Passive Design Toolkit

City of Vancouver — Passive Design Toolkit

Message from the Mayor

Vancouver City Council has taken an important first step toward our goal of becoming the greenest city in the world, as the first jurisdiction in North America to go beyond green building codes and use architecture itself to reduce greenhouse gases (GHGs).

More than half of all GHG emissions in Vancouver come from building operations, so the City has set a target that all new construction will be GHG neutral by 2030, through carbon-neutral measures in areas such as lighting and heating technologies.

The Passive Design Toolkits will serve as a resource to the development industry, and as a framework for the City's Planning department to review and update its design guidelines. Passive design elements, when evaluated in terms of relative cost and effectiveness, have been shown to reduce a building's energy demand by as much as 50 percent.

The new Toolkits will help us create a more sustainable architectural form across the city, while improving the comfort of the people who live and work in new buildings.

Gregor Robertson

Message from BC Hydro

BC Hydro is a proud supporter of the Passive Design Toolkits for the City of Vancouver.

We recognize that part of providing clean energy for generations is helping British Columbians build *Power Smart* high performance buildings.

We thank you for using this Toolkit in your project, and congratulate the City of Vancouver for providing leadership in helping designers create the buildings of tomorrow in BC today.

Lisa Coltart, Executive Director Power Smart and Customer Care

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1. Executive Summary

1.1 Purpose

This document presents best practices for the application of passive design in Vancouver. It is intended to establish a common vision and definition of passive design and support decision making for new developments[1] that will maximize occupant health and comfort and minimize energy use by relying less on mechanical and electrical systems. Furthermore, it is intended to move the Vancouver design community toward a new, higher standard of energy efficiency without sacrificing thermal comfort.

This document is not prescriptive, but rather discusses and analyzes recommended design approaches and the energy saving opportunities each presents. Additionally, the modeling results shown are useful and valid but do not replace project-specific modeling.

1.2 Navigating this Toolkit

This toolkit is organized into three main sections:

1. Context
2. Passive Design Strategies
3. Passive Design Elements

Context provides the fundamental frameworks for understanding and implementing passive design. The Passive Design Strategies lay out the overarching strategies that will optimize comfort and minimize energy requirements for new developments in Vancouver. Each strategy is made up of several design elements. Each element is addressed in further detail in Passive Design Elements.

Finally, the appendices provide supporting information, including detailed energy modeling analysis.

1.3 Summary of Recommendations

When building in Vancouver, it is recommended that designers adopt a passive design approach that uses the building architecture to maximize occupant comfort and minimize energy use. Design teams that understand the basic concepts and implement the strategies recommended in this toolkit will optimize passive performance and achieve the many spin-off benefits of energy efficient, thermally comfortable buildings. Of course, the application of passive design must be carefully considered within the specific constraints and opportunities of each project.

The key passive design recommendations for buildings in Vancouver are summarized below. (See Appendix E for energy modeling to support statements.)

- Design each facade specific to its orientation.
- Where possible, minimize east and west exposures to avoid

[1] This toolkit is intended for Part 3 buildings, as per the National Building Code of Canada (2005).

When building in Vancouver, it is recommended that designers adopt a passive design approach that uses the building architecture to maximize occupant comfort and minimize energy use.

Design for cooling by natural ventilation.

unwanted solar gains.

- For better energy performance, attempt to limit windows to 50% on any facade (for best performance, limit windows to 30%), taking into account other aesthetic and livability criteria. If higher window to wall area ratios are desired, incorporate high performance windows or a double facade and optimize shading.
- Target overall wall assembly RSI values between 2.3 (ASHRAE minimum) and 2.9. Use modeling to assess project-specific benefits, as the impact of insulation depends greatly on window to wall area ratio.
- Use an air-tight envelope to minimize uncontrolled infiltration.
- Use heat-recovery ventilation during heating season only, and design for natural ventilation and cooling by natural ventilation throughout the rest of the year.
- For residential buildings, use clear glass with good insulating value (low U-value with low-e coating). Mitigate unwanted solar gains with external shading and allow for passive cooling by natural ventilation.
- For commercial buildings, use either clear glass with effective external shading elements or dark or reflective glass (low shading coefficient) to control unwanted solar gains. Regardless of shading option, the glass should have good insulating value (low U-value with low-e coating). Remove internal heat gains with other passive elements (e.g., natural ventilation).
- Incorporate overhangs providing shading angles of 20°-30° off vertical (measured from the bottom window sill to the edge of the overhang) on south-facing windows.
- Incorporate operable external shading on east-, south- and west-facing windows.
- Use thermal mass that is exposed to the conditioned space and combine it with other passive elements to achieve its full energy-savings and comfort potential.
- Incorporate buffer spaces on all exposures whenever possible to optimize comfort and reduce both peak load and overall heating and cooling energy requirements.
- Design for cooling by natural ventilation in all building types.
- Optimize the effects of passive heating and cooling strategies by strategically combining passive elements.
- Incorporate as many passive design elements as possible to optimize comfort and minimize overall energy use.

