MORRISON HERSHFIELD

TEDI Comparison of Window-Wall Systems

Presented to:

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1 INTRODUCTION

Morrison Hershfield (MH) was contracted by Starline Windows Ltd. (Starline) to quantify the impact of various window-wall systems on building energy performance and compliance with the upper levels of the BC Energy Step Code for a typical residential high-rise building in the lower mainland area of BC[1] which reside in Climate Zone 4 per NECB 2017. This report is a summary of the analysis.

The objective of this study is to find the relative impacts of building design features on the energy performance of residential high-rise buildings with window-wall systems in the lower mainland area of BC. The results presented in this report are based on an archetype residential high-rise building and shows generalized trends and impacts of building designs on energy performance. Impacts may differ for specific buildings based on variations in the design and assemblies, and a full building energy analysis is recommended to quantify the actual energy performance for specific projects.

The BC Energy Step Code offers an optional compliance path in the BC Building Code (BCBC) that local governments and Developers may adopt to meet the energy efficiency requirements of the BCBC. Building energy performance in the BC Energy Step Code is measured by the following metrics, which are derived from whole building energy simulations following Article 10.2.3.4 of the BC Energy Step Code:

- **Total Energy Use Intensity (TEUI):** annual overall energy use per floor area of a building[2]. This includes energy required for space heating, space cooling, ventilation, plug loads etc.

- **Thermal Energy Demand Intensity (TEDI):** annual heating load per floor area of a building. This is the amount of heat that is needed to offset the heat loss through the building envelope and condition the ventilation air[2].

The BC Energy Step Code has different targets for TEUI and TEDI for various climates, building occupancies and performance levels, otherwise known as 'Steps'. The BC Energy Step Code targets for residential high-rise buildings in Climate Zone 4 are listed in Table 1.1.

Table 1.1: BC Energy Step Code Requirements for Residential High-Rise in Climate Zone 4[3]

Step	Maximum Total Energy Use Intensity (TEUI) $kWh/m^2/yr$	Maximum Thermal Energy Demand Intensity (TEDI) $kWh/m^2/yr$
1	Conform to Part 8 of NECB	
2	130	45
3	120	30
4	100	15

[1] Regions within the Metro Vancouver area with heating degree days less than 3000 (Climate Zone 4 per NECB 2017)

[2] Guide to Low Thermal Energy Demand for Large Buildings, BC Housing, 2018

[3] Table 10.2.3.3.-H of BCBC Part 10, for locations with heating degree days less than 3000

For the purposes of this study only the TEDI targets are considered for compliance with The BC Energy Step Code since TEDI is heavily relied upon building envelope thermal performance, whereas TEUI may be impacted by equipment efficiencies that are beyond the scope of this report.

Since The BC Energy Step Code only specifies building energy performance and does not have requirements for other aspects of the building, such as window area like in other building energy codes and standards, designers and Developers have the freedom to design and specify building envelope components and assemblies of different performance levels provided it meets the required TEDI targets. This study evaluated possible pathways to meet the TEDI targets for Step 3 (30 kWh/m^2/yr) and Step 4 (15 kWh/m^2/yr) for a typical residential high-rise building in Climate Zone 4 by considering various window-wall systems listed in Table 1.2 and building parameters shown in Table 1.3. The vision glazing performance values listed in Table 1.2 were provided by Starline.

Table 1.2: Vision Glazing Performance Values of Evaluated Window-Wall Systems

Window Wall System	Vision Glazing		
	Description	U-value Btu/ft^{2}h°F (W/m^{2}K)	SHGC
Starline 9000	Double Glazed with Single Low-E Coating	0.34 (1.93)	0.32
	Double Glazed with Double Low-E Coating	0.30 (1.70)	0.31
Starline 9600	Double Glazed with Single Low-E Coating	0.30 (1.70)	0.32
	Double Glazed with Double Low-E Coating	0.26 (1.47)	0.32
	Triple Glazed with Single Low-E Coating	0.25 (1.42)	0.30
	Triple Glazed with Double Low-E Coating	0.19 (1.08)	0.26

Table 1.3: Parameters Evaluated in Building Energy Analysis

Window Wall System	Vision to Opaque Ratio (WWR)	Heat Recovery Ventilator (HRV) Efficiency (%)	Air Infiltration Rate	Balcony Percentage	Roof R-Value ft^{2}h°F/Btu (m^{2}K/W)
Starline 9000	65%, 60%, 50%, 40%, 30%, 20%	60%, 67.5%, 75%, 82.5%, 90%	Typical: 2 L/s/m^2 @ 75 Pa Air-tight: 0.8 L/s/m^2 @ 75 Pa	0%, 25%, 40%	R-20 (3.52) R-50 (8.81)
Starline 9600	65%, 60%, 50%, 40%, 30%, 20%	60%, 67.5%, 75%, 82.5%, 90%	Typical: 2 L/s/m^2 @ 75 Pa Air-tight: 0.8 L/s/m^2 @ 75 Pa	0%, 25%, 40%	R-20 (3.52) R-50 (8.81)

Thermal bridging from balconies are determined by the balcony length, which is expressed as a percentage of the perimeter intermediate floor length at each level. The typical air infiltration rate is based on the maximum specified rate listed in Part 10 of the BCBC 2018 and Vancouver Building Bylaw (VBBL) 2019.

Thermal performance of the opaque building envelope area was determined by spandrel thermal performance of the window-wall system, spandrel area, and the amount of thermal bridging in the building envelope dictated by the building design which are summarized in Section 2.1.

2 PROCEDURE

Building energy performance of various design paths were evaluated using the High-Rise Multi-Unit archetype model in Building Pathfinder[4] by combining the different parameters listed in Tables 1.2 and 1.3 with building envelope thermal transmittance values based on the window-wall system, balcony length, and vision to opaque ratio (WWR).

The window-wall spandrel thermal transmittance values (U-value and effective R-values) are based on evaluated thermal performance in the Building Envelope Thermal Bridging Guide[5] (BETB) and a previous MH report as listed in Table 2.1. All window-wall spandrel sections have 3 inches to 4.5 inches (76 mm to 114 mm) of mineral wool insulation (R-12.6 to R-18.9) in the back pan and an uninsulated steel-frame wall with 1/2 in (13 mm) gypsum drywall.

Table 2.1: Window-Wall Spandrel Thermal Performance

Window Wall System	Spandrel Clear Field			Bypass Linear Transmittance Btu/fth°F (W/mK)	Reference
	Back Pan Insulation Nominal R-value ft²h°F/Btu (m²K/W)	**U-value** Btu/ft²h°F (W/m²K)	**Effective R-value** ft²h°F/Btu (m²K/W)		
Starline 9000	R-12.6 (2.22)	0.119 (0.68)	R-8.4 (1.48)	0.104 (0.181)	BETB v1.5 Detail 1.2.4, 1.2.7
Starline 9600	R-18.9 (3.33)	0.067 (0.38)	R-15.0 (2.64)	0.174 (0.30)	MH Report No. 1805087.01[6]

2.1 Window-Wall Spandrel Thermal Transmittance

Thermal performance of the opaque building envelope assemblies was determined by applying thermal transmittance values listed in Table 2.1 to various spandrel areas based on the vision to opaque ratio and the balcony lengths. Vertical mullion spacing of 3.5 ft (1069 mm) and floor-to-floor height of 9 ft (2743 mm) were assumed. Spandrel and window areas were calculated based on 10.5 ft (3200 mm) wide modules that comprised of three 3.5 ft (1069 mm) wide window-wall sections as shown in Figures 2.1 to 2.6. Both half-height and full-height and spandrel sections were evaluated depending on the vision to opaque ratio. The balconies were assumed to be non-thermally broken cantilevered concrete balconies. Tables 2.2 to 2.7 list the spandrel thermal transmittances based on the vision to opaque ratio and balcony percentage. A summary of the procedure for calculating the overall U-value and effective R-value of the spandrel assemblies is provided in Appendix A.

