. However, the reduced solar heat gains during the heating season can lead to an increase in heating demand, and therefore more extensive heating-focused ECMs may need to be implemented. The energy modeling analysis illustrates that the wall thermal performance needs to be further improved when combined with the fixed exterior shading, compared to the operable shading. Dynamic glazing offers even more controllability than operable shading.

In this analysis it is assumed that the operable shading is controlled (manually) to optimize the reduction of unwanted solar heat gains. In reality, this may not be optimally achieved, so a benefit of dynamic glazing compared to the operable shading is that it automatically reduces the unwanted solar heat gains and is more likely to effectively reduce the risk of overheating.

4 Key Takeaways

The energy modeling analysis in this study has led to the following key takeaways.

- For both the **Toronto and Metro Vancouver Passive House Office** archetypes, the heating demand and PER exceed the threshold when the dynamic glazing is replaced with a non-dynamic window of the same U-value.
  - This energy analysis shows that strategies to offset the dynamic glazing can include improved HRV efficiency or increasing the centre-of-glass g-value in combination with reduced window-to-wall ratio.
  - Reducing the window-to-wall ratio may not be associated with a cost-penalty, however, for some projects a reduced window-to-wall-ratio may restrict the building from achieving architectural and marketability objectives. The use of dynamic glazing can allow for a higher window-to-wall-ratio while still meeting the Passive House energy targets.
  - Although the heating demand and PER exceed the threshold when dynamic glazing is removed, the greatest increase is shown in the cooling energy metrics for the Passive House Office archetypes. Since the trade-offs were selected to reduce the heating demand, the cooling energy demand is significantly higher for the archetypes without dynamic glazing, compared to the archetypes with dynamic glazing. This indicates that the use of dynamic glazing may enable the use of smaller cooling equipment size, though this would need to be confirmed by the mechanical engineer.
- The use of dynamic glazing has a significant impact on the cooling energy demand for the **BC ESC and TGS Office archetypes**. Removing dynamic glazing significantly increases the cooling energy, and therefore results in exceeding the TEUI target for Step 3 of the BC ESC and Tier 3 of the TGS.
  - This study shows that by using dynamic glazing, extensive fixed exterior shading in combination with significant reduction in window-to-wall-ratio or increased wall thermal performance (if applicable) can be avoided.
  - Fixed exterior overhangs were modeled rather than operable shading devices since it is currently a more common strategy for office buildings. However, fixed shading greatly impacts the aesthetic of the building and may not be desired for certain projects.
  - The BC ESC and TGS Office archetypes already include high performance windows, HRVs, and heating and cooling system equipment. The wall and roof thermal performance of the TGS Office archetype is also at the practical upper limit for this type of building. Therefore, there are limited alternative energy conservation measures to replace dynamic glazing as trade-offs.
  - This study indicates that Office buildings with high window-to-wall ratio and that target the upper tiers/steps of the TGS or BC ESC may especially benefit from the use of dynamic glazing. The dynamic glazing is particularly beneficial for Office buildings located in climates such as Toronto's which has both cold winters and hot summers, and therefore significant cooling and heating loads.

- The **Passive House Multifamily Residential Building** is mechanically cooled, however, the cooling load is relatively low compared to the Office archetypes. Replacing dynamic glazing with a window of the same U-value results in the building exceeding the heating demand criteria.
  - Potential strategies that design teams may use instead of dynamic glazing to reduce the heating demand to meet the Passive House criteria include improving the HRV efficiency, or increasing the centre of glass g-value.
  - Increasing the centre of glass g-value may be an effective way of reducing the heating demand and viable for buildings with low cooling load. However, increasing the g-value may not be an option for non-mechanically cooled buildings, as it may increase the risk of overheating and result in need of mechanical cooling or other measures to improve the thermal comfort.
  - This study shows that dynamic glazing may not be beneficial for high performance mechanically cooled multifamily residential buildings with low window-to-wall-ratio located in heating dominated climates similar to Metro Vancouver. This is because the cooling energy demand, and thus the benefit of dynamic glazing on the cooling energy demand, is low. Furthermore, the benefit of dynamic glazing on the heating demand can likely be offset by other measures, such as increased g-value.
- Unlike the Passive House Multifamily Residential Building, the **BC ESC Multifamily Residential Building** is passively cooled and must therefore comply with thermal comfort criteria, along with the energy performance criteria. Removing the dynamic glazing results in an increase to both the TEDI and the thermal comfort criteria for Step 3 of the BC ESC.
  - This study shows that by using dynamic glazing, fixed or operable exterior shading in combination with increased wall thermal performance can be avoided.
  - A common strategy to reduce the risk of overheating is to add operable or fixed shading. Fixed exterior shading is effective at reducing solar heat gains to the space. However, the reduced solar heat gains during the heating season can lead to an increase in heating demand, and therefore more extensive heating focused ECMs (such as increased wall thermal performance, improved HRV efficiency, etc.) may need to be implemented.
  - Operable shading is also an effective way of reducing solar heat gains to the space. In this analysis it was assumed that the operable shading is controlled (manually) to optimize the reduction of unwanted solar heat gains. In reality, this may not be optimally achieved; consequently, a benefit of dynamic glazing compared to the operable shading is that it automatically reduces the unwanted solar heat gains and is more likely to optimally reduce the risk of overheating while allowing solar heat gains to offset heating when beneficial.
  - The thermal comfort requirement included in the BC ESC for passively cooled buildings may be met without mechanical cooling when dynamic glazing is employed.