2 Context

2.1 Definition of Passive Design

"Passive design"[2] is an approach to building design that uses the building architecture to minimize energy consumption and improve thermal comfort. The building form and thermal performance of building elements (including architectural, structural, envelope and passive mechanical) are carefully considered and optimized for interaction with the local microclimate. The ultimate vision of passive design is to fully eliminate requirements for active mechanical systems (and associated fossil fuel-based energy consumption) and to maintain occupant comfort at all times.

Even though we may not achieve the ultimate passive design vision on every building, implementing the passive design approach to the fullest extent possible will lower building energy use. Building shape, orientation and composition can improve occupant comfort by harnessing desirable site-specific energy forms and offering protection from undesirable forms of energy. Through properly applied passive design principles, we can greatly reduce building energy requirements before we even consider mechanical systems.

Designs that do not consider passive thermal behaviour must rely on extensive and costly mechanical HVAC systems to maintain adequate indoor conditions, which may or may not even be comfortable. Furthermore, even the most efficient technologies will use more energy than is necessary with a poorly designed building.

To successfully implement the passive design approach, one must first accomplish the following:

1. Understand and define acceptable thermal comfort criteria.
2. Understand and analyze the local climate, preferably with site-specific data.
3. Understand and establish clear, realistic and measurable energy performance targets.

2.2 Thermal Comfort

Proper understanding of the parameters around thermal comfort is a critical component of successful building and system design. It is especially important in passive design, where buildings must maintain thermal comfort without the aid of active mechanical systems for as much of the year as possible.

Thermal comfort refers specifically to our thermal perception of our surroundings. The topic of thermal comfort is a highly subjective and complex area of study. Through passive design, we can impact four indoor environmental factors that affect thermal comfort:

"Passive design" is an approach to building design that uses the building architecture to minimize energy consumption and improve thermal comfort.

2 Also known as "climate adapted design" or "climate responsive design"

Thermal comfort is a very subjective term thus making it difficult to model.

- Air temperature
- Air humidity
- Air velocity
- Surface temperatures

Each factor affects thermal comfort differently. The factors most commonly addressed in the conventional design process, air temperature and air humidity, in fact affect only 6% and 18% of our perception of thermal comfort, respectively. To take a more effective comfort-focused approach, we must also consider the temperature of surrounding surfaces and the air velocity, which account for 50% and 26% of thermal comfort perception, respectively.

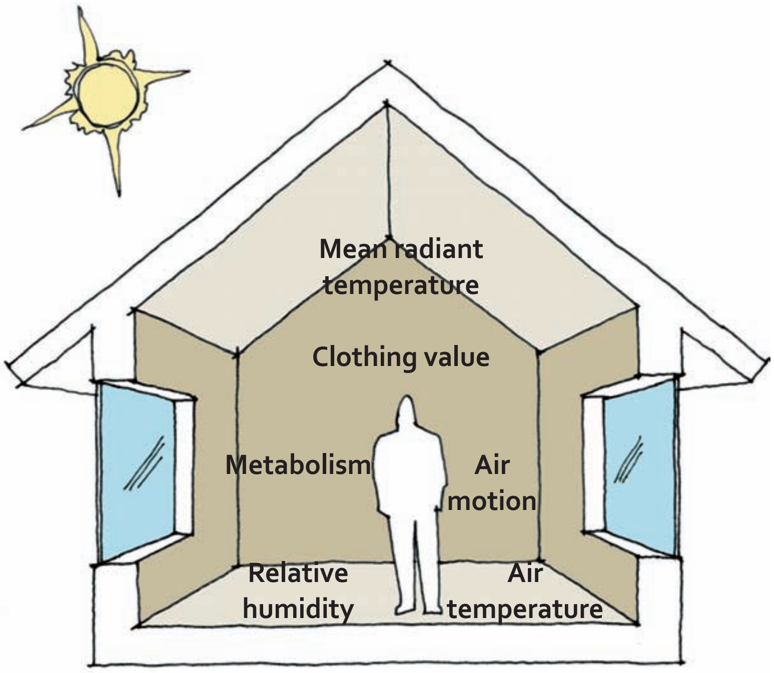
The effectiveness of passive strategies depends on the range of acceptable thermal comfort parameters set for the project.

