Chapter 4

WHOLE BUILDING CONTEXT

Introduction

A primary focus of this guide is to illustrate how to meet the challenges of low energy demand intensity (TEDI) for high-rise multi-unit residential buildings (MURBs) by understanding and mitigating the impact of thermal bridges at interface details, such as the wall to roof, wall to window and intermediate floor intersections. Other components that are important to reducing thermal loads are supported by available products (e.g. triple-glazed windows, HRVs) and better understood by current resources (e.g. "Illustrated Guide: Achieving Airtight Buildings" (RDH, 2017)). This chapter aims to put the thermal transmittance of the opaque building envelope in context with these other key parameters and identify design strategies that must be employed to achieve a low TEDI for high-rise residential buildings.

TEDI alone does not provide a complete representation of overall building energy consumption. Overall energy use, often presented as energy per building area or energy use intensity (EUI) encompasses the effects of all building systems, such as lighting, heating and domestic hot water. Many of these building systems interact with each other, with some loads impacting TEDI, but are not part of a low thermal demand strategy. For example, lighting and equipment add heat to a space and lower TEDI, but should be minimized to reduce overall EUI. Achieving both a low TEDI and EUI is important to achieve multiple high performance objectives, including lower energy use and cost, reduction of greenhouse gas emissions and improved thermal comfort. Various standards now have separate requirements for TEDI and EUI to manage this balance. For examples, see the City of Vancouver's "Zero Emissions Building Plan" (City of Vancouver, 2016), the City of Toronto's "Toronto Green Standard" (City of Toronto, 2017), "BC Energy Step Code" (Province of BC, 2017) and Passive House (Passive House Institute, 2016)). For the purposes of this chapter, many of these variables not directly linked to low thermal energy demand strategies (i.e. lighting, plug loads, operating schedules, etc.) are fixed, in line with industry standard "energy modelling guidelines" (City of Vancouver, 2017) referenced by "BC Energy Step Code" (Province of BC, 2017).

TEDI – ONE OF MANY

A building with low TEDI is only one of many performance criteria that are needed for low energy buildings. When TEDI is drastically reduced, loads other than heating become much more significant. Other loads, such as internal gains, can also impact TEDI. More people and lights, for example, reduce a building's TEDI. To avoid optimizing TEDI at the expense of other building systems, TEDI, when referenced in codes, is usually accompanied by rules around internal gains and/or EUI requirements.

As discussed in Chapter 1, the most well-known standards that currently employ a TEDI requirement include the "Zero Emissions Building Plan and Framework" in the cities of Vancouver and Toronto respectively (City of Vancouver, 2016) (City of Toronto, 2017), and the "BC Energy Step Code" (Province of BC, 2017). For high-rise residential buildings, the most stringent TEDI requirements have a maximum TEDI of 15 kWh/m^2/year, a limit generally representing net-zero ready or near net-zero ready buildings.

Figure 4.1 shows a sample end-use breakdown for a low energy building in Climate Zone 6 with a TEDI of 16.0 kWh/m^2 and an EUI of 85.9 kWh/m^2. This example building has a 100% efficient heating system (e.g. electric baseboard heating), 0.284 W/m^{2}K overall thermal transmittance of the walls (Effective R-20), triple-glazed windows, increased airtightness and premium HRVs. Less than a quarter of the building's energy use is related to space and ventilation heating for this example. The space heating is affected by several parameters as broken out in the graphs, including window, wall, ventilation and infiltration losses.

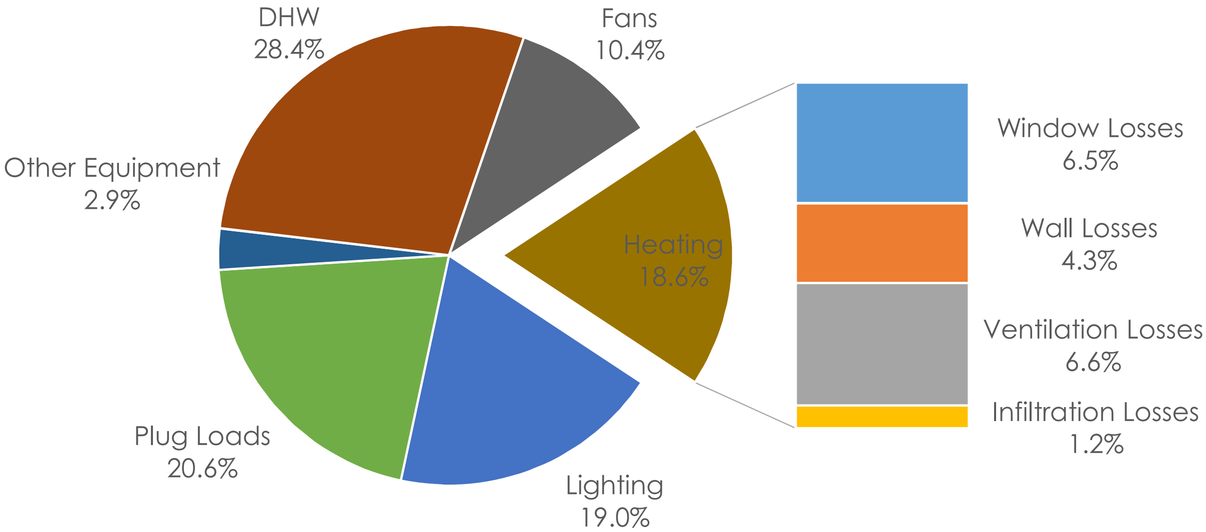


Figure 4.1: End-use Breakdown for a Low Energy MURB in Climate Zone 6

Figure 4.2 shows a sample breakdown of the heat gains and losses of a high-rise MURB with low thermal demand. Ventilation and windows have the highest heat losses, but also can provide the highest heat gains through the use of heat recovery and solar energy, respectively.

The breakdown shown in **Figure 4.2** depends on the building design, with the balance of the loads being affected by the heating balance point, climate and building envelope design. An important observation is that the internal gains from occupant-controlled sources are almost as large as the heat recovery component of the gains. As the loads in low TEDI buildings are reduced, these occupant-related gains become dominant. These internal gains are typically fixed to comply with codes and standards, but there is more of an incentive to reduce these loads when their share becomes relatively larger for low TEDI buildings. When reductions to internal gains can be realized, the need for better performing building envelopes becomes even more critical.