[4] Buildingpathfinder.com

[5] www.bchousing.org/research-centre/library/residential-design-construction/building-envelope-thermal-bridging-guide

[6] MH Report: Bypass Linear Transmittance of Starline 9600 Window Wall System, dated: September 9, 2019

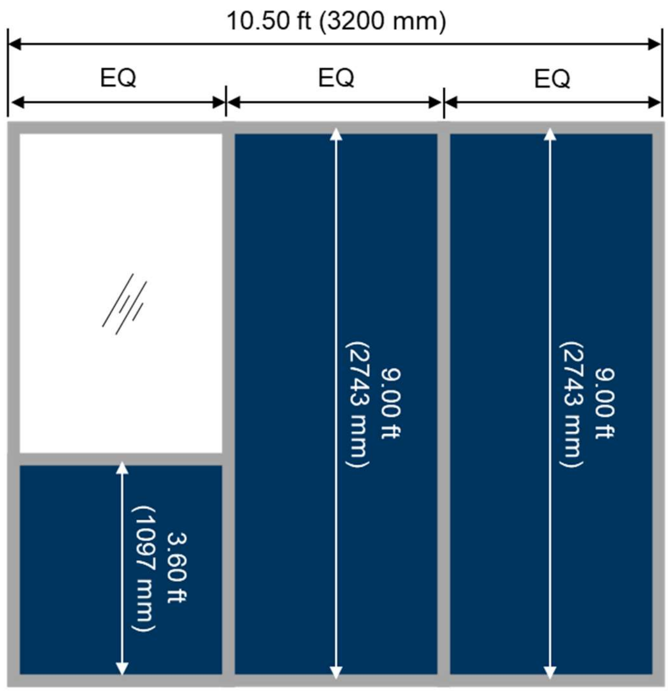


Figure 2.1: Window-Wall Layout with 20% Vision to Opaque Ratio (WWR)

Table 2.2: Overall Thermal Performance of Window-Wall Spandrel Sections with 20% Vision to Opaque Ratio (WWR)

Window Wall System	0% Balcony		25% Balcony		40% Balcony	
	Overall U-value Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)
Starline 9000	0.131 (0.74)	R-7.6 (1.34)	0.162 (0.92)	R-6.2 (1.09)	0.206 (1.17)	R-4.9 (0.85)
Starline 9600	0.088 (0.50)	R-11.4 (2.01)	0.117 (0.66)	R-8.6 (1.51)	0.157 (0.89)	R-6.4 (1.12)

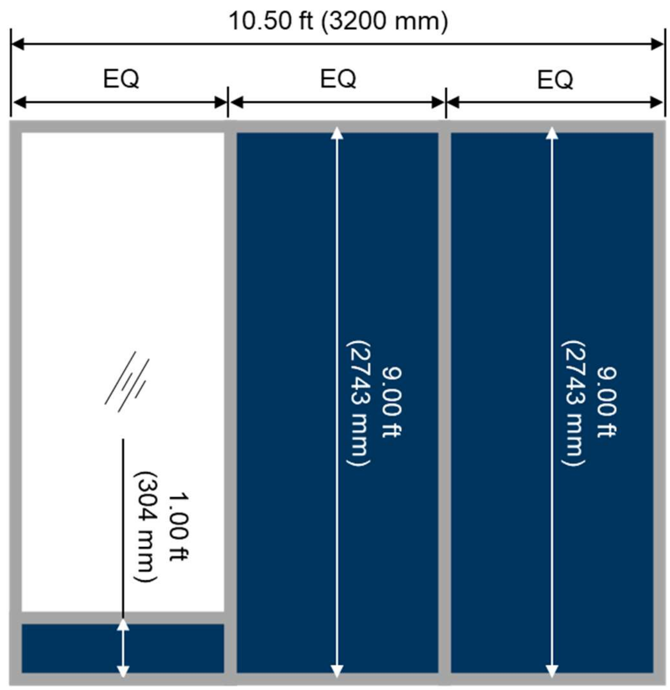


Figure 2.2: Window-Wall Layout with 30% Vision to Opaque Ratio (WWR)

Table 2.3: Overall Thermal Performance of Window-Wall Spandrel Sections with 30% Vision to Opaque Ratio (WWR)

Window Wall System	0% Balcony		25% Balcony		40% Balcony	
	Overall U-value Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)
Starline 9000	0.133 (0.75)	R-7.5 (1.33)	0.168 (0.95)	R-6.0 (1.05)	0.218 (1.24)	R-4.6 (0.81)
Starline 9600	0.091 (0.51)	R-11.0 (1.94)	0.123 (0.70)	R-8.1 (1.43)	0.169 (0.96)	R-5.9 (1.04)

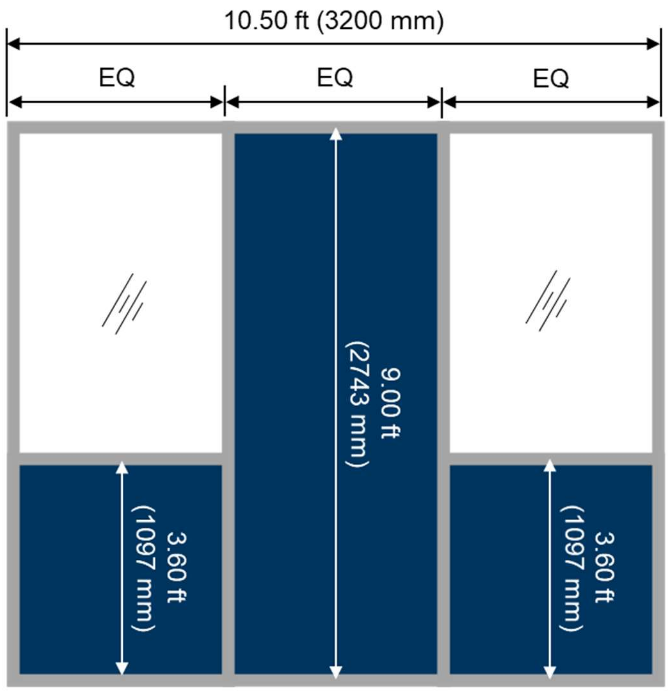


Figure 2.3: Window-Wall Layout with 40% Vision to Opaque Ratio (WWR)

Table 2.4: Overall Thermal Performance of Window-Wall Spandrel Sections with 40% Vision to Opaque Ratio (WWR)

Window Wall System	0% Balcony		25% Balcony		40% Balcony	
	Overall U-value Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)
Starline 9000	0.137 (0.78)	R-7.3 (1.29)	0.178 (1.01)	R-5.6 (0.99)	0.236 (1.34)	R-4.2 (0.75)
Starline 9600	0.095 (0.54)	R-10.6 (1.86)	0.133 (0.76)	R-7.5 (1.32)	0.187 (1.06)	R-5.4 (0.94)

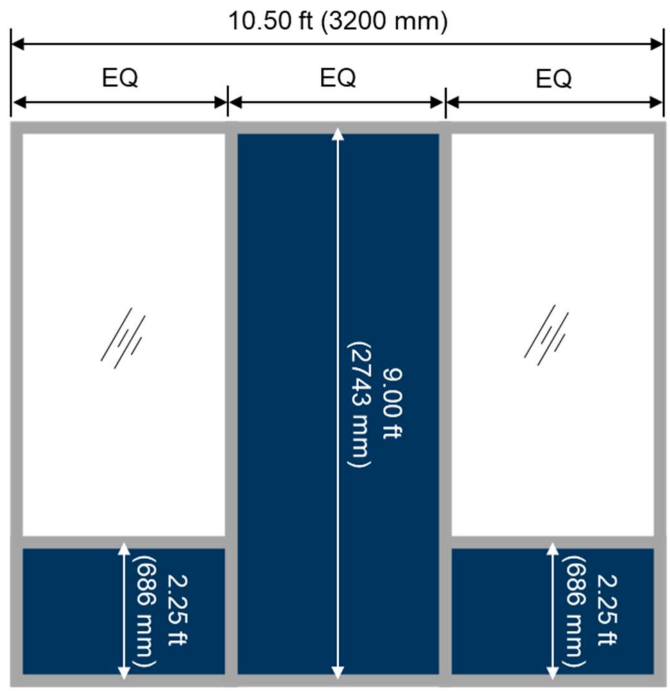


Figure 2.4: Window-Wall Layout with 50% Vision to Opaque Ratio (WWR)

Table 2.5: Overall Thermal Performance of Window-Wall Spandrel Sections with 50% Vision to Opaque Ratio (WWR)