5 Closure & Next Steps

We trust this report summarizes how dynamic glazing can be used for energy code compliance in Toronto (Ontario) and Metro Vancouver (British Columbia), and certification to the Passive House Standard, as well as how the use of dynamic glazing can offset the need for certain other energy conservation measures.

Yours truly,

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Appendix A

Baseline Modeling Inputs

TABLE A.1 MODEL INPUTS FOR PASSIVE HOUSE OFFICE ARCHETYPES				
	Units	**Toronto**	**Metro Vancouver**	**Notes & References**
ARCHITECTURAL				
Storeys	-	9-storey office tower		
Gross Floor Area	m^2 (ft^2)	12,200 (129,000)		
Exterior Shading	-	N/A		Shading from balconies and other building features is captured
BUILDING ENCLOSURE				
Exterior Walls – RSI-Value (R-value)	m^2K/W (hr-sf²-F/Btu)	RSI-7.0 (R-40)	RS-3.5 (R-20)	
Floors – RSI-Value (R-value)	m^2K/W (hr-sf²-F/Btu)	RSI-5.3 (R-30)		
Roofs – RSI-Value (R-value)	m^2K/W (hr-sf²-F/Btu)	RSI-8.8 (R-50)		
Airtightness	ACH @ 50Pa	0.6	0.6	
Window-to-Wall Ratio (WWR)	%	45%	55%	
Window – centre of glass USI-Value (U-value)	W/m^2K (Btu/hr-sf²-F)	USI-0.68 (U-0.12)		SageGlass dynamic triple glazed windows and curtain wall
Window – g-value	-	Low: 0.03 High: 0.36		
MECHANICAL SYSTEMS				
VENTILATION				
Heat Recovery Ventilator				
Flow Rate	cfm (m^3/h)	15,958 (27,113)		
Heat Recovery Effectiveness	%	84%	80%	
Outdoor Air Fraction	%	100%		
HEATING/COOLING DISTRIBUTION				
Heating Distribution	-	Fan Coil Units (FCUs) served by an air-source heat pump plant		
Design Heating/Cooling Capacity	W	Autosized		
Seasonal COP (Heating and Cooling)	-	2.5		
DOMESTIC HOT WATER				
Heating Source	-	Heat Pump DHW Heating		
DHW Load	l/s/person	3.6		
Supply Temperature	°C	60		
Storage Tank	-	315 x 2		
Pumping	-	Variable Speed Pumps		
OPERATION				
LIGHTING				
Lighting Power Density – Office	W/m^2	8.4		20% better than ASHRAE 90.1-2010

Lighting Power Density – Meeting Rooms	W/m²	10.6	20% better than ASHRAE 90.1-2010
Lighting Power Density – Common	W/m²	5.7	20% better than ASHRAE 90.1-2010
MISCELLANEOUS LOADS			
Computers	W	80	One computer/person. PHPP default
Monitors	W	28	Per monitor (2/person). PHPP Default.
Office Dishwasher	kWh/yr	139	Energy Star
Office Fridge	kWh/yr	181	Energy Star
Phones	W	6	Desk Phones (IP Phone)
Elevator	kWh/yr	9,980	Elevator consumption (kWh/year)

TABLE A.2 MODEL INPUTS FOR TGS AND BC ESC OFFICE ARCHETYPES				
	Units	**Toronto (TGS)**	**Metro Vancouver (BC ESC)**	**Notes & References**
ARCHITECTURAL				
Storeys	-	17-storey office tower on a 2-storey commercial podium		
Gross Floor Area	m^2 (ft^2)	17,500 (189,000)		
Exterior Shading	-	N/A		Shading from balconies and other building features is captured
BUILDING ENCLOSURE				
Exterior Walls – RSI-Value (R-value)	m^2K/W (hr-sf²-F/Btu)	RSI-2.6 (R-15)	RSI-1.1 (R-6)	Opaque wall and spandrel panel
Floors – Above Parkade – RSI-Value (R-value)	m^2K/W (hr-sf²-F/Btu)	RSI-3.5 (R-20)		
Roofs – RSI-Value (R-value)	m^2K/W (hr-sf²-F/Btu)	RSI-3.5 (R-20)		
Infiltration Rate	$L/s/m^2$ @ 5Pa	0.20		
Window-to-Wall Ratio (WWR)	%	50%	60%	
Window – installed USI-Value (U-value)	W/m^2K (Btu/hr-sf²-F)	USI-1.53 (U-0.27)	USI-1.81 (U-0.32)	SageGlass dynamic triple glazed curtain wall
Window – SHGC	-	Low: 0.36 High: 0.07		
MECHANICAL SYSTEMS				
VENTILATION				
Heat Recovery Ventilator				
Flow Rate	cfm (m^3/h)	24,500 (41,600)		ASHRAE 62.1-2001
Heat Recovery Effectiveness	%	91%		
Outdoor Air Fraction	%	100%		
HEATING/COOLING DISTRIBUTION				
Heating/Cooling Distribution	-	Fan Coil Units (FCUs) served by an air-source heat pump plant. This system can operate in heat recovery mode and provide heating and cooling simultaneously.		
Design Heating/Cooling Capacity	W	Autosized		
Seasonal COP – Heating	-	3		
Seasonal COP – Cooling	-	2.8		
DOMESTIC HOT WATER				
Heating Source	-	Electric		
DHW Load	gpm	8		
Supply Temperature	°C	60		
Storage Tank	-	Autosized		