2.2.1 Thermal Comfort Models

As human thermal comfort perception is extremely complex and subjective, defining acceptable comfort parameters is particularly challenging. Despite these difficulties, several models for quantitatively measuring occupant comfort have been widely used. The two most relevant in this case are the Fanger and Adaptive Models.

The Fanger Model is most commonly used for typical buildings that rely solely on active mechanical systems. It defines comfort in terms of air temperature and humidity because these parameters are easy to measure and control. It prescribes a relatively narrow range of acceptable levels which, in common practice, do not vary with outdoor conditions on a daily or yearly basis.

Figure 1: Key Thermal Comfort Parameters



This suits the conventional approach which has heavy reliance on active mechanical systems regardless of the outdoor climatic conditions. But this can also lead to unnecessary energy consumption. Furthermore, this simplification does not account for the temperature of surrounding surfaces, the dominant factor affecting thermal comfort.

The complexity of human thermal comfort, particularly in passively designed buildings, can be better described by the lesser-known Adaptive Model.

The Adaptive Model correlates variable outdoor conditions with indoor conditions and defines comfort with a wider range of thermal parameters, making it more suited to buildings with passive features and natural ventilation. In the mild Vancouver climate, passive buildings can maintain acceptable thermal comfort within the parameters of the Adaptive Model for the majority of the year, with the exception of the coldest outdoor temperatures during winter.

Using the passive design approach and the Adaptive Model can significantly reduce a building's reliance on energy-intensive active mechanical systems.

The required strategies to achieve such passive performance are discussed in Section 3 of this toolkit. See Appendix B - Thermal Comfort for further details on both thermal comfort models.

2.2.2 Resultant Temperature

Resultant temperature[3] is the average of the air temperature and temperature of the surrounding surfaces (i.e., Mean Radiant Temperature or MRT). Surface temperatures affect occupant comfort by radiant heat transfer, the most dominant factor of human comfort perception, and air temperature affects comfort by convection and conduction, less dominant factors.

As long as the resultant temperature of the space remains within the targeted comfort range, occupants will feel comfortable, even as the air temperature fluctuates outside the comfort range. Conversely, when the resultant temperature of the space is outside the defined comfort range because of a cold or hot surface (e.g., a hot window on a sunny day), occupants will feel uncomfortable even if the desired air temperature set point is maintained.

The resultant temperature and MRT can be controlled by passive design strategies, which are discussed in Section 3 of this toolkit.

2.2.3 Free Run Temperature

Free Run Temperature (FRT) represents the natural temperature variation inside a building operating in an entirely passive mode, that is, without the involvement of active mechanical systems. An annual FRT

3 Also known as operative temperature; RT = (Average Air Temp + Mean Radiant Temp)/2

Understanding the local climate is the foundation of passive design.

profile is a very effective tool for understanding a building's passive response to its local climate. Once generated with building simulation software, an FRT profile can be used to test passive strategies. Effective passive strategies keep the FRT within the comfort range (or close to it) for most of the year. Optimizing the FRT minimizes the amount of energy required of the mechanical system.

See Appendix B.4 - Free Run Temperature for further details.

2.3 Vancouver Climate Characteristics

Understanding the local climate is the foundation of passive design. It guides the selection of appropriate passive design strategies and affects the extent to which mechanical systems are needed to maintain comfort.