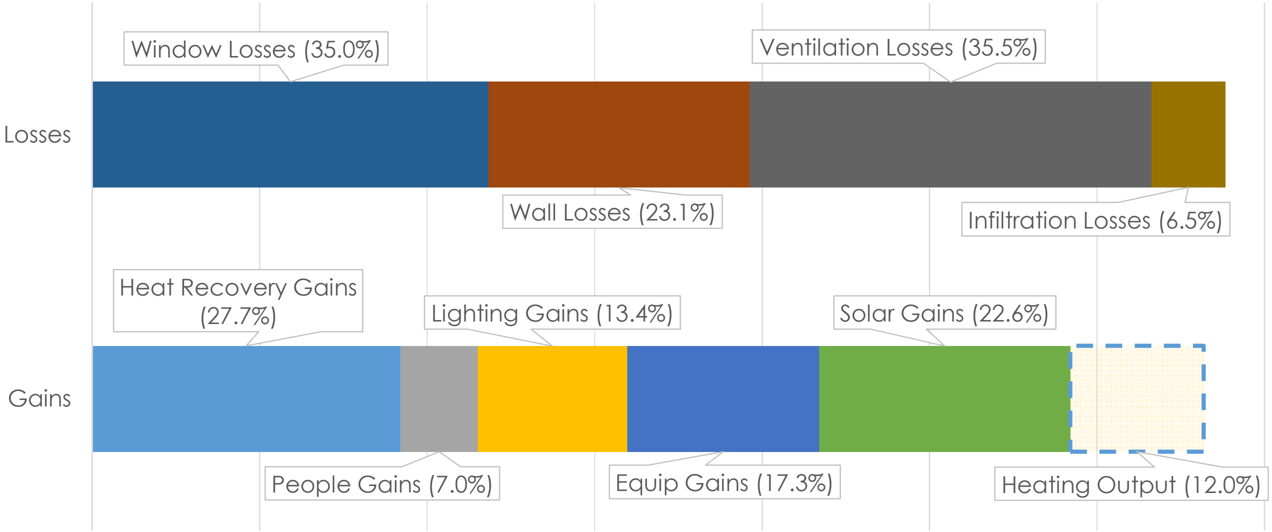


Figure 4.2: Example Breakdown of Heating Load Components

Characteristics of Low Energy Buildings

Achieving a low energy building requires making a significant number of design decisions, many of which are interrelated. A large number of design options, based on an archetype MURB (see BuildingPathfinder.com for details (OGBS, 2017)), were simulated to identify which combinations of options could meet the required performance targets. An interactive data visualization tool was used to visually represent the impact of combinations of design options on specified metrics, in this case TEDI. A screenshot of the tool is shown in **Figure 4.3**, where each line represents one simulation, and each axis represents a parameter in the simulation or an output from it. The location where the lines cross the axes corresponds to the value of that parameter or output for the given simulation.

A range of the major design parameters that govern TEDI were simulated to understand relative impacts and interactions between parameters. These parameters are discussed in more detail later in this chapter and include:

- Internal Gains
- Building Shape
- Opaque Envelope
- Glazing
- Overheating
- Air Infiltration
- Ventilation (See Chapter 3)

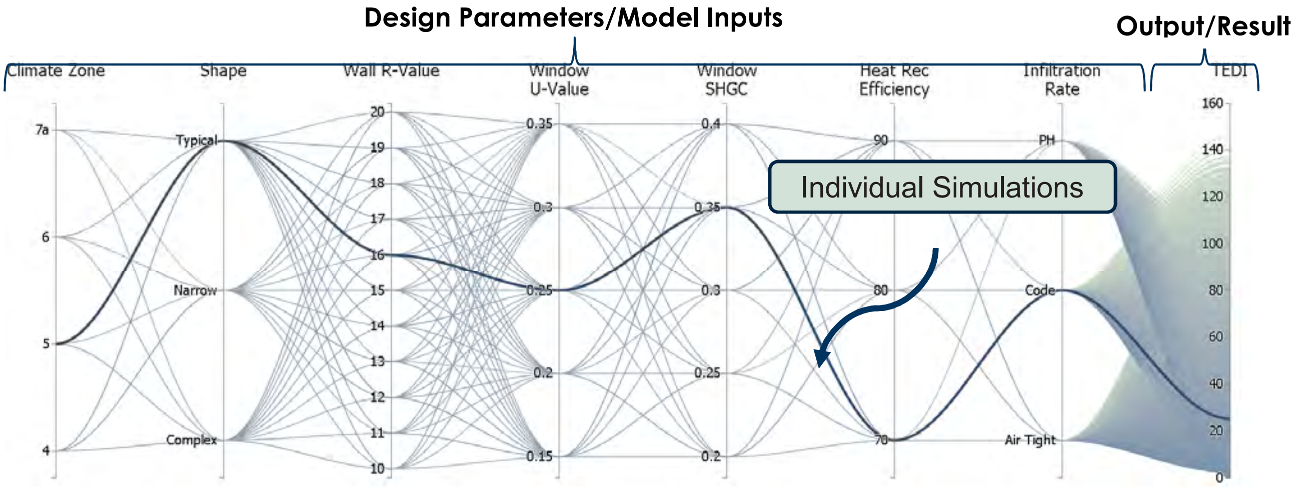


Figure 4.3: Example of Visualization of Simulation Results

INTERNAL GAINS

The term internal gains refers to the heat released by people, lighting and equipment in a building. Internal gains, when coincident with heating loads, can directly offset a building's thermal energy demand. Therefore, it is important to understand and account for these loads properly during the design process and evaluation of energy-use.

Occupant, equipment and lighting loads and schedules are typically assumptions defined by standards. Assumptions can vary significantly between standards and methodologies. The Passive House methodology, for example, uses a highly detailed adjustment factor to calculate the portion of internal energy consumption that contributes to offsetting heating loads. Standards such as "ASHRAE Standard 90.1-2007: Energy Standard for Buildings except Low-Rise Residential Buildings" (ASHRAE, 2007) and National Energy Code of Canada for Buildings (NECB) (NRC, 2011) assume virtually all internal energy use offsets heating loads directly. These two different approaches can make a significant difference on the building's thermal demand, so a project's goals must be clearly defined when evaluating TEDI.

KEY ASSUMPTIONS

Internal gains are important, but are often prescribed by specific code or standard. Assumptions must be appropriate for the project and to support the required outcome (e.g. BC Energy Step Code Compliance).

Specific loads and schedules often come from accepted third parties like NECB or ASHRAE. There are also City of Vancouver, City of Toronto and BC Step Code energy modelling guidelines (City of Vancouver, 2017) (City of Toronto, 2017), which prescribe the loads and schedules. These guidelines generally agree with other published data such as the report "Energy Consumption and Conservation in Mid- and High-Rise Multi-Unit Residential Buildings in British Columbia" (RDH, 2012).

An example of the impact of internal gains is demonstrated when comparing the assumptions used by Passive House and those from the City of Vancouver's "Energy Modelling Guidelines" (City of Vancouver, 2017) used by the "BC Energy Step Code" (Province of BC, 2017). The same building was modelled both ways and, after controlling for other factors, the results revealed different heating loads due to the differing assumptions for internal gains. Passive House significantly discounts peak internal gains (reducing their effect) to approximate variable internal gains that follow a schedule.