Pumping	-	Variable Speed Pumps	
Pump Power	W/gpm	19	
OPERATION			
LIGHTING			
Lighting Power Density – Office	W/m²	8.5	20% better than ASHRAE 90.1-2010
Lighting Power Density – Retail	W/m²	15.5	20% better than ASHRAE 90.1-2010
Schedule	-	NECB 2015 Office/Retail	
PROCESS LOADS			
Plug Loads – Office	W/m²	7.5	NECB 2015 Office
Plug Loads – Retail	-	2.5	NECB 2015 Retail
Elevator Load	-	3 @ 3kW	City of Vancouver Energy Modelling Guidelines v2.0
Elevator Schedule	-	BC Hydro Elevator Schedule	

TABLE A.3 MODEL INPUTS FOR PASSIVE HOUSE MULTIFAMILY RESIDENTIAL BUILDING			
	Units	**Metro Vancouver**	**Notes & References**
ARCHITECTURAL			
Storeys	-	6-storey residential building	
Gross Floor Area	m^2 (ft^2)	7,900 (85,000)	
Exterior Shading	-	N/A	Shading from balconies and other building features is captured
BUILDING ENCLOSURE			
Exterior Walls – RSI-Value (R-value)	m^2K/W (hr-sf^2-F/Btu)	RSI-5.3 (R-30)	
Floors – Above Parkade – RSI-Value (R-value)	m^2K/W (hr-sf^2-F/Btu)	RSI-8.6 (R-49)	
Roofs – RSI-Value (R-value)	m^2K/W (hr-sf^2-F/Btu)	RSI-7.7 (R-44)	
Airtightness	ACH @ 50Pa	0.6	
Window-to-Wall Ratio (WWR)	%	40%	
Window – centre of glass USI-Value (U-value)	W/m^2K (Btu/hr-sf^2-F)	USI-0.74 (U-0.13)	SageGlass dynamic triple glazed punched window
Window g-value	-	Low: 0.03 High: 0.36	
MECHANICAL SYSTEMS			
VENTILATION			
Heat Recovery Ventilator			
Flow Rate	cfm (m^3/h)	16,800 (28,500)	
Heat Recovery Effectiveness	%	84%	
Outdoor Air Fraction	%	100%	
HEATING/COOLING DISTRIBUTION			
Heating Distribution	-	DX heating and cooling coil in ventilating system. Electric baseboards in suites.	
Design Heating Capacity	W	Autosized	
DX Heating Coil – Seasonal COP	-	2.0	
DX Cooling Coil – Seasonal COP	-	2.5	
DOMESTIC HOT WATER			
Heating Source	-	Air source heat pumps	
DHW Load	l/s/person	25	PHPP default for residential buildings
Supply Temperature	°C	60	
Storage Tank	-	2 x 225 L	
Seasonal COP	-	2.5	

Pump	-	Variable Speed Pumps	
OPERATION			
LIGHTING			
Lighting Power Density – Suites	lm/W	65	PHPP default for retro LED white lighting
Lighting Power Density – Corridor	W/m²	5.3	25% better than ASHRAE 90.1-2016. Equipped with motion sensors.
PROCESS LOADS			
Dishwasher	kWh/use	1.1	PHPP default
Clothes washing	kWh/use	1.1	PHPP default
Clothes Drying	kWh/use	3.5	PHPP default
Refrigeration	kWh/day	1.0	PHPP default
Cooking	kWh/use	0.2	PHPP default
Consumer electronics	W / person	80	PHPP default
Small appliances	kWh/person/year	50	PHPP default
Elevator	kWh/year	12,646	2 elevators

TABLE A.4 MODEL INPUTS FOR BC ESC MULTIFAMILY RESIDENTIAL BUILDING			
	Units	**Metro Vancouver (BC ESC)**	**Notes & References**
ARCHITECTURAL			
Storeys	-	5-storey residential building	
Gross Floor Area	m^2 (ft^2)	5,200 (56,000)	
Exterior Shading	-	N/A	Shading from balconies and other building features is captured
BUILDING ENCLOSURE			
Exterior Walls – RSI-Value (R-value)	m^2K/W (hr-sf²-F/Btu)	RSI-4.4 (R-25)	
Floors – RSI-Value (R-value)	m^2K/W (hr-sf²-F/Btu)	RSI-5.3 (R-30)	
Roofs – RSI-Value (R-value)	m^2K/W (hr-sf²-F/Btu)	R-37 (R-6.5)	
Infiltration Rate	L/s/m^2 @ 5Pa	0.20	City of Vancouver Energy Modelling Guidelines v.2.0
Infiltration Schedule	-	Always On	
Window-to-Wall Ratio (WWR)	%	20%	
Fixed Window – Installed USI-Value (U-value)	W/m^2K (Btu/hr-sf²-F)	USI-1.65 (U-0.29)	SageGlass double glazed punched windows (fixed and operable)
Operable Window – Installed USI-Value (U-value)	W/m^2K (Btu/hr-sf²-F)	USI-1.81 (U-0.32)	
Window – SHGC	-	Low: 0.12 High: 0.44	
MECHANICAL SYSTEMS			
MAKE-UP AIR UNIT			
Flow rate	cfm (m^3/s)	1,150 (2,000)	20 cfm/door to supply corridors
Fraction Outdoor Air	%	100%	
Fan Type	-	Constant Air Volume	
Economizer	-	None	
Heating Type	-	Gas fired	
Heating Efficiency	%	80%	
Schedule	-	Always On	
SUITE VENTILATION			
Heat Recovery Ventilator (in-suite)			
Flow Rate	cfm (m^3/h)	2,050 (3,500)	Ventilation rates based on ASHRAE 62.1 2001
Heat Recovery Efficiency	%	60%	
Fraction Outdoor Air	%	100%	