Vancouver (49.18° N, 123.17° W) is located at sea level on the southwestern Pacific coast of British Columbia. In general, Vancouver has a temperate climate with mild temperatures and moderate humidity levels year round. Summers are pleasantly warm and dry and winters are relatively mild with high levels of precipitation. This weather pattern is due to the combination of the nearby ocean and the protection from the cold continental winter offered by the Coast Mountains rising abruptly from the ocean immediately to the north of the city.

The following table shows the average minimum and maximum air temperatures for Vancouver during the coldest month (January) and the hottest month (August).[4]

Table 1: Vancouver Average Temperatures

January		August	
Average Minimum	Average Maximum	Average Minimum	Average Maximum
0.5 °C	6.2 °C	13.2 °C	21.9 °C

4 Source: http://www.climate.weatheroffice.ec.gc.ca

Because Vancouver is on the Pacific Northwest coast and it rains frequently, we often refer to Vancouver as "humid." However, only Vancouver's relative humidity is consistently high, not its absolute humidity. When high relative humidity coincides with low temperatures, the absolute amount of moisture in the air is still low. See Appendix C.2 for a more detailed discussion of humidity in Vancouver.

Vancouver receives moderate levels of solar radiation during spring, summer and fall.

The prevailing wind direction is from the east, followed in frequency by westerly winds. Due to the protection of the Coast Mountains, north winds are marginal.

The outdoor design temperatures for Vancouver as defined by the BC Building Code (2006) and ASHRAE 90.1 v.2007 are shown in Table 2.

2.4 Energy Performance Targets

Minimum energy performance is defined by current North American standards in indirect, non-energy-specific terms. The standards fall short of what is being achieved in other parts of the world and what is possible in our Vancouver climate.

Both North American standards address only two passive building components: envelope insulation and window performance. Neither standard addresses other crucial passive design parameters affecting energy performance such as building shape, compactness, orientation, layout, and thermal storage effects of building mass.

The currently prescribed methodology does not provide clear, measurable energy performance targets. It is not possible to compare energy performance between buildings or determine how a building compares to the best energy performance in a given climate.

Establishing building energy performance targets in clear and measurable terms is a fundamental prerequisite of successful passive design. This new methodology has already been successfully

Table 2: Vancouver Outdoor Design Temperatures

	BCBC	ASHRAE
Winter Dry Bulb Temperature, 99.6%	-9°C	-8°C
Summer Dry Bulb Temperature, 1%	26°C	23°C
Summer Wet-Bulb Temperature (max coincident with 23°C dry-bulb)	19°C	18°C

5 In general, ASHRAE 90.1 is used in the US, and the Model National Energy Code of Canada for Buildings (MNECB) is used in Canada. However, local Canadian jurisdictions can choose to supersede MNECB, as Vancouver has done by adopting ASHRAE 90.1 v.2007.

implemented in most of Europe.[6] Minimum building energy performance is prescribed in terms of energy intensity, kWh/m²·year, for a specific building type in a specific climate. Maximum allowable energy intensity targets can either be determined from the historical building energy consumption data or derived from fundamental laws of physics such as with the free-run temperature methodology.