Window Wall System	0% Balcony		25% Balcony		40% Balcony	
	Overall U-value Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)
Starline 9000	0.140 (0.80)	R-7.1 (1.26)	0.190 (1.08)	R-5.3 (0.93)	0.260 (1.47)	R-3.9 (0.68)
Starline 9600	0.100 (0.57)	R-10.0 (1.76)	0.146 (0.83)	R-6.8 (1.20)	0.210 (1.20)	R-4.8 (0.84)

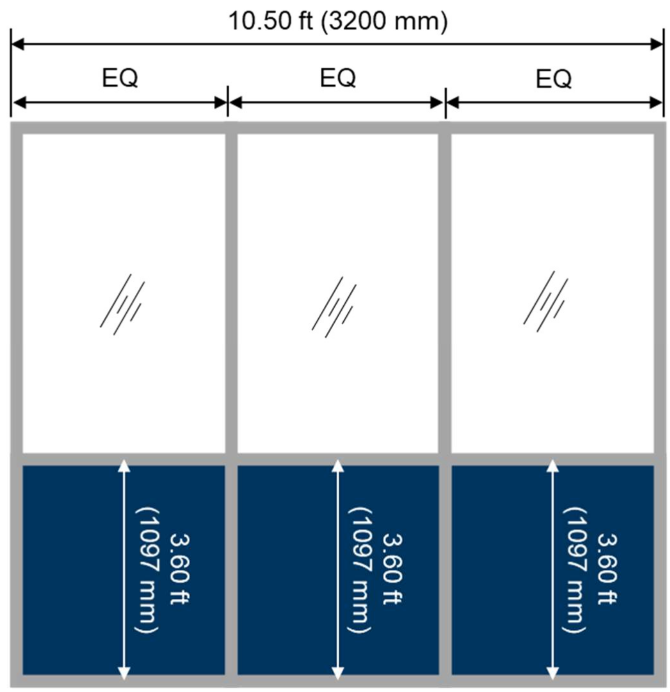


Figure 2.5: Window-Wall Layout with 60% Vision to Opaque Ratio (WWR)

Table 2.6: Overall Thermal Performance of Window-Wall Spandrel Sections with 60% Vision to Opaque Ratio (WWR)

Window Wall System	0% Balcony		25% Balcony		40% Balcony	
	Overall U-value Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)
Starline 9000	0.148 (0.84)	R-6.8 (1.19)	0.210 (1.19)	R-4.8 (0.84)	0.297 (1.69)	R-3.4 (0.59)
Starline 9600	0.115 (0.65)	R-8.7 (1.53)	0.173 (0.98)	R-5.8 (1.02)	0.253 (1.44)	R-4.0 (0.70)

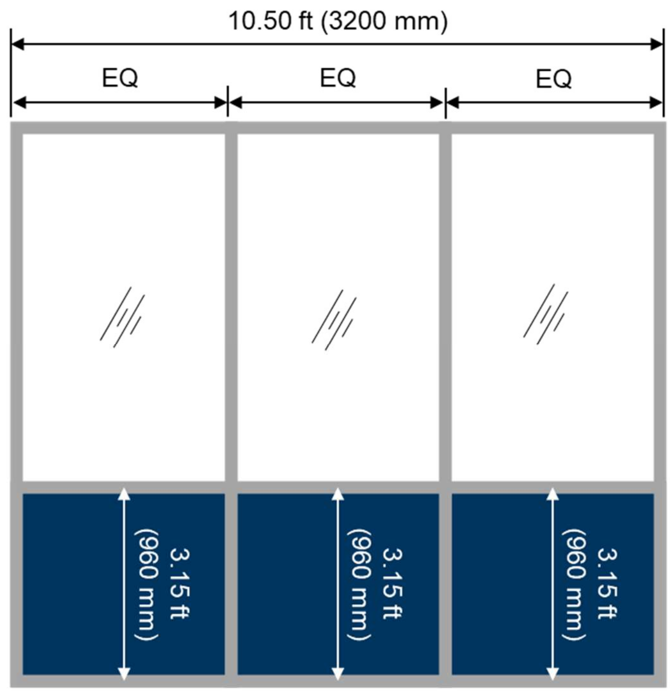


Figure 2.6: Window-Wall Layout with 65% Vision to Opaque Ratio (WWR)

Table 2.7: Overall Thermal Performance of Window-Wall Spandrel Sections with 65% Vision to Opaque Ratio (WWR)

Window Wall System	0% Balcony		25% Balcony		40% Balcony	
	Overall U-value Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)	**Overall U-value** Btu/hft²°F (W/m²K)	**Effective R-value** hft²°F/Btu (m²K/W)
Starline 9000	0.152 (0.86)	R-6.6 (1.16)	0.223 (1.27)	R-4.5 (0.79)	0.323 (1.83)	R-3.1 (0.55)
Starline 9600	0.122 (0.69)	R-8.2 (1.44)	0.188 (1.07)	R-5.3 (0.94)	0.280 (1.59)	R-3.6 (0.63)

3 BUILDING ENERGY ANALYSIS

250 scenarios were evaluated from the parameters considered in this study. The results were compiled in MH's Building Energy Performance Map parallel coordinates tool as shown in Figure 3.1. Each line in the performance map represents a design path with a corresponding TEDI value.

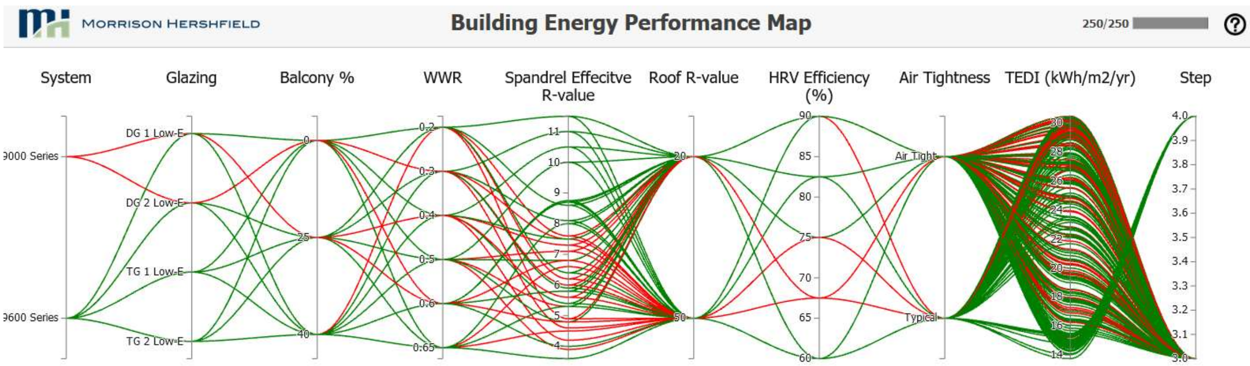


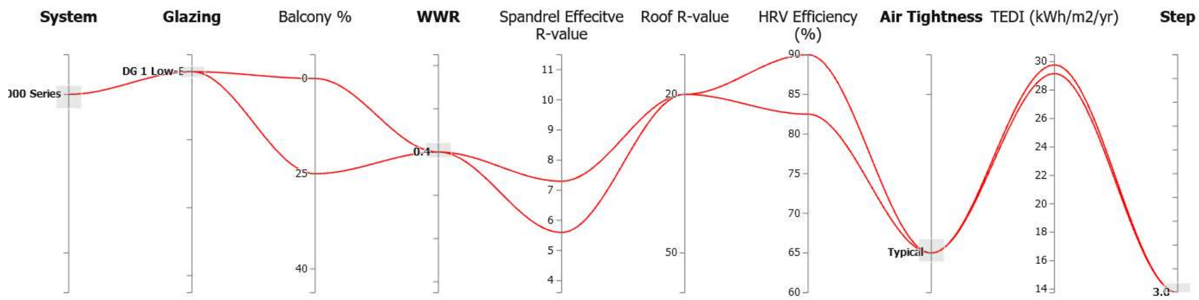
Figure 3.1: Building Energy Performance Map of Parametric Analysis

This section provides a summary of the findings and highlights different design paths to meet the TEDI targets for Steps 3 and 4 of the BC Energy Step Code for a typical residential high-rise building in the lower mainland area of BC, based on variations in parameters such as window-wall system types, vision to opaque ratio (WWR), balcony percentage, heat recovery ventilation efficiency, and air infiltration rates.