For an example building with low thermal demand, the annual heating load calculated using City of Vancouver's "Energy Modelling Guidelines" (City of Vancouver, 2017) for internal gains and associated schedules resulted in a TEDI that was approximately 8 kWh/m^2 lower than the same building using internal gains following the Passive House methodology. Since the impact is significant, assumptions for internal heat gain have to match the project objectives, be well understood by the energy modeller and be well documented for the rest of the project team.

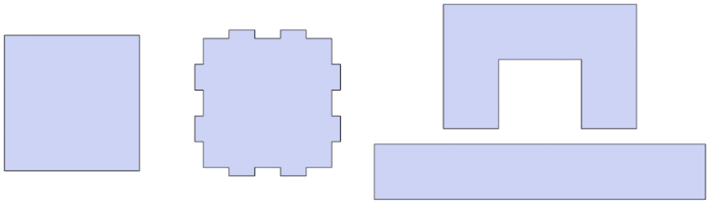
BUILDING SHAPE

A building's vertical surface area to floor area ratio (VFAR) is a significant influential factor on the heating energy use of a building, especially when the TEDI target is normalized for floor area. This metric is similar to a more common metric of surface area to volume ratio. However, for high-rise MURBs, the majority of heat loss occurs in the vertical surface areas due to the relative high percentage surface area compared to total exposed surfaces and due to the difficulty of effectively insulating vertical assemblies that also meet the other design requirements as outlined in Chapter 5. As such, VFAR has a more direct relationship with TEDI than surface area to volume ratio and has been used as the primary shape metric for consideration.

Complex and/or narrow shapes have more vertical surface area per floor area, leading to greater heat losses per unit floor area. Complex shapes with significant articulation have about 40% more vertical surface area per floor area than simple shapes like a square, while narrow shapes have about 80% more. **Table 4.1** demonstrates a selection of building shapes and their associated VFAR. Very small or narrow buildings will likely require improved envelope systems to compensate for higher vertical surface areas. A single family detached home typically has a VFAR between 1.2 and 1.5, while a high-rise MURB has a VFAR in the range of 0.5 to 0.65. The floor plates in **Table 4.1** are 600 m^2 and the TEDI values are for Climate Zone 6. When all other design elements are kept constant, TEDI increases as VFAR increases.

A building's shape can also impact the building envelope thermal transmittance because complex architecture often increases both the complexity and quantity of interfaces that lead to thermal bridging.

Table 4.1: VFAR for Example Building Shapes and Floor Plate Sizes



	Square	Articulated	Narrow
VFAR	0.49	0.59	0.7
TEDI (kWh/m^2)	15.1	20.3	26.1

THERMAL TRANSMITTANCE OF THE OPAQUE BUILDING ENVELOPE

A building envelope with low thermal transmittances or highly effective R-values is critical to achieving low thermal energy demand. This is achieved by well insulated assemblies and minimizing thermal bridging. Thermal bridging is best minimized and avoided early in the design process by evaluating the impact using default values founds in catalogues, such as the Building Envelope Thermal Bridging (BETB) Guide or ISO 14683. Assumptions can then be revisited and refined with project specific values as the design evolves and the other design requirements become more tangible.

Table 4.2 and **Table 4.3** shows the difference in overall wall thermal transmittance or effective R-value between a conventional and a low TEDI building using the MURB archetype building from the BETB Guide (Morrison Hershfield, 2016) for quantity takeoffs. The baseline case has an effective R-6.2 for the opaque wall compared to the low TEDI scenario of R-27.0 using details outlined in Chapter 5. The improvement is due to the combined improvement in the details and more insulation. This examples illustrates the potential for optimization on projects with a broad range of possibilities to mitigate thermal bridging. See Chapter 6 for more examples that highlight the impact of using the details presented in Chapter 5.

TIGHTLY COUPLED DESIGN PARAMETERS

Building envelope thermal transmittance and building shape are tightly coupled, each influencing the other. These characteristics should be considered early in the design as they can have a large impact on TEDI.

Table 4.2: Wall Thermal Transmittance for Conventional Assemblies and Details

Detail	Area or Length	Transmittance Value	Heat Flow (W/K)	Percent of Total Heat Flow (%)
Steel Stud Wall	5903 m^2	0.35 W/m^2K	2066	36.7%
Balcony Slab at Door	226 m^2	4.72 W/m^2K	1068	18.9%
Parapet at Wall	55 m	0.78 W/m K	43	0.8%
Parapet at Glazing	73 m	0.98 W/m K	72	1.3%
Intermediate Floor at Wall	616 m	0.20 W/m K	123	2.2%
Intermediate Floor at Balcony	778 m	1.06 W/m K	825	14.6%
Intermediate Floor at Glazing	1536 m	0.20 W/m K	307	5.5%
Window to Wall	5559 m	0.20 W/m K	1112	19.7%
Interior Wall Separation	988 m	0.20 W/m K	20	0.4%

Overall Thermal Transmittance (W/m^2 K) 0.92
Effective R-Value (hr·ft^2·F/BTU) 6.2

Table 4.3: Wall Thermal Transmittance for Low TEDI Assemblies and Details

Detail	Area or Length	Transmittance Value	Heat Flow (W/K)	Percent of Total Heat Flow (%)
Wall with FRP Brackets	6129 m^2	0.142 W/m^2K	870	67.4%
Delta U for Aluminum Brackets	6129 m^2	0.041 W/m^2K	251	19.5%
Wall to Roof	128 m	0.171 W/m K	22	1.7%
Intermediate Floor	2930 m	0.003 W/m K	10	0.8%
Window to Wall	5559 m	0.024 W/m K	133	10.3%
Interior Wall Separation	988 m	0.003 W/m K	3	0.3%

Overall Thermal Transmittance (W/m^2 K) 0.21
Effective R-Value (hr·ft^2·F/BTU) 27.0

GLAZING

Window to wall ratio is the percent of the total above grade wall surface area that is made up of windows. Glazing generally has higher thermal transmittance (U-value) than walls, but glazing also admits solar radiation that can offset heating loads. Accordingly, wall and glazing performance should generally not be compared directly in terms of U-value but rather assessed independently in the context of whole building energy use.

The interface quantity and arrangement of glazing can significantly influence the impact of thermal bridging at the window to wall interface. Typically, a balance of both window area and window shape should be considered when trying to achieve low TEDI. **Figure 4.4** illustrates four generic orientations and glazing layouts that lead to different outcomes for thermal transmittance due to the quantity of the window to wall interface.