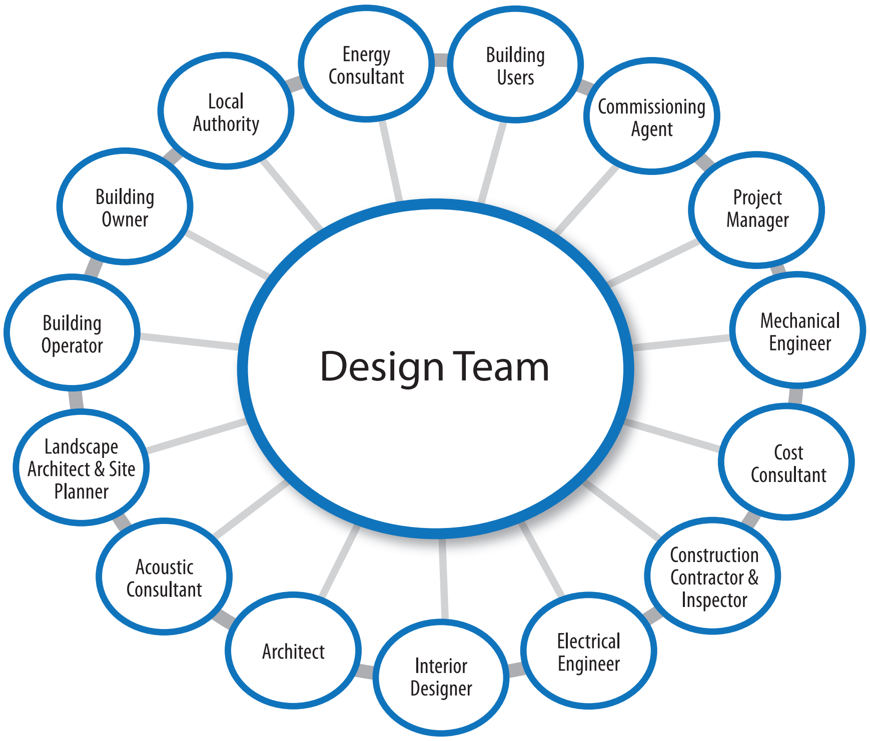
It is recommended that the City of Vancouver adopt maximum allowable energy intensity targets for specific building types. At present (late 2008), the City of Vancouver is working with BC Hydro and Terasen Gas to gather energy intensity data on existing buildings. Once an adequate and accurate data set has been collected, the City will be able to set energy intensity targets appropriate to the Vancouver climate and building market.

2.5 Integrated Design Process

Optimized building design requires the integration of many types of information from diverse sources into a comprehensive whole throughout the project. The Integrated Design Process (IDP) ensures all issues affecting sustainable performance are addressed throughout the process, from conception to occupancy. It is most critical to implement the IDP early on in the design activities, when issues can be addressed with minimal disruption. Active, consistent and coordinated collaboration between all team members and disciplines is critical to a successful IDP.

When implementing a passive design approach, many disciplines must collaborate to have the building and its surrounding site working together as a passive system. Figure 2 illustrates some of the many possible members of an IDP team.

Figure 2: Integrated Design Process Team



6 European Energy Performance of Buildings Directive, MINERGIE (originated in Switzerland), Passive Haus (originated in Germany), etc.

3 Passive Design Strategies

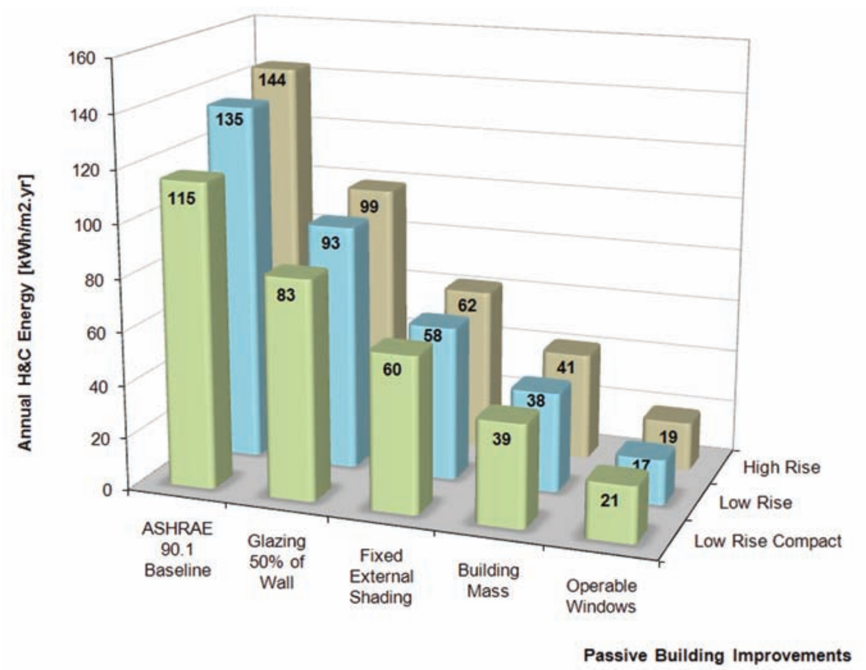
Certain passive building elements have inherent synergies and can be combined to produce different and potentially greater improvements in comfort and building energy performance.

However, combining elements incorrectly or using certain elements in isolation can negatively impact thermal comfort and building energy efficiency. For example, large south and west facing windows beneficial for passive solar heating must be implemented in combination with high performance windows and external shading to protect the interior from excessive solar heat gains during summer in order to achieve the desired overall building efficiency gains.