3.1 Impact of Vision to Opaque Ratio (WWR)

The vision area of the building envelope can have an impact on the energy performance of buildings. While buildings with large vision area receive more solar gain to help offset space heating demand, it can also result in greater thermal loss through the building envelope since the vision area typically have poorer thermal performance than opaque building envelope assemblies. Buildings with a high percentage of vision area can still meet the TEDI targets for Steps 3 and 4 of the BC Energy Step Code, however, it comes at the cost of other design parameters to help offset the reduction in energy performance.

A building with 40% vision to opaque ratio (WWR) can meet the Step 3 target of TEDI ≤ 30 kWh/m^2/yr of the BC Energy Step Code for residential high-rise buildings in the lower mainland area of BC with the Starline 9000 window-wall system with double glazed IGU with single low E coating and typical air infiltration rate as shown in Figure 3.2. In this scenario, designs with balcony lengths equal to 25% of the perimeter intermediate floor length can meet the 30 kWh/m^2/yr TEDI target by setting the heat recovery ventilation efficiency to 90%. Other design scenarios with less than 40% WWR can also meet the TEDI target of TEDI ≤ 30 kWh/m^2/yr with lower heat recovery efficiencies and typical building air infiltration rates.

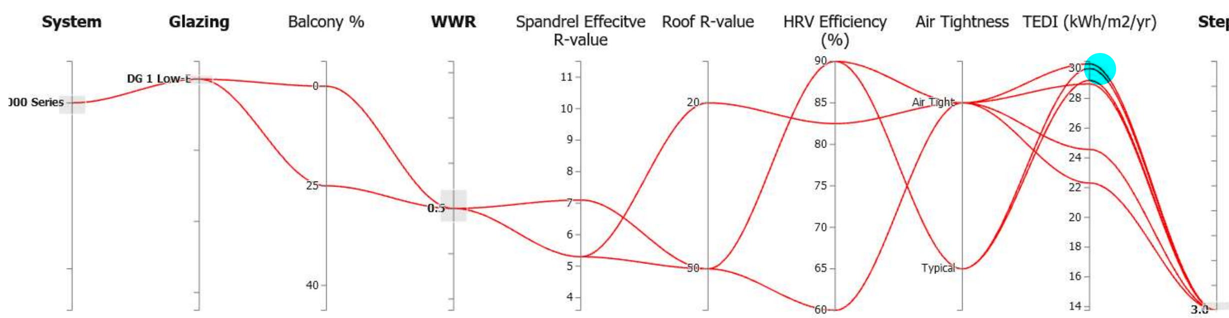


Select design scenarios

Window Wall System	IGU Type	WWR %	Balcony %	Spandrel Effective R-value	Roof Effective R-value	HRV Efficiency %	Air Tightness	TEDI kWh/m²/yr	Step
Starline 9000	Double Glazed – 1 Low-E	40	0	R-7.3	R-20	82.5	Typical	29.2	3
Starline 9000	Double Glazed – 1 Low-E	40	25	R-5.6	R-20	90	Typical	29.8	3

Figure 3.2: Design Options to Meet Step 3 TEDI Target for Residential High-Rise Building with a Starline 9000 Window-Wall and 40% Vision to Opaque Ratio (WWR) in Lower Mainland Area of BC (Climate Zone 4)

Increasing the vision to opaque ratio to 50% WWR reduces building energy performance and thus other building design parameters must be adjusted to offset the performance loss. Figure 3.3 shows design paths for meeting the 30 kWh/m²/yr TEDI target to comply with Step 3 of the BC Energy Step Code for a typical residential high-rise with a Starline 9000 window-wall system with 50% WWR. For the parameters considered in this study, improving the heat recovery efficiency and building envelope airtightness are most the effective ways to offset the energy performance loss from the increased vision area.

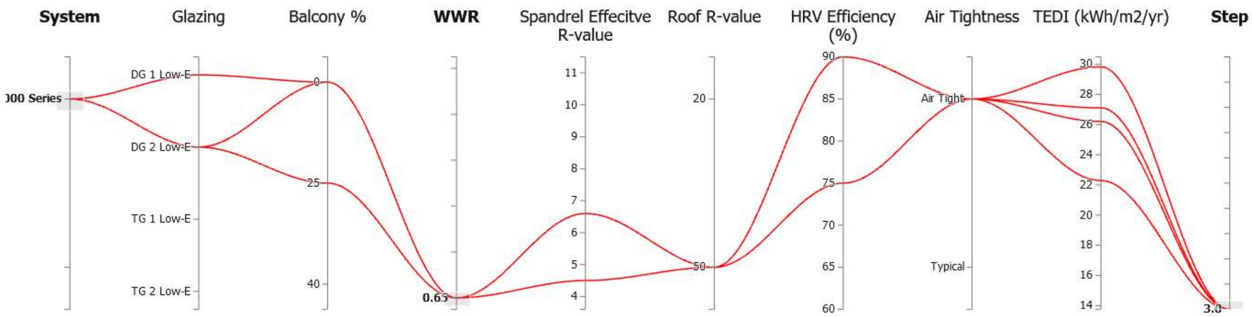


Select design scenarios

Window Wall System	IGU Type	WWR %	Balcony %	Spandrel Effective R-value	Roof Effective R-value	HRV Efficiency %	Air Tightness	TEDI kWh/m²/yr	Step
Starline 9000	Double Glazed – 1 Low-E	50	0	R-7.1	R-50	90	Typical	30.0	3
Starline 9000	Double Glazed – 1 Low-E	50	0	R-7.1	R-50	90	Air-Tight	22.3	3
Starline 9000	Double Glazed – 1 Low-E	50	25	R-5.3	R-20	82.5	Air-Tight	29.0	3
Starline 9000	Double Glazed – 1 Low-E	50	25	R-5.3	R-50	90	Air-Tight	24.6	3

Figure 3.3: Design Options to Meet Step 3 TEDI Target for Residential High-Rise Building with a Starline 9000 Window-Wall and 50% Vision to Opaque Ratio (WWR) in Lower Mainland Area of BC (Climate Zone 4)

Step 3 TEDI targets can still be met with 65% vision to opaque ratio using the Starline 9000 window-wall system, however, additional design trade-offs must be made by limiting balcony lengths and reducing building envelope infiltration which may further restrict the building design. Figure 3.4 shows some of the design options for meeting the Step 3 TEDI target of ≤ 30 kWh/m^2/yr for a residential high-rise building with Starline 9000 window-wall system with 65% vision to opaque ratio.

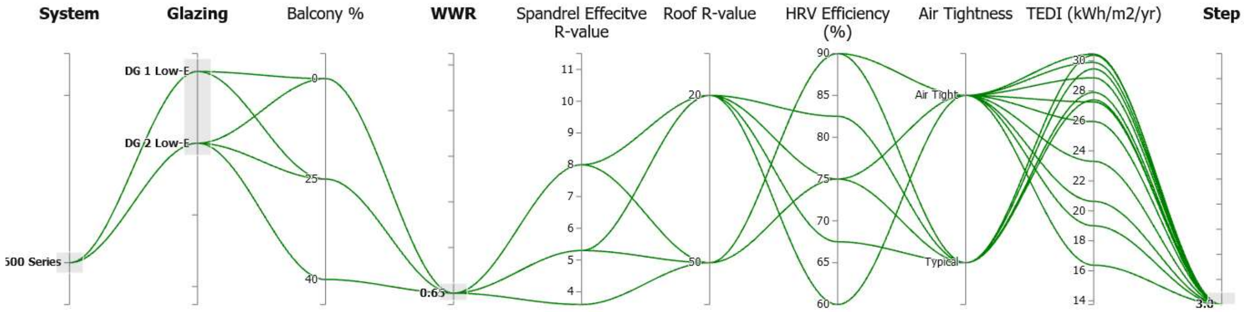


Select design scenarios

Window Wall System	IGU Type	WWR %	Balcony %	Spandrel Effective R-value	Roof Effective R-value	HRV Efficiency %	Air Tightness	TEDI kWh/m²/yr	Step
Starline 9000	Double Glazed – 1 Low-E	65	0	R-6.6	R-50	75	Air-Tight	29.8	3
Starline 9000	Double Glazed – 1 Low-E	65	0	R-6.6	R-50	90	Air-Tight	26.2	3
Starline 9000	Double Glazed – 2 Low-E	65	0	R-6.6	R-50	90	Air-Tight	22.3	3
Starline 9000	Double Glazed – 2 Low-E	65	25	R-4.5	R-50	90	Air-Tight	27.1	3

Figure 3.4: Design Options to Meet Step 3 TEDI Target for Residential High-Rise Building with a Starline 9000 Window-Wall and 65% Vision to Opaque Ratio (WWR) in Lower Mainland Area of BC (Climate Zone 4)

Improving the thermal performance of the window-wall system allows for more design options to help offset energy performance loss from the larger vision area, thereby enabling more options for designers to choose from. Figure 3.5 shows some design paths for meeting the Step 3 TEDI target of ≤ 30 kWh/m^2/yr for a residential high-rise building with the Starline 9600 window-wall system with 65% vision to opaque ratio. Overall, high-rise residential buildings may still meet the Step 3 TEDI target with less efficient HRVs, or at higher air infiltration rates, or with longer balcony lengths, and greater vision area with a thermally improved window-wall system such as the Starline 9600 series.