HEATING/COOLING DISTRIBUTION			
Heating Distribution	-	Electric baseboards	
Design Heating Capacity	W	Autosized	
DOMESTIC HOT WATER			
Heating Source	-	Gas Boiler	
Efficiency	%	89%	
DHW Load	l/s/person	0.0016	City of Vancouver Energy Modelling Guideline
Supply Temperature	°C	60	
Storage Tank	-	Autosized	
Pumping	-	Variable Speed Pumps	
Pump Power	W/gpm	19	
OPERATION			
LIGHTING			
Lighting Power Density – Suites	W/m²	5	City of Vancouver Energy Modelling Guideline
Schedule - Suites	-	NECB 2011 Schedule G	
Lighting Power Density – Corridor	W/m²	8.4	NECB 2011
Schedule – Corridor	-	Always On	
PROCESS LOADS			
Plug Loads	W/m²	5	City of Vancouver Energy Modelling Guidelines
Schedule	-	NECB 2011 Schedule G	
Elevator Load	-	2 @ 3kW	3 kW per elevator (City of Vancouver Energy Modelling Guideline), assumed 2 elevators.
Elevator Schedule	-	BC Hydro Elevator Schedule	

Appendix B

Passive House Modeling Workflow

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Making Buildings Better™

TO **Jordan Doria**
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22596.000
SageGlass Dynamic Glazing Assessment of Energy Performance
DATE June 25, 2020

REGARDING **Modeling SageGlass Dynamic Glazing in PHPP and WUFI Passive**

Dear Mr. Doria,

RDH Building Science Inc. (RDH) is pleased to provide you with this summary of a proposed modeling workflow of the SageGlass dynamic glazing for compliance with the certification program as maintained by the Passive House Institute (PHI) and the Passive House Institute US (PHIUS). It should be noted that this protocol must be reviewed by PHI and PHIUS before it can be accepted for projects seeking certification. As the two Passive House certification standards use different modeling tools, workflows are presented below for each modeling tool.

Passive House Planning Package

The Passive House Planning Package (PHPP) is used for compliance with the Passive House Standard as maintained by the PHI. We have identified two potential modeling approaches in PHPP; *Variants* and *Reduction factors*.

Modeling Approach – Variants

We propose to model SageGlass dynamic glazing using the Variants page within PHPP to model the high and low g-values. The final results for certification will be a blend between the two variants. Figure 1 shows each g-value modeled as a variant. Variant 1 is modeled as the high g-value scenario and Variant 2 is modeled as the low g-value scenario. The Heating demand/Heating load will be determined from the high g-value case (highlighted in orange) while the Cooling demand/Cooling load (highlighted in blue) will be determined using the low g-value case. The Primary Energy Renewable (PER) result will be the sum of the Heating primary energy taken from the high g-value variant, and the Cooling and dehumidification will be calculated from the low g-value variant (highlighted in yellow).

Variant calculation

Passive House with PHPP Version 9.6a

6 Storey Multi-Unit Residential building / Climate: Vancouver / TFA: 7846 m² / Heating: 11.9 kWh/(m²a) / Cooling: 0.3 kWh/(m²a) / PER: 57.4 kWh/(m²a)

		Active			
Select the active variant here >>>>>>>		1-High g-value	High g-value	Low g-value	
Results	Units	1	1	2	3
Heating demand	kWh/(m²a)	11.9	11.9	14.8	1.9
Heating load	W/m²	8.8	8.8	9.0	4.1
Cooling & dehum. demand	kWh/(m²a)	0.3	0.3	0.0	1.8
Cooling load	W/m²	0.0	0.0	0.0	0.8
Frequency of overheating (> 25 °C)	%				
PER demand	kWh/(m²a)	57.4	57.4	61.6	48.2
Passive House Classic?	yes / no	yes	yes	yes	no
Final energy		-	-	-	-
User determined results					-
Heating PER	kWh/m²/yr	8.2	8.24	12.55	5.88
Cooling PER	kWh/m²/yr	0.1	0.11	0.02	0.22
DHW PER	kWh/m²/yr	14.8	15	15	15
Household Electricity PER	kWh/m²/yr	34.2	34	34	27

Figure 1 The high and low g-value scenario are modeled on the variants page. The final results are the blended results from each variant. In this example, Heating Demand: 11.9 kWh/m²/yr, Heating Load: 8.8 W/m², Cooling and Dehumidification demand: 0.0 kWh/m²/yr, Cooling Load: 0.0 W/m², PER Demand: 8.42+0.02+15+34 = 57.2 kWh/m²/yr.

Step by step modeling protocol

1. Define the high (clear) and low (tinted) g-value and u-value glazing elements on the components sheet Figure 2.

Glazing — **Glazing**

ID	Description	g-Value	U_g-Value
	Recommended glazing type to start planning: Triple thermally insulated glazing (Please consider the comfort criterion!)		
			W/(m²K)
01ud	High g-value	0.36	0.79
02ud	Low g-value	0.06	0.79

Figure 2 Defining the high and low g-value on the Components sheet.