It is important to note that these guidelines distinguish between cooling and ventilation. In a conventional forced-air HVAC system, ventilation and space temperature control functions are combined. However, there are great advantages to separating the function of space temperature control from the function of ventilation, especially when designing for optimal passive performance. This separation allows the choice of a hydronic heating and cooling system, using water instead of air for energy transfer. Water has over 3,000 times the energy carrying capacity of air, so hydronic systems can achieve dramatically increased system efficiency. The separation also allows the use of an independent ventilation system providing 100% fresh air.

Figure 3 below shows an example of the compounding effect of combining various passive elements on a typical building in Vancouver as thermal comfort is held constant. The baseline meets the minimum requirements of ASHRAE Standard 90.1. As each additional element is incorporated, the annual energy consumption is further reduced, finally achieving a high level of efficiency that would be impossible using any single measure in isolation. The passive design measures essentially build upon and improve the requirements and results of most commonly used North American energy standards methodologies.

Figure 3: Effect of Passive Design on Energy Intensity



CASE STUDY

Turn to page 102 to learn how the Millennium Water development takes advantage of cross-ventilation.

With many passive strategies, there is a trade-off between heating performance and cooling performance. The building type and operation determine which strategies will have the best overall impact on energy performance. In all cases, building energy modeling specific to the project should be conducted. Once again it is important to note that the simulation results presented in this report are parametric comparisons only; they do not replace the value of project-specific modeling.

3.1 Passive Heating

Using building design to harness solar radiation and capture the internal heat gains is the only passive way to add free thermal energy to a building. Passive solar heating combines a well-insulated envelope with other elements that minimize energy losses and harness and store solar gains to offset the energy requirements of the supplemental mechanical heating and ventilation systems. Elements that contribute to passive solar heating include the following:

- Orientation
- Building shape
- Buffer spaces and double facades
- Space planning
- High-performance windows (clear, low-e)
- Mixed-mode heat recovery ventilation (HRV)[7]
- Low window to wall area ratio (N/E)
- High window to wall area ratio (S/W)
- Operable external shading
- High-performance insulation
- Thermal mass
- Minimized infiltration

3.2 Passive Ventilation

Passive ventilation strategies use naturally occurring air flow patterns around and in a building to introduce outdoor air into the space. Wind and buoyancy caused by air temperature differences create air pressure differences throughout occupied spaces. Buildings can be designed to enhance these natural air flows and take advantage of them rather than work against them.

Passive ventilation must be considered during the design process because many architectural features affect air flows through a building, including the building shape, layout of interior walls, floors and even furniture. Design features must strike a balance between privacy/noise attenuation needs and the desired path of least resistance for air distribution. Ventilation rates will also be affected by prevailing wind direction.

There are three common approaches to passive ventilation. The simplest form is single-sided ventilation with operable windows, where ventilation air enters and exhausts through the same window(s) on the same side of

7 HRV is an active system; however, due it its effective synergies with passive ventilation, we are mentioning it here. See Appendix E for modeling results on the efficiency of this mixed-mode system.

the occupied space. There are design limitations on how large a space can be effectively ventilated this way: single-sided ventilation does not achieve a significant result unless ceilings are very high.

More effective is cross-ventilation, where operable windows on adjacent or opposing walls draw ventilation air across the occupied space. Designs should strive for at least two exposed walls per residential or commercial unit to allow for cross-ventilation.

Finally, in larger buildings with significant core spaces, induced ventilation with high spaces such as atria, stacks and wind towers may be necessary to provide adequate ventilation by strictly passive means. These strategic architectural features create optimized pathways for natural, passive ventilation.