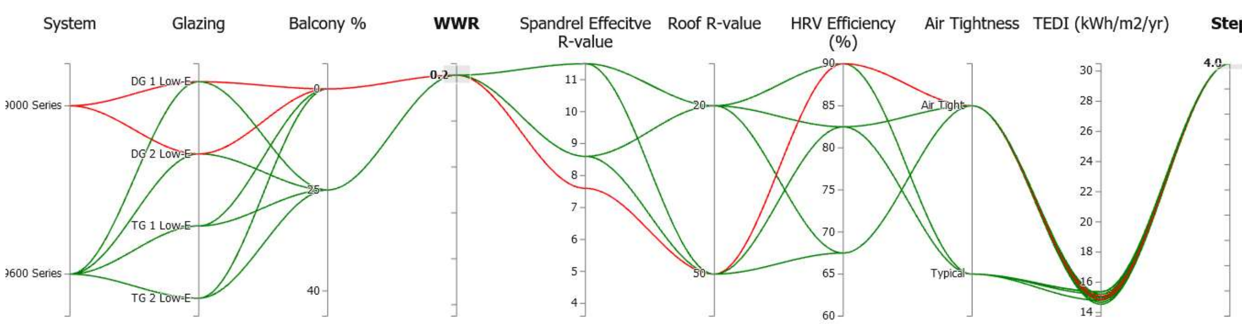


Select design scenarios

Window Wall System	IGU Type	WWR %	Balcony %	Spandrel Effective R-value	Roof Effective R-value	HRV Efficiency %	Air Tightness	TEDI kWh/m²/yr	Step
Starline 9600	Double Glazed – 1 Low-E	65	0	R-8	R-20	82.5	Typical	30.4	3
Starline 9600	Double Glazed – 1 Low-E	65	0	R-8	R-20	60	Air-Tight	30.4	3
Starline 9600	Double Glazed – 1 Low-E	65	25	R-5.3	R-20	75	Air-Tight	29.9	3
Starline 9600	Double Glazed – 2 Low-E	65	40	R-3.6	R-50	90	Air-Tight	27.3	3

Figure 3.5: Design Options to Meet Step 3 TEDI Target for Residential High-Rise Building with Starline 9600 Window-Wall and 65% Vision to Opaque Ratio (WWR) in Lower Mainland Area of BC (Climate Zone 4)

There are fewer design options that meet the TEDI target of ≤ 15 kWh/m²/yr for compliance with Step 4 of the BC Energy Step Code for residential high-rise buildings. Even with a small vision area of 20% vision to opaque ratio (WWR) there are few design options with the Starline 9000 window-wall system that can meet the TEDI target of 15 kWh/m²/yr, while there are more options with the Starline 9600 window-wall system as shown in Figure 3.6.

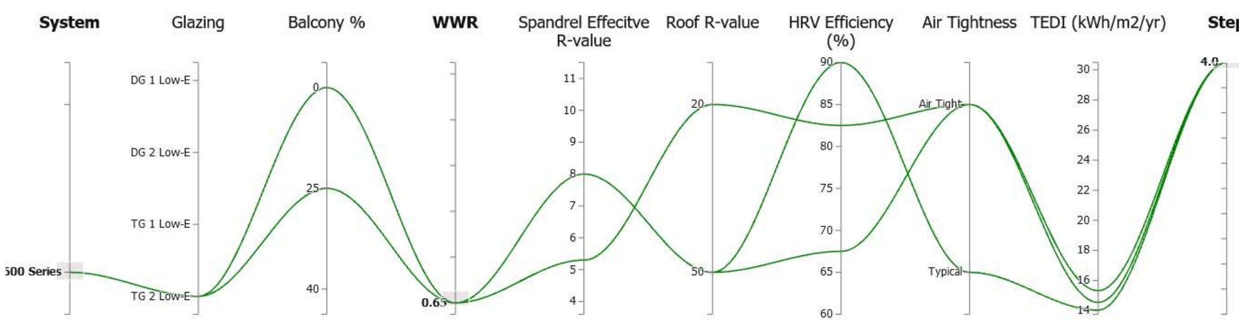


Select design scenarios

Window Wall System	IGU Type	WWR %	Balcony %	Spandrel Effective R-value	Roof Effective R-value	HRV Efficiency %	Air Tightness	TEDI kWh/m²/yr	Step
Starline 9000	Double Glazed – 2 Low-E	20	0	R-7.6	R-50	90	Air-Tight	14.9	4
Starline 9600	Double Glazed – 2 Low-E	20	0	R-11.5	R-20	67.5	Air-Tight	15.0	4
Starline 9600	Double Glazed – 2 Low-E	20	25	R-8.6	R-50	82.5	Air-Tight	14.8	4
Starline 9600	Triple Glazed – 2 Low-E	20	25	R-8.6	R-20	82.5	Air-Tight	14.7	4

Figure 3.6: Design Options to Meet Step 4 TEDI Target for Residential High-Rise Building with the Starline 9000 and Starline 9600 Window-Wall Systems and 20% Vision to Opaque Ratio (WWR) in Lower Mainland Area of BC (Climate Zone 4)

Increasing the vision area to 65% vision to opaque ratio while still meeting the Step 4 TEDI target of ≤ 15 kWh/m²/yr reduces the number of design paths for the building as shown in Figure 3.7. All design paths listed include triple glazed IGUs with double low-E coating. Designs that include balconies will require an air-tight building envelope with air infiltration rates less than 0.8 L/s/m² at 75 Pa with an HRV efficiency of 82.5% and higher.



Select design scenarios

Window Wall System	IGU Type	WWR %	Balcony %	Spandrel Effective R-value	Roof Effective R-value	HRV Efficiency %	Air Tightness	TEDI kWh/m²/yr	Step
Starline 9600	Triple Glazed – 2 Low-E	65	0	R-8	R-50	90	Typical	14.0	4
Starline 9600	Triple Glazed – 2 Low-E	65	25	R-5.3	R-20	82.5	Air-Tight	14.5	4

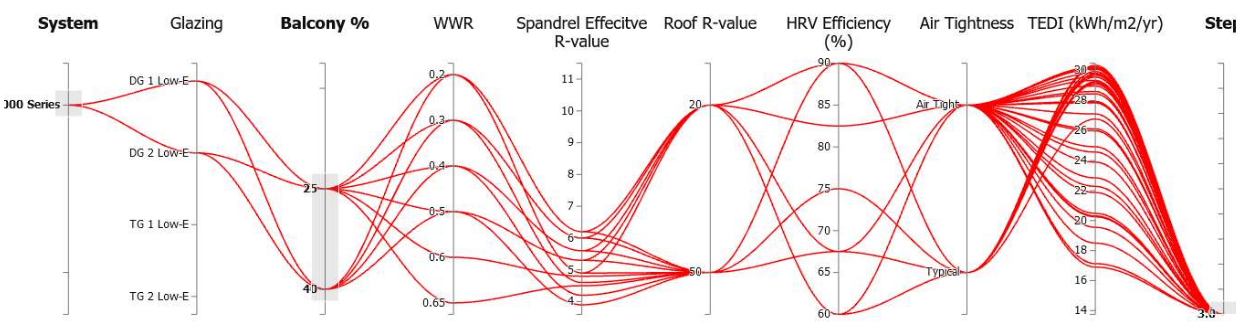
Figure 3.7: Design Options to Meet Step 4 TEDI Target for Residential High-Rise Building with Starline 9600 Series Window-Wall System and 65% Vision to Opaque Ratio (WWR) in Lower Mainland Area of BC (Climate Zone 4)

One notable point on the impact of larger vision area that was not considered in this analysis is the added risk of overheating and increasing space cooling demand. While designs with larger vision to opaque ratios may help reduce heating loads, it can also lead to occupant discomfort from high indoor temperatures and glare. Solar heat gain must be carefully considered in the design of high-performance buildings along with passive and/or active cooling strategies.