2. Create a user determined parameter for each glazing type in the Variants sheet and set up the first variant to use the high g-value glazing and the second variant with the low g-value glazing Figure 3.

Passive House with

Variant calculation

6 Storey Multi-Unit Residential building / Climate: Vancouver / TFA: 7846 m² / Heating: 11.9 kWh/(m²a) / Cooling: 0.3 kWh/(m²a) / PER: 57.4 kWh/(m²a)

		Active		
Select the active variant here >>>>>>>		1-High g-value	High g-value	Low g-value
Results	Units	1	1	2
Heating demand	kWh/(m²a)	11.9	11.9	14.8
Heating load	W/m²	8.8	8.8	9.0
Cooling & dehum. demand	kWh/(m²a)	0.3	0.3	0.0
Cooling load	W/m²	0.0	0.0	0.0
Frequency of overheating (> 25 °C)	%			
PER demand	kWh/(m²a)	57.4	57.4	61.6
Passive House Classic?	yes / no	yes	yes	yes
Final energy		-	-	-
User determined results		-	-	-
			0	0
Input variables	Units	Value	1	2
Building assembly layers	U-Value			
Radiation balance	Areas			
Thermal bridges	Areas			
Windows and shading	Windows	Shading		
Ventilation	Ventilation			
Summer ventilation	SummVent			
Heat generator	PER			
Compressor cooling units	Cooling units			
User determined parameters				
1 Glazing type	-	01ud-High g-value	01ud-High g-value	02ud-Low g-value

Figure 3 Defining a user determined parameter on the Variants sheet for the high g-value and low g-value scenario. (boxed in red)

3. On the Windows sheet, link the glazing component (boxed in red in Figure 4) to the active user defined parameter variant cell on the Variant sheet (highlighted in yellow in Figure 5).

Windows

6 Storey Multi-Unit Residential building / Climate: Vancouver / TFA: 7846 m² / Heating: 11.9 kWh/(m²a) / Cooling: 0.3 kWh/(m²a) / PER: 57.4 kWh/(m²a)

Window area orientation	Global radiation (main orientations)	Shading	Dirt	Non-vertical radiation incidence	Glazing fraction	g-Value	Solar irradiation reduction factor	Window area
Standard values →	kWh/(m²a)	0.75	0.95	0.85				m²
North	118	0.75	0.95	0.85	0.68	0.36	0.41	190.82
East	260	0.62	0.95	0.85	0.67	0.36	0.33	242.75
South	475	0.57	0.95	0.85	0.67	0.36	0.31	134.79
West	282	0.62	0.95	0.85	0.68	0.36	0.34	270.82
Horizontal	411	1.00	0.95	0.85	0.00	0.00	0.00	0.00
Total or average value for all windows.						0.36	0.35	839.18

Heating degree hours [kKh/a]: 73.5

Go to glazing list | Go to window frames list

Qua n- tity	Description	Deviation from north	Angle of inclination from the horizontal	Orien- tation	Window rough openings: Width	Window rough openings: Height	Installed in: Selection from 'Areas' worksheet	Glazing: Selection from 'Components' worksheet	Frame: Selection from 'Components' worksheet
		°	°		m	m		1-Sorting: LIKE LIST	1-Sorting: LIKE LIST
1	Win_001_E	67.5	90	East	1.043	2.500	39-Wall_039_E	01ud-High g-value	03ud
1	Win_002_E	67.5	90	East	1.043	2.500	39-Wall_039_E	01ud-High g-value	38ud
1	Win_003_W	247.5	90	West	0.914	2.476	51-Wall_051_W	01ud-High g-value	04ud
1	Win_004_W	247.5	90	West	0.914	2.476	51-Wall_051_W	01ud-High g-value	04ud
1	Win_005_W	247.5	90	West	0.914	2.476	51-Wall_051_W	01ud-High g-value	04ud

Figure 4 Link the glazing component (boxed in red) on the window sheet to the user determined glazing component.

Variant calculation

Passive House with

6 Storey Multi-Unit Residential building / Climate: Vancouver / TFA: 7846 m² / Heating: 11.9 kWh/(m²a) / Cooling: 0.3 kWh/(m²a) / PER: 57.4 kWh/(m²a)

		Active		
	Select the active variant here >>>>>>>	1-High g-value	High g-value	Low g-value
Results	Units	1	1	2
Heating demand	kWh/(m²a)	11.9	11.9	14.8
Heating load	W/m²	8.8	8.8	9.0
Cooling & dehum. demand	kWh/(m²a)	0.3	0.3	0.0
Cooling load	W/m²	0.0	0.0	0.0
Frequency of overheating (> 25 °C)	%			
PER demand	kWh/(m²a)	57.4	57.4	61.6
Passive House Classic?	yes / no	yes	yes	yes
Final energy		-	-	-
User determined results		-	-	-
			0	0
Input variables	Units	Value	1	2
Building assembly layers	U-Value			
Radiation balance	Areas			
Thermal bridges	Areas			
Windows and shading	Windows	Shading		
Ventilation	Ventilation			
Summer ventilation	SummVent			
Heat generator	PER			
Compressor cooling units	Cooling units			
User determined parameters				
Glazing type	-	01ud-High g-value	01ud-High g-value	02ud-Low g-value

Figure 5 The glazing component on the window sheet should equal the active variant cell as highlighted in yellow.