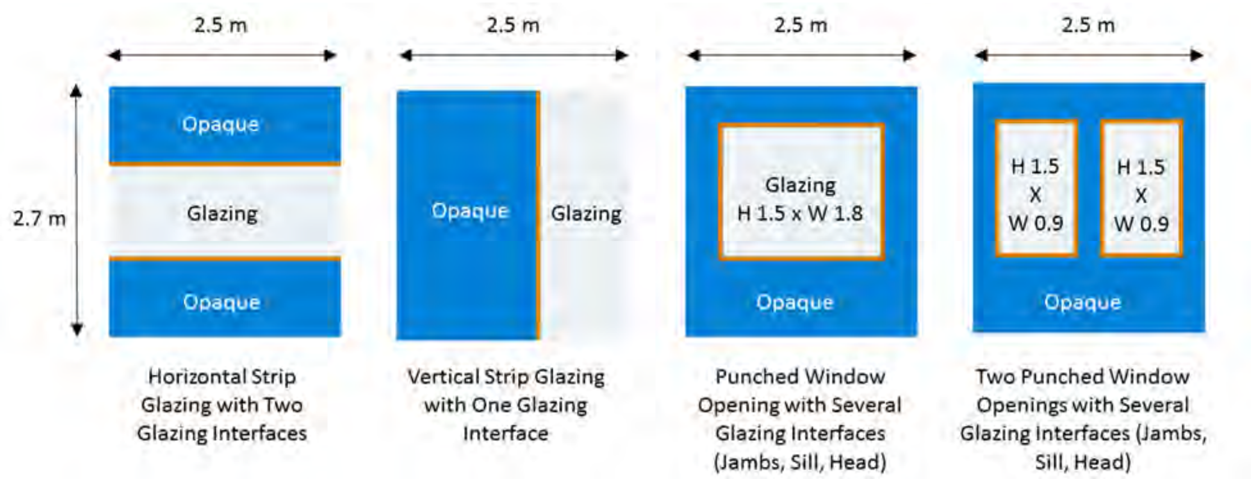


Figure 4.4: Example Window Orientations and Layouts

Table 4.4 summarizes the impact of glazing orientation and layout on the thermal transmittance for wall assembly with an effective R-value of R-16. Each scenario results in a different thermal transmittance depending on the window to wall interface length. This example assumes that each scenario has the same assemblies, same detailing, and same wall and glazing areas.

Table 4.4: Effects of Window Arrangement on Thermal Transmittance

	Horizontal Strip Glazing	Vertical Strip Glazing	Punched Window Opening	Two Punched Window Openings
Interface Length (m)	5	2.7	6.6	9.6
U-value (W/m² K)	**0.566**	**0.467**	**0.617**	**0.733**
Effective R-Value	10.2	12.2	9.2	7.8

Although details were kept the same for this comparison, the interface details typically are not identical for different glazing orientations and layouts. For example, the details for a window in a punched opening are typically different than for a curtain wall in a vertical orientation. Moreover, the jamb versus sill or head details can be quite different in terms of thermal bridging for a window in a punched opening. These differences can accentuate the differences presented in the table above because minimizing thermal bridging at the window to wall interface can be a challenge for windows for low TEDI buildings. See Chapter 5 for examples and more discussion.

The quantity and quality of glazing framing components also affects the window performance and thermal bridging at the window to wall. More framing can increase TEDI by increasing the window thermal transmittance and a fair assumption is that the overall airtightness will be decreased. Framing materials and components can affect thermal bridging because of how easily heat can transfer laterally through the window frames to the adjacent wall assembly and bypass the thermal insulation through structural framing.

WINDOW HEAT BALANCE

The balance between solar heat gain coefficient (SHGC) and thermal transmittance (U-value) for a window is a critical design consideration. The concept of the heat balance of windows can help in understanding this balance. Each window installed in a building will increase TEDI, relative to U-value, but decrease TEDI relative to the SHGC. When the gain is greater than the loss the window has a positive heat balance, otherwise it is a net loss to the building and considered to have a negative heat balance. Shading is also a factor in the heat balance of a window, because an ineffective shading strategy can block too much solar gain, which can lead to a net-negative window.

Table 4.5 and **Table 4.6** show how the window SHGC and U-value for different orientations will have positive or negative contribution to TEDI depending on the solar gains. The example is for a high-rise MURB with wall thermal transmittance of 0.35 W/m²K (approximately R-16 effective R-value), R-30 roofs and 50% window to wall ratio.

Table 4.5: Net Contribution of Windows on TEDI for High-Rise MURB for Climate Zone 4

Orientation	Net Contribution of Windows on TEDI (kWh/m²)	
	U-0.15 and SHGC 0.25	U-0.45 and SHGC 0.4
South	0.2	-1.7
East	-0.3	-3.6
North	-0.4	-3.9
West	-0.3	-2.9
Overall	-0.8	-12.1

Table 4.6: Net Contribution of Windows on TEDI for High-Rise MURB for Climate Zone 6

Orientation	Net Contribution of Windows on TEDI (kWh/m²)	
	U-0.15 and SHGC 0.25	U-0.45 and SHGC 0.4
South	0.1	-3.3
East	-1.1	-6.1
North	-1.4	-7.0
West	-1.0	-5.8
Overall	-3.4	-22.3

Other design requirements, such as daylighting and views, typically constrain the placement and amount of windows per orientation. As a result, similar window areas and arrangements are typically provided on each façade orientation for high-rise construction. With TEDI becoming a more important design criteria, however, there are opportunities to optimize window placement, U-value and SHGC for low TEDI buildings, while balancing overall impacts on EUI.

COOLING LOADS AND OVERHEATING

Various measures for reducing TEDI may reduce building heating energy consumption, but can negatively affect cooling loads. In buildings without cooling, overheating is also a concern. This means there are both overall energy use (EUI) and thermal comfort issues (overheating) that must be considered when designing to low TEDI targets. Various passive cooling measures are typically required to manage overheating, with the most critical being shading and windows of appropriate size and number for natural ventilation. Other measures to counter increased cooling load or overheating, while preserving low TEDI include:

- Careful balance between SHGC and window U-values
- Bypassing heat recovery cores in the summer to provide outdoor air without tempering
- Air or water economizers to reduce cooling energy consumption, after cooling loads are reduced by the measures outlined above
- Night-time pre-cooling can limit cooling loads for the next day

A recent study for the City of Vancouver titled "Passive Cooling Measures for Multi-Unit Residential Buildings" (Morrison Hershfield, 2017) showed that bypassing heat recovery in the summer, proper design of shading reduced and openings for natural ventilation were effective in reducing overheating. **Table 4.7** and **Figure 4.5** use data from the report mentioned above to demonstrate some likely overheating solutions and their impact on potential overheated hours.