3.2 Impact of Balconies

Balconies also have an impact on the energy performance of buildings by reducing the thermal performance of the building envelope through thermal bridging. Similar to buildings with large vision area, buildings with balconies can still meet the TEDI targets for Steps 3 and 4 of the BC Energy Step Code in the lower mainland area of BC through managing other design parameters to offset the loss in energy performance.

A building with no balconies can meet the Step 3 TEDI target of ≤ 30 kWh/m^2/yr of the BC Energy Step Code for residential high-rise building in the lower mainland area of BC with a Starline 9000 window-wall system with double glazed IGU, vision to opaque ratio of 40% (WWR), and typical air infiltration rates with a HRV efficiency that is greater than 82.5% as shown in Figure 3.2. Adding balconies to the building will hinder building energy performance and the building design must be adjusted to offset the performance loss by reducing the vision area, reducing the air infiltration rate, or improving the HRV efficiency. Figure 3.8 shows some of the design options for meeting the Step 3 TEDI target of ≤ 30 kWh/m^2/yr for a typical residential high-rise building with the Starline 9000 window-wall system with balconies.

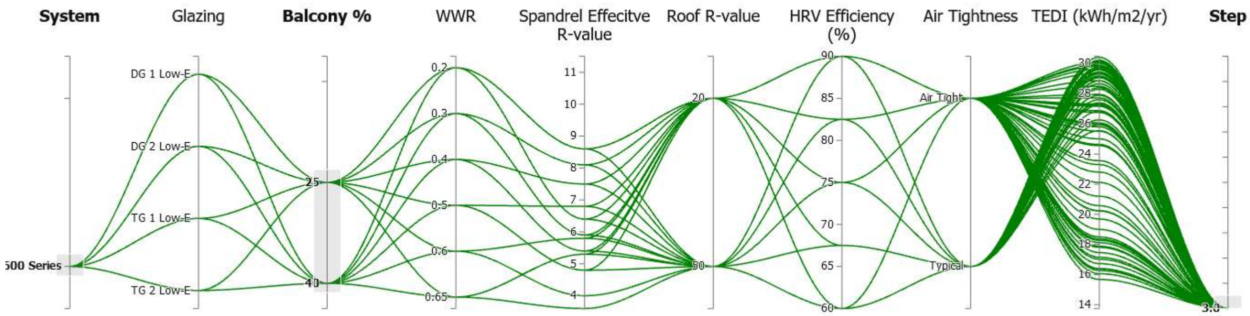


Select design scenarios

Window Wall System	IGU Type	WWR %	Balcony %	Spandrel Effective R-value	Roof Effective R-value	HRV Efficiency %	Air Tightness	TEDI kWh/m^2/yr	Step
Starline 9000	Double Glazed – 1 Low-E	20	40	R-4.9	R-50	75	Typical	30.2	3
Starline 9000	Double Glazed – 1 Low-E	30	40	R-4.6	R-50	90	Air-Tight	24.9	3
Starline 9000	Double Glazed – 1 Low-E	40	40	R-4.2	R-50	90	Air-Tight	27.8	3
Starline 9000	Double Glazed – 1 Low-E	50	25	R-5.3	R-50	90	Typical	29.2	3
Starline 9000	Double Glazed – 2 Low-E	50	25	R-3.9	R-50	90	Air-Tight	28.6	3

Figure 3.8: Design Options to Meet Step 3 TEDI Target for Residential High-Rise Building with Starline 9000 Window-Wall and Balconies in Lower Mainland Area of BC (Climate Zone 4)

Improving the thermal performance of the window-wall system allows for more design paths to help offset the energy performance loss from adding balconies. Figure 3.9 shows some of the design paths for meeting the Step 3 TEDI target of ≤ 30 kWh/m^2/yr for a typical residential high-rise building with the Starline 9600 window-wall system with balconies.



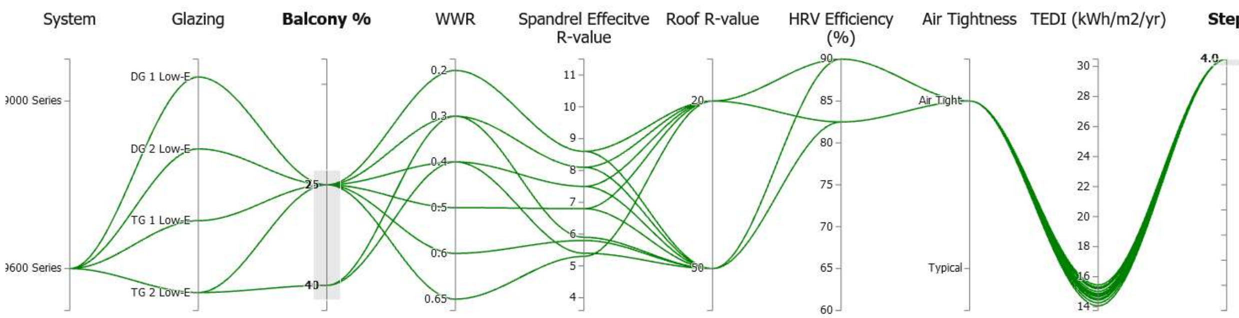
Select design scenarios

Window Wall System	IGU Type	WWR %	Balcony %	Spandrel Effective R-value	Roof Effective R-value	HRV Efficiency %	Air Tightness	TEDI kWh/m²/yr	Step
Starline 9600	Double Glazed – 1 Low-E	65	25	R-5.3	R-50	90	Typical	27.9	3
Starline 9600	Double Glazed – 1 Low-E	40	40	R-5.4	R-50	75	Typical	29.5	3
Starline 9600	Double Glazed – 1 Low-E	60	40	R-4.0	R-50	90	Air-Tight	28.9	3
Starline 9600	Double Glazed – 2 Low-E	65	40	R-3.6	R-50	90	Air-Tight	27.2	3

Figure 3.9: Design Options to Meet Step 3 TEDI Target for Residential High-Rise Building with the Starline 9600 Window-Wall and Balconies in Lower Mainland Area of BC (Climate Zone 4)

Improving the thermal performance of the window-wall system allows for more design flexibility in vision area, balcony lengths, HRV efficiency, and building envelope airtightness. This provides the design and construction teams with more choices to find cost-effective solutions that can still meet the TEDI target for their projects.

Similar to buildings with different window areas, there are fewer design paths that meet the TEDI target of ≤ 15 kWh/m²/yr for compliance with Step 4 of the BC Energy Step Code. Building designs with balconies considered in this study can only meet the Step 4 TEDI target with the Starline 9600 window-wall system as shown in Figure 3.10.