4. Define four user determined results; Heating PER, Cooling and Dehumidification PER, DHW generation PER, and Household electricity PER on the variants sheet. The user determined cells as highlighted in yellow in Figure 6 should be linked to the respective cells on the PER sheet.

Variant calculation

Passive House with

6 Storey Multi-Unit Residential building / Climate: Vancouver / TFA: 7846 m² / Heating: 11.9 kWh/(m²a) / Cooling: 0.3 kWh/(m²a) / PER: 57.4 kWh/(m²a)

		Active		
	Select the active variant here >>>>>>>	1-High g-value	High g-value	Low g-value
Results	Units	1	1	2
Heating demand	kWh/(m²a)	11.9	11.9	14.8
Heating load	W/m²	8.8	8.8	9.0
Cooling & dehum. demand	kWh/(m²a)	0.3	0.3	0.0
Cooling load	W/m²	0.0	0.0	0.0
Frequency of overheating (> 25 °C)	%			
PER demand	kWh/(m²a)	57.4	57.4	61.6
Passive House Classic?	yes / no	yes	yes	yes
Final energy		-	-	-
User determined results		-	-	-
Heating PER	kWh/m²/yr	8.2	8.24	12.55
Cooling & dehumidification PER	kWh/m²/yr	0.1	0.11	0.02
DHW generation PER	kWh/m²/yr	14.8	15	15
Household electricity PER	kWh/m²/yr	34.2	34	34

Figure 6 Defining user determined results on the variant sheet.

Energy demand	Efficiency		Final energy		PER		
Reference: Treated floor area	Calculation -	User defined value -	Contribution (final energy)	**Final energy demand** kWh/(m²a)	PER factor kWh/kWh	Effective PER factor (including biomass kWh/kWh	**PER specific value** kWh/(m²a)
							57.4
Heating			100%			1.11	**8.2**
Electricity (HP compact unit)					1.50		
Electricity (heat pump)	1.26	2.00	82%	4.9	1.50	1.10	5.4
District heating: 1-None					2.8|4.5|3.3		
Wood and other biomass					1.10		
Natural gas / RE gas					1.75		
Heating oil / RE methanol					2.30		
Solar thermal system							
Electricity (direct)	1.00		18%	2.1	1.50	1.10	2.3
Aux. electricity (heating, wintertime ventilation)				0.4	1.50	1.24	0.6
Cooling and dehumidification					1.00		**0.1**
Electricity cooling (heat pump)	2.50			0.1	1.00		0.1
Auxiliary electricity cooling, ventilation summer					1.00		
Electricity dehumidification (heat pump)					1.00		
Auxiliary electricity (dehumidification)					1.00		
DHW generation			100%			1.15	**14.8**
Electricity (HP compact unit)					1.15		
Electricity (heat pump)	0.99	2.50	97%	8.2	1.15	1.15	9.4
District heating: 1-None					2.8|4.5|3.3		
Wood and other biomass					1.10		
Natural gas / RE gas					1.75		
Heating oil / Methanol					2.30		
Solar thermal system							
Electricity (direct)	1.00		3%	0.6	1.15	1.15	0.7
Aux. electricity (DHW + solar DHW)				4.1	1.15	1.15	4.7
Household electricity				28.5		1.20	**34.2**
Electricity (household or non-residential lighting, etc.)				22.9	1.20	1.20	27.4
Auxiliary electricity (other)				5.7	1.20	1.20	6.8

Figure 7 The user determined results should be linked to the respective heating, cooling and dehumidification, DHW generation and Household electricity cells (highlighted in yellow) on the PER sheet.

5. Compute the total PER demand by adding the Heating PER from the high g-value case, Cooling PER from the low g-value case, domestic hot water PER and household electricity as shown by the highlighted cells in Figure 8. The heating demand and load is shown in the High g-value variant and the cooling demand and load is shown in the Low g-value variant. In this example, Heating Demand: 11.9 kWh/m²/yr, Heating Load: 8.8 W/m², Cooling and Dehumidification demand: 0.0 kWh/m²/yr, Cooling Load: 0.0 W/m², PER Demand: 8.42+0.02+15+34 = 57.2 kWh/m²/yr.

Variant calculation

Passive H use with

6 Storey Multi-Unit Residential building / Climate: Vancouver / TFA: 7846 m² / Heating: 11.9 kWh/(m²a) / Cooling: 0.3 kWh/(m²a) / PER: 57.4 kWh/ a)

		Active		
Select the active variant here >>>>>>>		1-High g-value	High g-value	Low g-value
Results	Units	1	1	2
Heating demand	kWh/(m²a)	**11.9**	11.9	14.8
Heating load	W/m²	**8.8**	8.8	9.0
Cooling & dehum. demand	kWh/(m²a)	**0.3**	0.3	0.0
Cooling load	W/m²	**0.0**	0.0	0.0
Frequency of overheating (> 25 °C)	%			
PER demand	kWh/(m²a)	**57.4**	57.4	61.6
Passive House Classic?	yes / no	**yes**	yes	yes
Final energy		-	-	-
User determined results		-	-	-
Heating PER	kWh/m²/yr	8.2	8.24	12.55
Cooling & dehumidification PER	kWh/m²/yr	0.1	0.11	0.02
DHW generation PER	kWh/m²/yr	14.8	15	15
Household electricity PER	kWh/m²/yr	34.2	34	34

Figure 8 Compute the project specific PER demand by summing the Heating PER from the high g-value variant, the Cooling PER from the low g-value variant, and the DHW generation and Household electricity PER demand.