The passive elements that contribute to natural ventilation include the following:

- Operable windows
- Buffer spaces and double facades
- Building shape
- Space planning
- Orientation
- Strategic architectural features
- Openings to corridors and between otherwise separated spaces
- Central atria and lobbies
- Wind towers

Figure 4: Single-Sided Ventilation

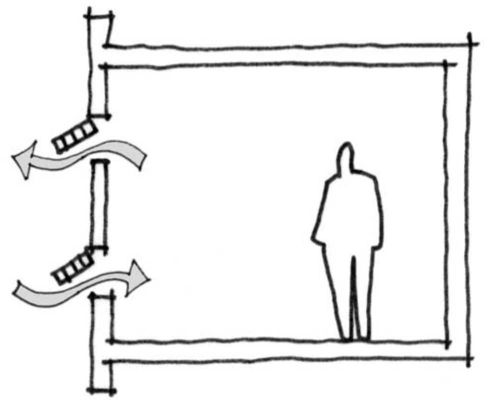


Figure 5: Cross Ventilation

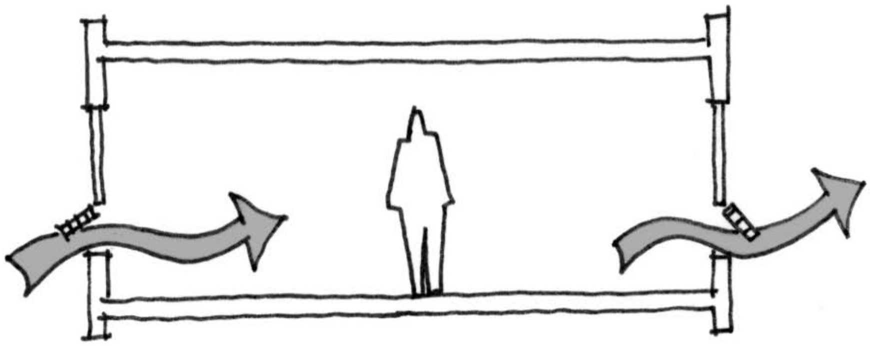
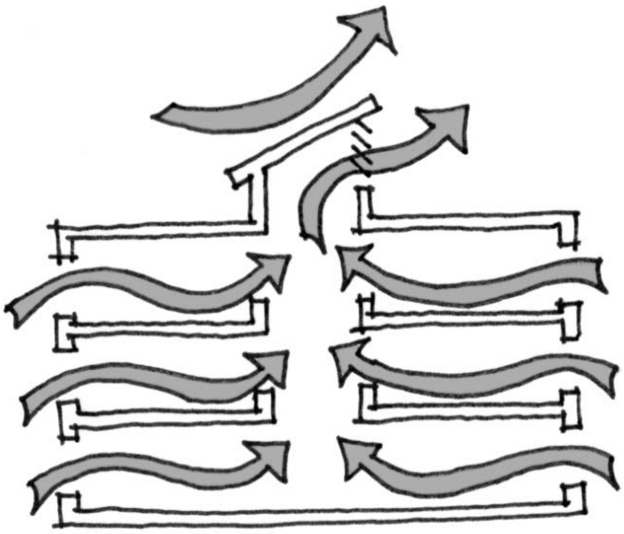


Figure 6: Stack Effect Through an Atrium



Careful design is required to avoid overheating from direct solar gains and to minimize glare.

3.3 Passive Cooling

Passive cooling strategies prevent the building from overheating by blocking solar gains and removing internal heat gains (e.g. using cooler outdoor air for ventilation, storing excess heat in thermal mass).

Passive cooling strategies are often coupled with passive ventilation strategies, and the cooling function is achieved by increased passive ventilation air flow rates during periods when the outdoor air temperature is low enough to flush heat from the building.

Elements that contribute to passive cooling include the following:

- Fixed/operable external shading
- Thermal mass
- Low window to wall area ratio (S/W)
- Passive ventilation
- Nocturnal cooling
- Stacked windows
- Passive evaporative cooling
- Earth-tempering ducts

Nocturnal cooling uses overnight natural ventilation to remove heat accumulated in the building mass during the day. The cooler night-time air flushes and cools the warm building structure/mass.

Stacked windows allow cool air in at a lower window, creating an upward-moving vacuum that forces warm air out a high-placed window.

Evaporative cooling uses heat from the spaces to convert water from a liquid to a vapor, which changes the air from warm and dry to cool and moist. In order to cool a space by evaporative cooling, moisture must be added to an airstream. This can be achieved by drawing air across or through existing water (e.g., a water feature located within the building, a natural exterior body of water, a hydroponic living wall, etc.).

Earth tempering takes advantage of the relatively constant temperature of the ground at depths exceeding 1.5 m to provide tempering for building ventilation air. This requires burying a ventilation air intake path, also called an earth tube.