Select design scenarios

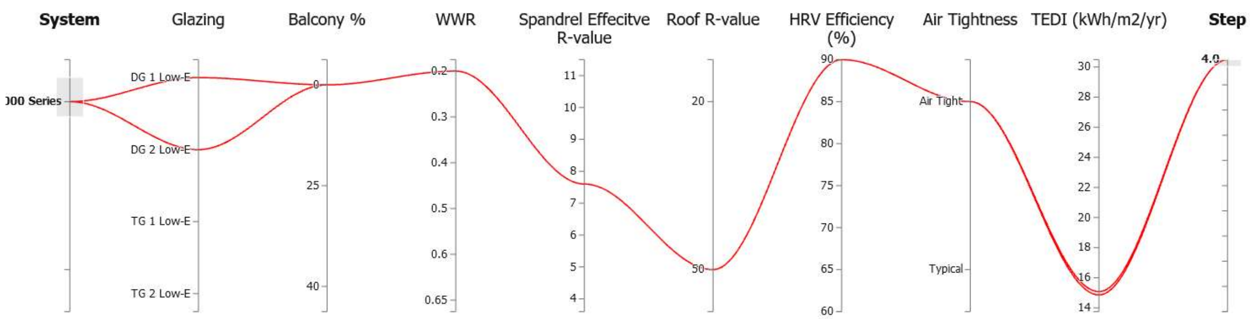
Window Wall System	IGU Type	WWR %	Balcony %	Spandrel Effective R-value	Roof Effective R-value	HRV Efficiency %	Air Tightness	TEDI kWh/m²/yr	Step
Starline 9600	Double Glazed – 1 Low-E	20	25	R-8.6	R-20	82.5	Air-Tight	15.2	4
Starline 9600	Triple Glazed – 2 Low-E	65	25	R-5.3	R-20	82.5	Air-Tight	14.5	4
Starline 9600	Triple Glazed – 2 Low-E	30	40	R-5.9	R-50	90	Air-Tight	15.3	4
Starline 9600	Triple Glazed – 2 Low-E	40	40	R-5.4	R-50	90	Air-Tight	15.0	4

Figure 3.10: Design Options to Meet Step 4 TEDI Target for Residential High-Rise Building with the Starline 9600 Window-Wall and Balconies in Lower Mainland Area of BC (Climate Zone 4)

3.3 Energy Performance with the Starline 9000 Window-Wall System

The energy performance of buildings with a the Starline 9000 window-wall system are poorer than buildings with the Starline 9600 window-wall system. As a result, compromises to building design must be made to meet the upper TEDI targets of the BC Energy Step Code.

A typical residential high-rise building with the Starline 9000 window-wall system in the lower mainland area of BC can meet the TEDI target of 15 kWh/m²/yr for Step 4 of the BC Energy Step Code. However, the design features are very limited with low vision to opaque ratios (WWR) and no balconies, as shown in Figure 3.11.



Select design scenarios

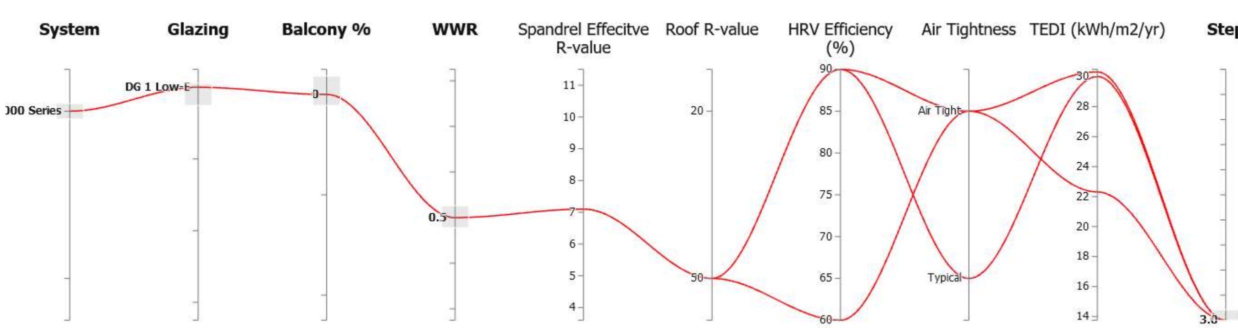
Window Wall System	IGU Type	WWR %	Balcony %	Spandrel Effective R-value	Roof Effective R-value	HRV Efficiency %	Air Tightness	TEDI kWh/m²/yr	Step
Starline 9000	Double Glazed – 1 Low-E	20	0	R-7.6	R-50	90	Air-Tight	15.0	4
Starline 9000	Double Glazed – 2 Low-E	20	0	R-7.6	R-50	90	Air-Tight	14.9	4

Figure 3.11: Design Parameters for Minimum TEDI for Residential High-Rise Building with Starline 9000 Window-Wall System in Lower Mainland Area of BC (Climate Zone 4)

From the evaluated scenarios in this study, buildings with the Starline 9000 window-wall system are not well suited to meet the TEDI target of ≤ 15 kWh/m^2/yr for compliance with Step 4 of the BC Energy Step Code for residential high-rise buildings in the lower mainland area of BC without modifications to improve the thermal performance of the window-wall system. Without these improvements, trade-offs must be made to the building design that may hinder occupant comfort that may be prohibited in certain jurisdictions, such the elimination of balconies in residential buildings.

3.4 Considerations for Building Envelope Airtightness and Heat Recovery Efficiency

Building envelope airtightness and heat recovery of the ventilation system both have significant impacts on the TEDI of buildings. Reducing the amount of uncontrolled air entering and leaving the building and recovering heat from ventilated exhaust air help keep heat inside the building and reduces the thermal energy demand as shown in Figure 3.12. However, additional considerations should be considered when relying on these measures to meet TEDI targets.



Select design scenarios

Window Wall System	IGU Type	WWR %	Balcony %	Spandrel Effective R-value	Roof Effective R-value	HRV Efficiency %	Air Tightness	TEDI kWh/m²/yr	Step
Starline 9000	Double Glazed – 1 Low-E	50	0	R-7.1	R-50	90	Typical	30.0	3
Starline 9000	Double Glazed – 1 Low-E	50	0	R-7.1	R-50	60	Air-Tight	30.3	3
Starline 9000	Double Glazed – 1 Low-E	50	0	R-7.1	R-50	90	Air-Tight	22.3	3

Figure 3.12: Impact of Building Envelope Air Tightness and HRV Efficiency on TEDI of Residential High-Rise Building with the Starline 9000 Window-Wall System in Lower Mainland Area of BC (Climate Zone 4)

While most of the building design parameters can be designed and specified, achieving a high level of building envelope airtightness requires additional work and attention that goes beyond the design of the building. Building designers must not only specify a continuous air barrier in their building envelope assemblies, they must also ensure their designs clearly show air barrier continuity at all details and communicate this clearly to the contracting team to ensure details are properly constructed. In addition, a higher quality of care must be applied during construction to ensure that all building details are properly sealed to mitigate air leakage through the building assembly.

Construction mock-up reviews are recommended to ensure details are constructed to an acceptable quality as well as troubleshoot coordination issues between the general and sub-contracting teams. Building envelope air-leakage tests are required to ensure the constructed building envelope meets the designed air infiltration rate that was used to determine the TEDI value for compliance with the BC Energy Step Code.

Due to the uncertainties from construction that may be beyond the control of building designers, there are inherent risks from heavily relying on building envelope airtightness to achieve TEDI targets. It is recommended that designers provide a buffer to their building air infiltration rates or TEDI target to compensate for higher than expected air leakage rates since failure to meet the desired air leakage rates may result in missing the code required TEDI targets and ultimately not meeting building code requirements.

High efficiency heat recovery ventilators (HRV) can also improve the energy performance of buildings, by reducing the heat loss due to ventilation. High efficiency HRVs are most effective when combined with an air-tight building envelope to reduce heat loss through uncontrolled building envelope exfiltration and infiltration. While high efficiency HRVs can be specified in the design, there are additional considerations that must be accounted for.

High efficiency HRVs are generally more expensive and come in larger units than conventional HRVs. This may be a problem for multi-unit residential buildings where an HRV is required for each unit and space is limited. Another consideration is how the heat recovery efficiency is reported. There are variations in efficiency evaluation methods that designers must be aware of. HRVs should be modelled in the way that it is intended to be used in the building design to ensure its impact on building energy performance is properly captured.