Table 4.7: Summary of Solutions to Overheating and Related Impacts

Cumulative Scenario (Each Includes the Previous)	Potential Overheated Hours	Reduction in Overheated Hours
None	1940	-
Natural Ventilation	315	1625
Balcony Shading	200	115
Reduced SHGC	110	90
Movable Exterior Screens	40	70
HRV Bypass	10	30

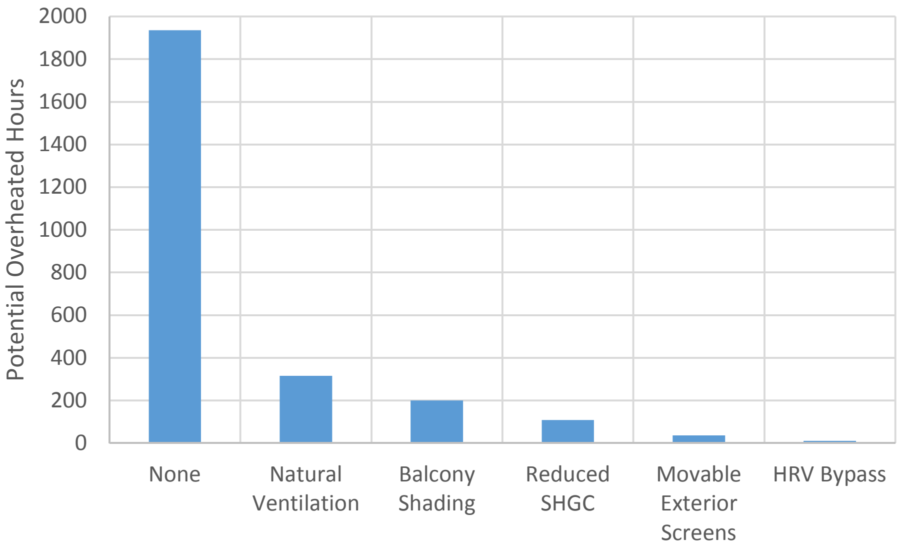


Figure 4.5: Cumulative Effects of Measures to Reduce Overheating

AIR INFILTRATION

Air infiltration significantly affects TEDI and is proportionally related to climate. Accurately accounting for infiltration can thus be a challenge that warrants concentrated effort to reflect "as built" reality. Several methodologies are available, including the ASHRAE Handbook – Fundamentals (ASHRAE, 2017). Reducing air infiltration in practice requires careful consideration to air-barrier requirements as outlined in Chapter 5 and testing to verify the level of airtightness. High levels of airtightness can significantly reduce TEDI as shown in **Figure 4.6**. The figure shows the impact on TEDI of Code (2.0 L/s/m^2 @ 75 Pa), Airtight (0.8 L/s/m^2 @ 75 Pa) and Passive House (0.08 L/s/m^2 @ 75 Pa) infiltration rates.

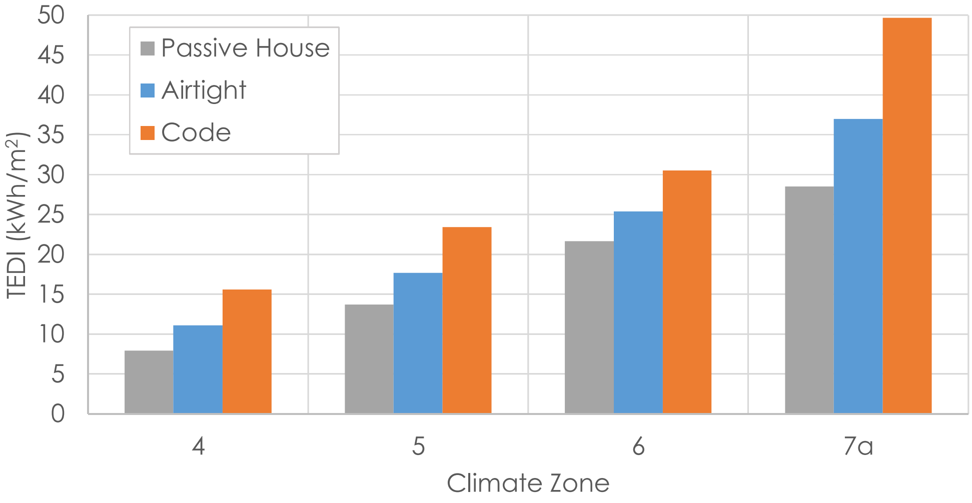


Figure 4.6: Impact of Air Infiltration on TEDI

VENTILATION

Ventilation and heat recovery play a strong role in a low TEDI building, but the relative impact is reduced with increasing effectiveness of heat recovery. **Figure 4.7** illustrates the impact of heat recovery effectiveness on the ventilation component of TEDI for different climates. All other building parameters are the same for this comparison. The impact of heat recovery effectiveness is reduced for warmer climates, but remains a critical consideration to meet low TEDI for targets of 15 kWh/m^2 regardless of climate. Additionally, once a premium efficiency HRV (85% or greater) is used, the ventilation load is small regardless of the climate.

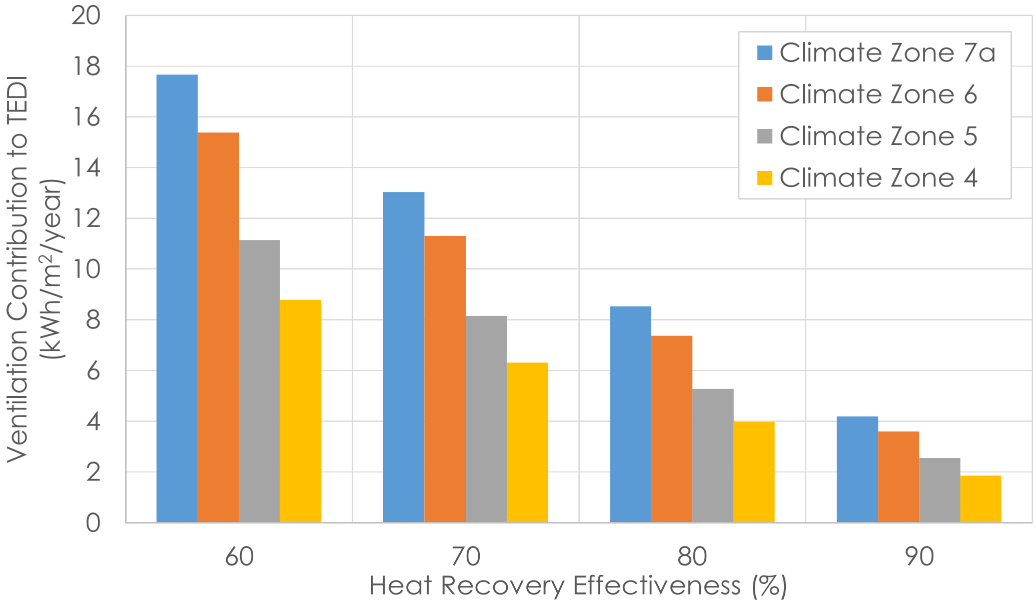


Figure 4.7: Impact of HRV Effectiveness on Ventilation Component of TEDI

The benefits of premium HRVs are clear from a TEDI perspective, but technologies that allow HRVs to achieve higher efficiencies are also bigger units. A 70% efficient unit can be approximately 57 cm x 55 cm x 26 cm (22 in x 21 in x 10 in) in comparison to a premium 90% efficient unit that can be approximately 70 cm x 84 cm x 57 cm (28 in x 34 in x 23 in). This larger size can have implications on where an HRV can be placed in a suite.