Alternative Modeling Approach – Reduction Factors

This alternative modeling approach in PHPP will be to use the additional reduction factors[1] for winter (r_w) and summer (r_s) shading to adjust the amount of solar gain into the building. The shading tab in PHPP is shown below in Figure 9. Each shading element is calculated independently, horizon (r_H), lateral reveal (r_R), and overhang reveal (r_O). Three additional columns are used to adjust the shading factor for each window entry; the winter shading boxed in blue (r_W), summer shading boxed in red (r_S) and temporary shading (z). The winter and summer shading inputs have traditionally been used for shading caused by trees while the temporary shading inputs are used for operable blinds.

[1] PHPP uses shading factor to adjust the solar gains to the building. The overall shading factor (r_s) is calculated by multiplying the horizontal obstruction factor (r_H), vertical reveal shading factor (r_R), horizontal overhang shading factor (r_O) winter shading factor (r_w), summer shading factor (r_s) and the reduction shading factor for temporary sun protection (z).

Horizon		Lateral reveal		Reveal / Overhang				
Height of the shading object	Horizontal distance	Window reveal depth	Distance from glazing edge to reveal	Overhang depth	Distance from upper glazing edge to overhang	Additional reduction factor winter shading	Additional reduction factor summer shading	Reduction factor z for temporary sun protection
h_{Hori} [m]	d_{Hori} [m]	o_{Reveal} [m]	d_{Reveal} [m]	o_{over} [m]	d_{over} [m]	$r_{other,w}$ [%]	$r_{other,s}$ [%]	z [%]

Figure 9 Typical shading inputs from PHPP include horizon, lateral reveal, overhang. Three additional columns are used to capture temporary shading devices and objects.

The proposed modeling approach is similar to modeling temporary exterior shading devices or a single line of deciduous trees as a factor is applied to each window depending on the type of shading device, the insulated glazing unit, and the position of the shading device. This approach can be used for modeling dynamic glazing where the winter and summer factors will be determined by simulating the dynamic glazing with an hourly tool that can model each operation mode.

Discussion

The advantage of the Variants approach is that it does not require additional modeling with an hourly tool. However, it can only be optimized for managing heating and cooling loads since PHPP cannot adequately capture daylighting, glare, and schedule operation modes. The resulting PHPP will include an additional calculation of the high and low g-value scenarios. This workaround may add complexity to reviews by Authorities Having Jurisdiction and PHI certifiers.

The advantage of the Reduction Factor approach is the familiarity with the existing protocol for temporary shading devices and the ability to capture different operation modes. However, it requires calibration with an hourly modeling software and the resulting factors are generalized for triple and double insulated glazing units. The calculated factors would be tabulated like temporary shading devices found in the PHPP manual as shown in Table 1.

TABLE 1 REDUCTION FACTORS FOR TEMPORARY SHADING DEVICES (PASSIVE HOUSE INSTITUTE, 2015, PHPP THE ENERGY BALANCE AND DESIGN TOOL V9)

	Triple Insulated Glazing		**Double Insulated Glazing**	
Type of Shading Device	**Exterior position**	**Interior position**	**Exterior position**	**Interior position**
Blinds, vertical lamellas	0.06	0.7	0.07	0.6
Blinds, lamellas 45˚	0.1	0.75	0.12	0.65
Roller blinds / marquees, white	0.24	0.6	0.25	0.5
Roller blinds / marquees, greg	0.12	0.8	0.14	0.75
Foil	-	0.6	-	0.5

Also, modifications to the shading sheet will be required if tree shading or DesignPH[1] is used as those standard workflows already utilize the same columns within PHPP.

Limitations

The methodology presented above has been developed with the understanding that PHPP is a single zone monthly modeling software. The tool is designed to calculate annual average energy consumption based on average monthly temperatures and annual average occupancy, internal heat gain, ventilation rates etc. As such, this methodology is only applicable for PHPP modeling. This approach is designed to estimate the impact of dynamic glazing on overall energy use based on annual averages. Users should recognize that in practice, the dynamic glazing can be controlled based on the zoning, orientation, schedules, and HVAC loads.

WUFI-Passive

WUFI Passive is used for compliance with the PHIUS+ Passive Building Standard (PHIUS+) as maintained by PHIUS. We have identified one potential modeling approach for with WUFI Passive: *Reduction factors*.

Modeling Approach

A single modeling path is proposed within WUFI-Passive which would require the development of a separate calculator to determine reduction factors for both Winter and Summer. This calculator would include common entries for use, occupancy, levels of intended solar control, and other entries utilized in an hourly modeling tool. This calculator can be simplified from an hourly modeling tool as the required outputs would be for monthly energy balances.

This supplemental calculator would in turn generate two seasonal shading reduction factors. These calculations can be completed for an individual glazing unit or for an orientation, depending on the unique characteristics of the application. If the use of Sage-Glass is only intended for controlling solar gains during the cooling season, only one calculation would be required.

Solar exposure for glazing is modeled within WUFI-Passive in the tabs shown in Figure 10 below. Each glazed component on the building has an associated set of entries, including a tab for *Solar protection*. Sub-tabs for *Solar protection* include two locations where shading per glazed component can be entered. We propose the use of the *General* sub-tab, in which there are two locations to enter shading which is introduced seasonally. WUFI-Passive calculates shading from all architectural, window coverings (such as interior curtains or exterior blinds), and landscape sources in separate locations, allowing for these two *General* entries to be utilized for this type of specialty glazing.