4 CONCLUSIONS

While there is a common perception that buildings with aluminum window-wall systems will not meet the TEDI targets required by the upper levels of the BC Energy Step Code, low TEDI buildings with window-wall systems as the primary building envelope assembly may still be designed and constructed by taking a holistic approach to building design. Considerations such as the thermal performance of the window-wall system, vision area, vision glazing type, airtightness of the building envelope, and heat recovery are all key to meeting low TEDI targets. The parametric analysis summarized in this report show TEDI targets for Steps 3 and 4 of the BC Energy Step Code may be met for a typical residential high-rise building in the lower mainland area of BC when the building design takes a holistic approach to improving building energy efficiency. Some of the generalized trends from the study include:

- High performance window-wall system, such as the Starline 9600 series, is required to meet the Step 4 TEDI target (≤ 15 $kWh/m^2/yr$) for residential high-rise buildings in the lower mainland area of BC with high WWR and balconies

- Window-wall systems of lesser performance, such as the Starline 9000 series, may meet TEDI targets of the higher steps of the BC Energy Step Code, such as Step 4, with lower WWR, no balconies, an airtight building envelope and highly efficient heat recovery ventilator (HRV) in the lower mainland area of BC

- Typical residential buildings with the Starline 9000 window-wall system with 3-inch (76 mm) back pan insulation (R-12.6) may meet the Step 3 TEDI target (≤ 30 $kWh/m^2/yr$) with 65% vision to opaque ratio and balconies by minimizing air infiltration in the lower mainland area of BC

- Improving the thermal performance of the window-wall system offers more design freedom in terms of larger vision area, longer balcony length, relaxed air infiltration rates, or lower efficiency HRVs while still meeting low TEDI targets

- Balconies reduce the thermal performance of the building envelope through thermal bridging, however, Step 3 TEDI targets for residential high-rise building in lower mainland area of BC, may still be met with the Starline 9000 window-wall systems with balconies by improving the airtightness of the building envelope and using high efficiency HRV.

- Building envelope air infiltration can have a major impact on building TEDI, but designers should not heavily rely on low air infiltration rates to meet their TEDI targets since building envelope airtightness cannot be confirmed until at the end of construction with whole building air leakage testing. Designers should incorporate a ‘buffer’ in their TEDI budgets compensate for higher than desired air infiltration rate.

- Heat recovery from exhaust air when coupled with an airtight building envelope is very effective at reducing TEDI. However, higher efficiency HRVs are more expensive and take up more space, which could be a problem in multi-unit residential buildings where each unit is independently ventilated and space is limited.

We believe that this report meets your objectives for evaluating the energy impacts of using various window-wall systems to meet the upper levels of the BC Energy Step Code for a typical residential high-rise building in the lower mainland area of BC.

Morrison Hershfield Limited

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APPENDIX A: DERIVATION OF SPANDREL EFFECTIVE R-VALUES

The spandrel overall U-values and effective R-Values used in the study were derived using the stepwise process outlined in the Building Envelope Thermal Bridging Guide[1] (BETB). First, the area and length takeoffs of each spandrel panel bypass and/or balcony were determined, followed by clear field and linear transmittances. Given the transmittance values and takeoff areas/lengths, the overall spandrel U-values were derived using the equation below.

$$U_{Total} = \frac{\sum\{(U_s \cdot A_s) + (\Psi_s \cdot L_s) + (\Psi_i \cdot L_i)\}}{A_{Total}} \qquad \text{(A1.1)}$$

Where, $U_s \cdot A_s$ is the spandrel clear field heat flow, $\Psi_s \cdot L_s$ is the bypass linear transmittance heat flow, and $\Psi_i \cdot L_i$ is the balcony transmittance heat flow. An example of this stepwise process to calculate the opaque spandrel area overall U-value and effective R-value is presented below with the Starline 9000 window-wall system layout with 40% vision to opaque ratio (WWR) and a balcony length equal to 25% of the building perimeter, as shown in Figure A1.1

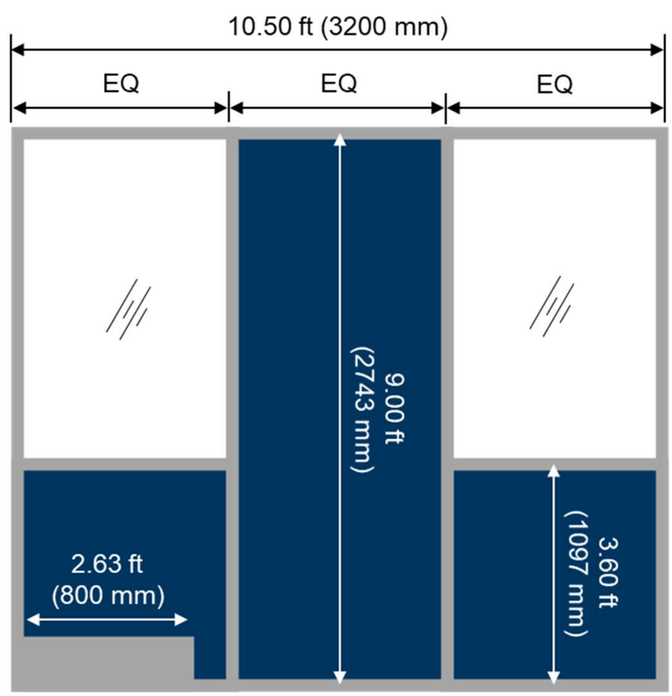

Figure A1.1: The typical Window-Wall Layout with 40% Vision to Opaque Ratio (WWR) and 25% Balcony Length

Step 1: Determine Area and Length Takeoffs

A window-wall module with floor-to-floor height of 9 ft (2743 mm) and overall width of 10.5 ft (3200 mm) is assumed as shown in Figure A1.1. The vertical mullions are spaced 3.5 ft (1069 mm) forming three equal panels. The 40% vision to opaque ratio resulted in the window-wall layout having a full-height spandrel bypass in the middle panel and half-height spandrel bypass

[1] www.bchousing.org/research-centre/library/residential-design-construction/building-envelope-thermal-bridging-guide

panels at the edge panes of the window-wall module. The 2.63 ft (800 mm) spandrel – balcony length is equivalent to 25% of the overall width of the window-wall system.

Step 2: Determine Clear Field and Linear Transmittances

Table A1.1 shows the base spandrel thermal transmittance values for the Starline 9000 window-wall system. The window-wall spandrel thermal transmittance values (U-value and effective R-values) are based on evaluated thermal performance in the BETB.

Table A1.1: Starline 9000 Window-Wall Spandrel Thermal Performance

Spandrel Type	Spandrel Clear Field			Bypass Linear Transmittance Ψ_s Btu/fth°F (W/mK)	Balcony Linear Transmittance Ψ_i Btu/fth°F (W/mK)
	Back Pan Insulation Nominal R-value ft²h°F/Btu (m²K/W)	**U-value** Btu/ft²h°F (W/m²K)	**Effective R-value** ft²h°F/Btu (m²K/W)		
Half-height[2]	R-12.6 (2.22)	0.119 (0.68)	R-8.4 (1.48)	0.104 (0.181)	1 (1.73)
Full-height[3]	R-12.6 (2.22)	0.117 (0.66)	R-8.6 (1.51)	0.096 (0.166)	1 (1.73)

[2]*Detail 1.2.4 – Building Envelope Thermal Bridging Guide*
[3]*Detail 1.2.7 – Building Envelope Thermal Bridging Guide*

The thermal transmittance values listed in Table A1.1. are for half-height and full-height spandrels with 3 inches (76 mm) of mineral wool insulation (R-12.6) in the back pan and an uninsulated steel-frame wall with 1/2 inch (13 mm) gypsum drywall. This provided the typical spandrel performances, although higher R-values can be achieved by adding insulation behind the back pan.

Step 3: Calculate Overall U-Value and Effective R-Value

With Equation A1.1, the overall U-value and effective R-value has been determined and summarized in Table A1.2.

Table A1.2: Summary Spandrel Thermal Transmittance Calculations for the Starline 9000 Window-Wall System with 40% WWR and 25% Balcony Length

Spandrel Location	U-value Btu/ft²h°F (W/m²K)	Spandrel Area ft² (m²)	Bypass Transmittance Ψ_s Btu/ft h°F (W/mK)	Bypass Length ft (m)	Balcony Transmittance Ψ_i Btu/ft h°F (W/mK)	Balcony Length ft (m)
1st Bay	0.119 (0.68)	12.6 (1.17)	0.104 (0.181)	0.88 (0.27)	1 (1.73)	2.63 (0.80)
2nd Bay	0.117 (0.66)	31.5 (2.93)	0.096 (0.166)	3.50 (1.07)	n/a	n/a
3rd Bay	0.119 (0.68)	12.6 (1.17)	0.104 (0.181)	3.50 (1.07)	n/a	n/a
Overall Window-wall Spandrel U-value, BTU / h ft² °F (W/m²K)					0.178 (1.01)	
Overall Window-wall Spandrel Effective R-value, hr ft² °F/ BTU (m²K/W)					R-5.6 (0.99)	

The same stepwise procedure was used to determine the spandrel thermal transmittance for the other window-wall systems and vision to opaque ratio combinations considered in this study.