KEYS TO A LOW THERMAL DEMAND MURB

High efficiency heat recovery ventilators, high R-value walls, triple-glazing and decreased air infiltration are key characteristics of low thermal demand MURBs.

Paths to Low Energy Buildings

There are many possible combinations using the strategies presented in this chapter to achieve a low TEDI. **Figure 4.8** demonstrates over 275 possible options that meet a TEDI target of 15 kWh/m^2 for Climate Zone 6. The particular path that a project takes depends on a variety of factors, such as the building envelope systems, climate and site restrictions. The output metric is TEDI (kWh/m^2/year) and the design criteria (inputs) examined here include:

- **Climate Zone:** NBC Zones 4, 5, 6 and 7a
- **Shape**: Baseline (VFAR 0.5), complex (VFAR 0.7) and narrow (VFAR 0.9)
- **Wall Thermal Transmittance**: presented as effective R-values from R-10 to R-20 (hr ft² °F/BTU) for the opaque elements and including all thermal bridging
- **Window Thermal Transmittance**: U-values from 0.15 to 0.35 (BTU/ hr ft² °F), representing premium triple-glazed to good double-glazed windows
- **Window Solar Heat Gain Coefficient**: SHGC from 0.2 to 0.4
- **Heat Recovery Effectiveness**: 70, 80 or 90% effectiveness, representing good to premium HRVs
- **Infiltration**: Code (2 L/s/m^2 @ 75 Pa), Airtight (0.8 L/s/m^2 @ 75 Pa) and Passive House (0.6 ACH @ 50 Pa or approximately 0.08 L/s/m^2 @ 75 Pa)

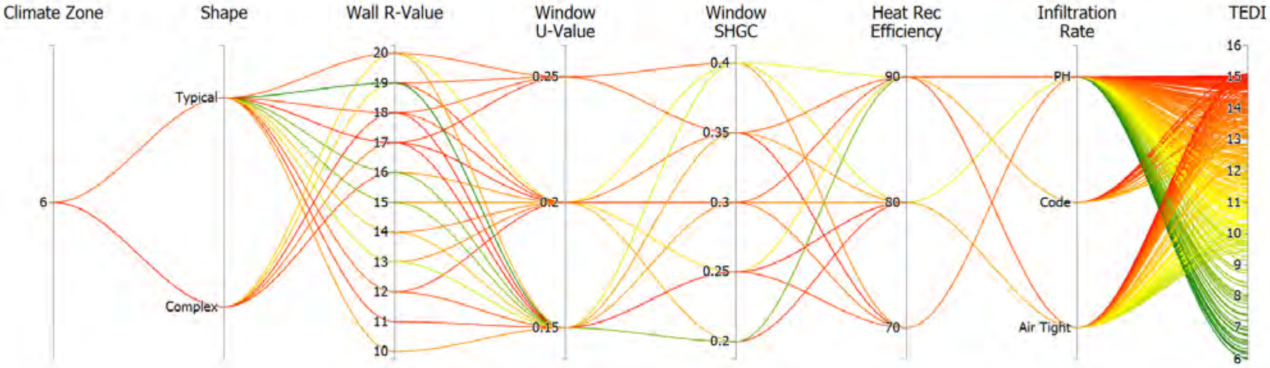


Figure 4.8: Various Paths to Low Energy Buildings in Climate Zone 6

Figures 4.9 to 4.12 illustrate designs that will lead to low energy buildings for four major NEBC Climate Zones for cities such as Victoria, BC (Zone 4), Kamloops, BC (Zone 5), Ottawa, Ontario (Zone 6) and Edmonton, Alberta (Zone 7a). The design options are not exhaustive, but illustrate the likely measures needed to achieve a TEDI below 15 kWh/m^2. All options include window to wall ratio of 40% and loads are simulated in accordance with the City of Vancouver's "Energy Modelling Guidelines" (City of Vancouver, 2017).

CLIMATE ZONE 4 DESIGN MEASURES

Climate Zone 4 is the easiest climate in Canada to achieve a low TEDI. Various paths are possible, including options that would not require a significant deviation from current practice for wall assemblies and glazing when high performance HRVs are provided. The examples shown in **Figure 4.9**, which meet a TEDI target of 15 kWh/m^2, include:

Orange Line	Double-glazed windows (0.35 U-value) are feasible when the following is provided: • Window SHGC of 0.4 • A highly insulated wall with mitigated thermal bridging (R-20) • High efficiency HRV (80%) • Improved airtightness (0.8 L/s/m^2 @ 75 Pa)
Green Line	Wall assemblies with moderate levels of insulation and mitigated thermal bridging (R-15) are feasible when the following is provided: • Triple-glazed windows (0.25 U-value and 0.3 SHGC) • High efficiency HRV (80%) • Improved airtightness (0.8 L/s/m^2 @ 75 Pa)
Blue Line	Wall assemblies that are not a stretch from current practice (R-10) are feasible when the following is provided: • Premium triple-glazed windows (0.15 U-value) • Medium efficiency HRV (70%) • Improved airtightness (0.8 L/s/m^2 @ 75 Pa)

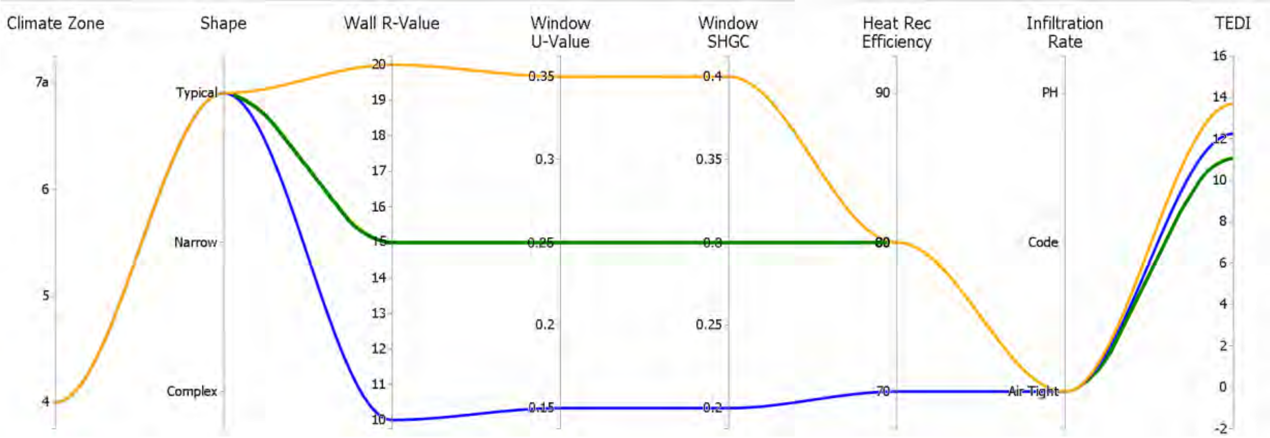


Figure 4.9: Example Paths to Low Energy Buildings in Climate Zone 4

CLIMATE ZONE 5 DESIGN MEASURES

There are fewer potential solutions for achieving a TEDI of 15 kWh/m^2 in Climate Zone 5 but it is still achievable. Most options available in this zone require a building shape with a VFAR less than 0.5. Complex or narrow shapes have limited options. Very few options are available without mid-to-higher performance HRVs. The examples shown in **Figure 4.10**, which meet a TEDI target of 15 kWh/m^2, include:

Orange Line	High quality double-glazed windows (0.3 U-value) are feasible when the following is provided: • Window SHGC of 0.3 • A highly insulated wall with mitigated thermal bridging (R-20) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m^2 @ 75 Pa)
Green Line	Wall assemblies with moderate levels of insulation and mitigated thermal bridging (R-15) are feasible when the following is provided: • Triple-glazed windows (0.25 U-value and 0.3 SHGC) • Premium efficiency HRV (90%) • Improved airtightness (0.8 L/s/m^2 @ 75 Pa)
Blue Line	Wall assemblies that are not a stretch from current practice (R-10) are feasible when the following is provided: • Premium triple-glazed windows (0.15 U-value) • Premium efficiency HRV (90%) • Improved airtightness (0.8 L/s/m^2 @ 75 Pa)

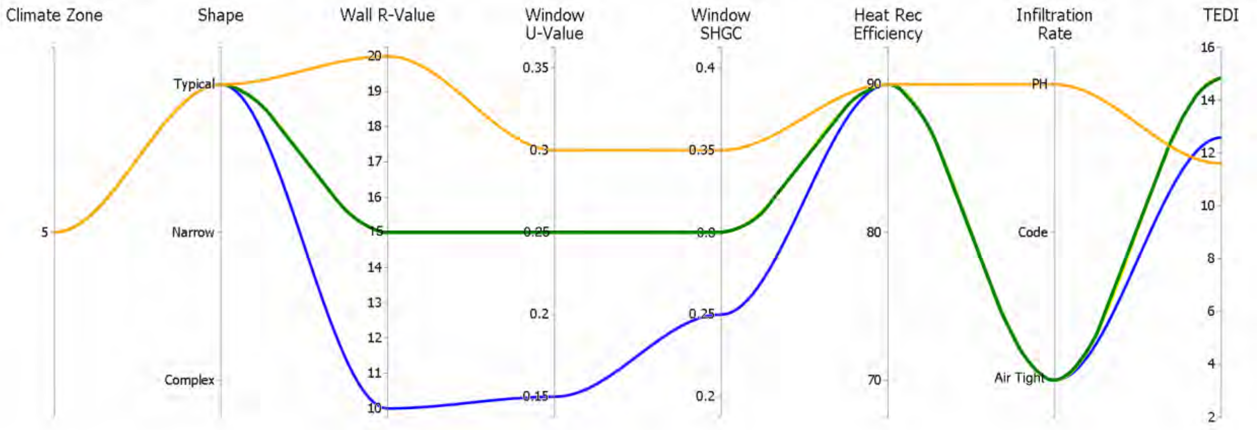


Figure 4.10: Example Paths to Low Energy Buildings in Climate Zone 5

CLIMATE ZONE 6 DESIGN MEASURES

The options for achieving a TEDI of 15 kWh/m^2 in Zone 6 are constrained, but a low TEDI is still achievable. Very few paths include complex or narrow building shapes. The examples shown in **Figure 4.11**, which meet a TEDI target of 15 kWh/m^2, include:

Orange Line	Standard triple-glazed windows (0.25 U-value) are feasible when the following is provided: • Window SHGC of 0.35 • A highly insulated wall with mitigated thermal bridging (R-20) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m^2 @ 75 Pa)
Green Line	Wall assemblies with moderate levels of insulation and mitigated thermal bridging (R-15) are feasible when the following is provided: • High quality triple-glazed windows (0.2 U-value and 0.3 SHGC) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m^2 @ 75 Pa)
Blue Line	Wall assemblies that are not a stretch from current practice (R-10) are feasible when the following is provided: • Premium triple-glazed windows (0.15 U-value and 0.35 SHGC) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m^2 @ 75 Pa)

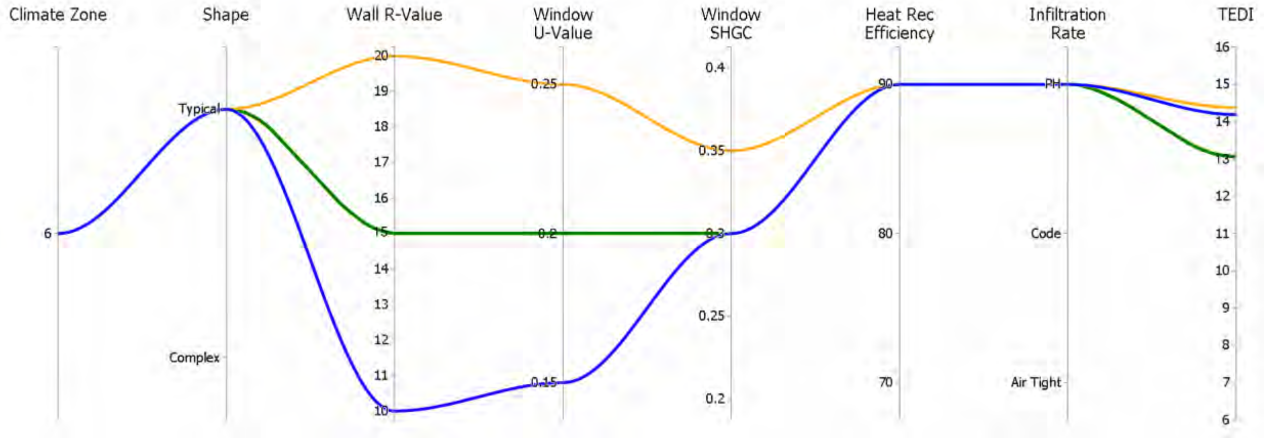


Figure 4.11: Example Paths to Low Energy Buildings in Climate Zone 6

CLIMATE ZONE 7A DESIGN MEASURES

There are significant challenges in achieving a low TEDI for Climate Zone 7a. A design needs to incorporate all of the high performance elements mentioned in this section, in addition to premium efficiency heat recovery and Passive House levels of airtightness. Premium quality triple-glazed windows with moderate SHGC are required. Wall R-values greater than the R-20 shown here are possible (up to R-40 was examined) and may reduce the pressure on other design elements, such as SHGC, but the other previously mentioned requirements remain. The examples shown in **Figure 4.12**, which meet low energy building requirements include:

Orange Line	High quality triple-glazed windows (0.2 U-value) are feasible when the following is provided: • Window SHGC of 0.35 • A highly insulated wall with mitigated thermal bridging (R-20) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m^2 @ 75 Pa)
Green Line	Wall assemblies with moderate levels of insulation and mitigated thermal bridging (R-15) are feasible when the following is provided: • Premium triple-glazed windows (0.15 U-value and 0.3 SHGC) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m^2 @ 75 Pa)
Blue Line	Wall assemblies that are not a stretch from current practice (R-10) are feasible when the following is provided: • Premium triple-glazed windows (0.15 U-value and 0.35 SHGC) • Premium efficiency HRV (90%) • Passive House level of airtightness (0.08 L/s/m^2 @ 75 Pa)

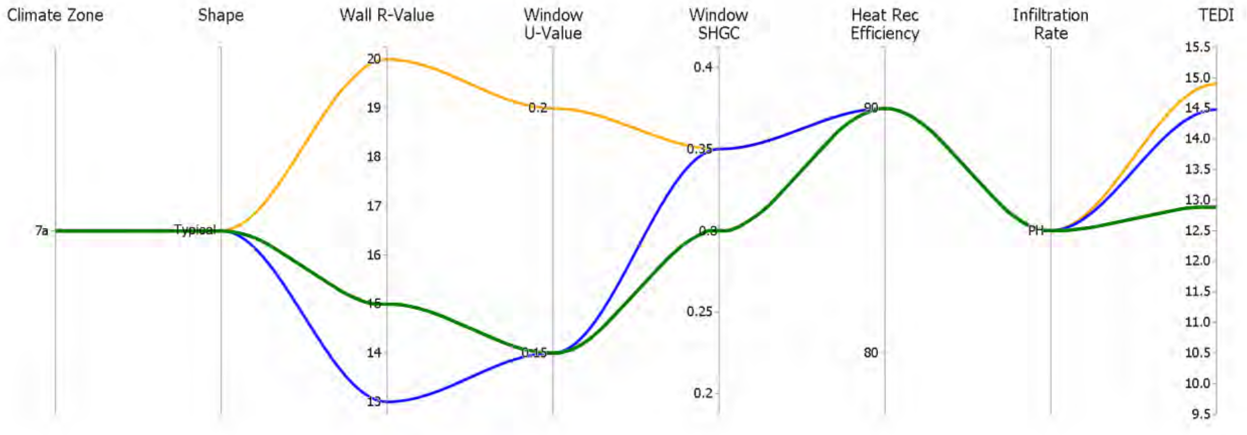


Figure 4.12: Example Paths to Low Energy Buildings in Climate Zone 7a

Table 4.8 below summarizes the example paths to low energy buildings described above. Visit BuildingPathfinder.com to explore more options for meeting low TEDI using the same archetype buildings and methodology presented in this chapter.

Table 4.8: Summary of Example Paths to Low Energy Buildings

NBC Climate Zone	Shape	Wall R-Value (hr ft^2 °F)/BTU	Window U-Value BTU/(hr ft^2 °F)	Window SHGC	Heat Rec Efficiency %	Infiltration Rate	TEDI kWh/m^2
4	Typical	20	0.35	0.4	80	Airtight	14
4	Typical	15	0.25	0.3	80	Airtight	11
4	Typical	10	0.15	0.2	70	Airtight	12
5	Typical	20	0.3	0.35	90	PH	12
5	Typical	15	0.25	0.3	90	Airtight	15
5	Typical	10	0.15	0.25	90	Airtight	13
6	Typical	20	0.25	0.35	90	PH	14
6	Typical	15	0.2	0.3	90	PH	13
6	Typical	10	0.15	0.3	90	PH	14
7a	Typical	20	0.2	0.35	90	PH	15
7a	Typical	15	0.15	0.3	90	PH	13
7a	Typical	10	0.15	0.35	90	PH	15

CORRIDOR PRESSURIZATION

The above paths assume ventilation rates are strictly code-compliant. However, it is common industry practice to provide additional ventilation through corridor pressurization. The degree of additional air provided and whether there is heat recovery on this air will significantly affect the additional thermal energy demand added to the building. A high-rise MURB in Vancouver with 20 cfm/suite of additional ventilation could see approximately 9 kWh/m^2 of additional TEDI. This makes reaching a target of 15 kWh/m^2 significantly more difficult so the design team will need to carefully consider the implications of utilizing corridor pressurization.

COST

The recent "BC Energy Step Code Metrics Research Report" (Integral Group et al, 2017) studied the cost premium of achieving various levels of the new BC Step Code. This code has absolute targets for EUI and TEDI for which the highest step is equivalent to a net-zero ready building. The report found that the low thermal demand targets could be met in most cases with a cost premium of no more than 4%.

Software Tools

Various components affecting building energy consumption have been discussed in previous sections, such as internal gains, domestic hot water (DHW) and envelope-related characteristics. Ventilation was addressed in Chapter 3, but heating and cooling systems also require careful consideration when overall energy use reduction is a goal. Complex heating systems are not required for high-rise MURBs, but they are becoming more common as design teams strive to meet current energy standards. These systems, such as central plants, heat pumps and variable refrigerant systems, require more advanced understanding of engineering principles and usually more advanced software tools (EnergyPlus, IES, etc.) as well.

The degree of complexity of the tool used will depend on the degree of complexity of the building in question. These tools must at a minimum, have the capability to assess the impact and interactions between equipment loads, occupancy, lighting, schedules, outdoor temperatures, envelope, equipment part-load performance and ventilation rates, and must do so within short time-steps, preferably hourly or more frequently. One example to consider is dynamic shading (e.g. operable shading or dynamic glass) that has the ability to allow or block solar gains based on solar exposure and/or user input. The amount of solar radiation entering the building would be highly dependent on the position of the shading device, which can change several times throughout the day. Only an hourly simulation could capture this constantly changing variable and its impact on the heat balance within a building.

DYNAMIC SIMULATIONS AND COMPLEX MECHANICAL SYSTEMS

Understand the tools available and the types of mechanical, ventilation and other systems that they can simulate. When more complex HVAC systems are being considered and/or when design intent varies from a given tool's "default" assumptions or capabilities, it will likely be necessary to use a fully dynamic, hourly simulation software.

Passive House is referenced several times in this report due to its key low thermal energy demand requirement. Passive House certification requires using the PHPP spreadsheet based tool to assess the thermal energy and overall energy criteria specified by Passive House. PHPP and Passive House methodologies were studied as part of this report and the basic first-principles applied are common to other energy analysis tools such as envelope losses, accounting for solar gains, and accounting for occupant and equipment loads. However, PHPP uses various adjustment factors and correlations to estimate variances in schedules, daily temperature swings, occupant behavior and other factors. These assumptions may hold true for certain applications for which the tool was originally designed, but it is difficult to assess how well they would hold for larger, more complex buildings, where these adjustments and correlations start to deviate from "typical" to project specific assumptions.