The reduction factors generated by the supplemental calculator described above can be entered in both the “Other shading fraction of solar exposure” for determining the effect

[1] DesignPH is a plugin for the 3D design software Sketchup. It is a 3D interface for PHPP that has been developed by PHI. It enables modelers to model the majority of the thermal components such as building assemblies, areas, windows, thermal bridges and shading in a 3D environment. These inputs can then be imported into the corresponding sheets in PHPP. For the shading sheet, the combination of horizon, reveal and overhang shading factors will be calculated by DesignPH and imported into the winter and summer shading factor cells.

on heating energy calculations and the “Other shading summer fraction of solar exposure” for determining the effect on cooling energy calculations.

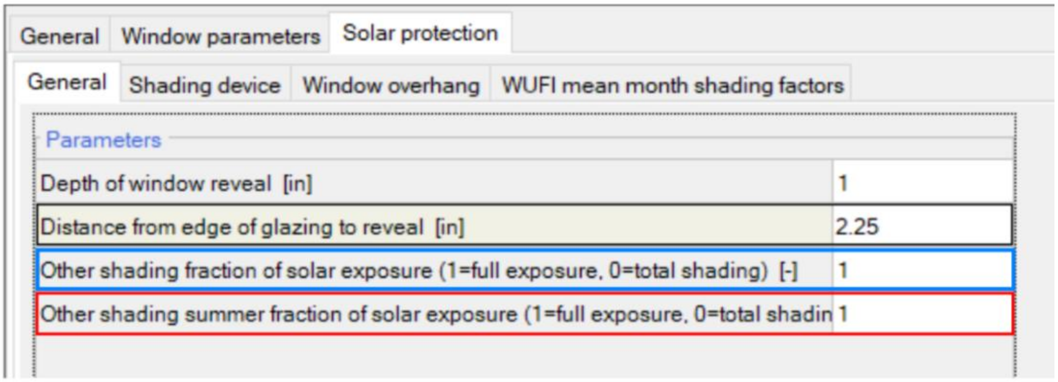

Figure 10 Typical shading inputs from WUFI-Passive include horizon, lateral reveal, overhang, adjacent architecture, and landscaping. Additional entries are used to capture temporary shading devices and objects. The proposed entry for shading effecting heating energy is identified by the blue rectangle, the proposed entry for shading effecting cooling energy is identified by the red rectangle.

Heating and cooling energy, as they are affected by the use of Sage-Glass as entered in the *Solar protection > General* tab, will be generated within the single energy model. Results from this single model can be compared to the PHIUS+ limits required for certification compliance, including hourly heating and cooling loads, annual heating and cooling demands and total building energy, defined within WUFI-Passive as Source Energy.

Discussion

Although the above methodology for including the effects of dynamic glazing requires the use of a separate calculator, entries within the calculator can be adapted for the unique installation, including the variables for occupancy, control systems, daylighting requirements, and level of solar gain allowed through the Sage-Glass.

Calculations completed by WUFI-Passive require only a single energy model and individual cases can be developed to assess the impacts of the dynamic glazing. Additionally, the PHIUS+ modeling effort can be completed using two simple variables within WUFI-Passive in order to determine a target which the Sage-Glass can then be designed to reach.

PHIUS+ protocols require compliance for both hourly and annual limits on both heating and cooling loads. WUFI-Passive software is based on monthly calculations; the ability to model the hourly loads with software which utilizes monthly calculations is limited and requires calibration with dynamic, hourly software. As WUFI-Passive calculations are not based on hourly computations, results are not utilized for the development of heating or cooling equipment designs; however, they can be conservatively applied to most energy efficient buildings in order to effect building design and meeting PHIUS+ space conditioning and source energy requirements. Following historical precedent, PHIUS will likely accept a simplified calculator with monthly-based entries if the results can be demonstrated to be comparable to dynamic software results when applied to a pre-determined number of cases.

The development of the supplemental calculator will require further investigation however it can be based on or utilize existing software to assess the impacts of dynamic glazing.

Limitations

The methodology presented above has been developed with the understanding that WUFI-Passive is a monthly modeling software. Though the tool has zoning capabilities, it is designed to calculate annual average energy consumption based on average monthly temperatures and annual average occupancy, internal heat gain, ventilation rates etc. As such, this methodology is only applicable for WUFI-Passive modeling. This approach is designed to estimate the impact of dynamic glazing on overall energy use based on annual averages. Users should recognize that in practice, the dynamic glazing can be controlled based on the zoning, orientation, schedules, and HVAC loads.

In order to address these limitations, WUFI-Passive modeling entries may be the preliminary basis of WUFI-Plus modeling, a modeling software which incorporates hourly dynamic modeling and zoning capabilities. PHIUS+ certification does not require this level of energy modeling. The adaptation of entries in WUFI-Plus are beyond the scope of this document.

Next Steps

The next step is to apply the PHI modeling protocol to the accepted building types to determine what trade offs may be possible. For this analysis, we will use the Variants approach as the development of the Reduction Factors approach will require additional hourly modeling which is outside the current scope of work. However, if there is a desire to explore this approach, we would be happy to discuss this further.

While we have presented possible methods for modeling dynamic glazing, it is important to understand that these modeling protocols must be reviewed by the PHI and PHIUS before it can be used for certification. We would be happy to bring this discussion to PHI and PHIUS however, this is currently outside our scope of work.

We look forward to receiving your feedback.

Yours truly,

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