3.4 Daylighting

Daylighting maximizes the use and distribution of natural diffused daylight throughout a building's interior to reduce the need for artificial electric lighting. Careful design is required to avoid overheating and to minimize glare, and to complement passive heating and cooling strategies such as shading. In order to maximize energy savings , advanced electrical control systems like sensors should be integrated. The features which contribute to a daylighting strategy include:

- Space planning
- High ceilings paired with tall windows
- Window size and placement (window to wall area ratio)
- Interior surface colours and finishes
- Strategic architectural features
- Light shelves
- Skylights and light tubes
- Clerestories

The key energy savings benefit of daylighting is straightforward: daylighting reduces energy requirements for electrical lighting. Indirectly, daylighting can also reduce energy requirements for space cooling.

Daylighting strategies are highly project-specific: detailed building modeling and analysis is required to achieve an effective design and to estimate energy savings. As such, daylighting is not included in the parametric simulations of this study.

3.5 Applying the Strategies: Residential

In the Vancouver market, the vast majority of residential developments are medium- and high-rise towers. Residential spaces have night-time occupancy and relatively low internal heat gains (aside from intermittent cooking), which results in a heating-dominant residential energy profile in the Vancouver climate.

Specific passive approaches that will improve the overall energy performance of residential buildings in Vancouver include:

- Carefully detailed and constructed high-performance insulation in the envelope with minimal thermal bridging, including exterior walls and roofs.
- Clear, low-e, high-performance windows in combination with operable external shading to block solar gains during summer and admit solar gains during shoulder seasons and winter
- Note: any building in which the window to wall area ratio is greater than 50% will be challenged to achieve higher energy performance
- Unconditioned, enclosed buffer spaces (not regularly occupied) that cover the perimeter of the space, fitted with operable windows to provide natural ventilation from the exterior to the interior space when desired.
- Thermal mass on the interior side of the insulation, located in the floors, external walls, and walls between adjoining units (i.e., party walls).
- Compact and simple form.
- Air- and moisture-tight envelope.
- Mixed-mode ventilation using HRV during the winter only and passive ventilation throughout the rest of the year.

The following table displays the elements that positively contribute to the various passive design strategies for residential buildings.

	Relative Impact (★)	Passive Heating	Passive Cooling	Passive Ventilation	Daylighting
High-performance insulation	★★★	•	•		
High-performance windows	★★	•	•		•
Window to wall area ratio <50%	★★★	•	•		•
Buffer spaces	★★★	•	•	•	•
External shading	★★★		•		•
Thermal mass	★★	•	•		
Compact form	★	•			
Air- and moisture-tight envelope	★★	•			

These features were added to the parametric model one at a time to clearly illustrate the compounding benefit of each. Refer to modeling results in Appendix E.

3.6 Applying the Strategies: Commercial

Commercial buildings have different characteristics from residential buildings, such as greater internal heat gains from equipment and lighting, higher ventilation requirements, and different occupancy trends. Commercial buildings benefit from passive cooling, but in the Vancouver climate, design must strike a balance between heating and cooling performance.

Specific passive approaches that will improve the overall energy performance of commercial buildings in Vancouver include:

- Carefully detailed and constructed high-performance insulation in the envelope with minimal thermal bridging, including exterior walls and roofs.
- Solar gain control using either high-performance windows with low shading coefficient (tinted or reflective) or clear high-performance windows with a low-e coating in combination with operable external shading to block solar gains during summer and shoulder seasons and admit solar gains during winter.
- Window to wall area ratio limited to <50%.
- Double facades with operable shading elements and operable windows to act as thermal buffer spaces, preheat ventilation air in the winter, and block solar gains and provide natural ventilation in the summer.
- Building shape and massing that enhances natural ventilation and daylighting, ideally with central atria and ventilation towers.
- Thermal mass on the interior side of the insulation, located in the floors, external walls, and walls between adjoining units (i.e., party walls).
- Passive cooling strategies, such as nocturnal ventilation to pre-cool spaces during summer and ventilation air intakes located in cool areas and delivered to the building using earth tubes.
- Air- and moisture-tight envelope.

The following table displays the elements that positively contribute to the various passive design strategies for commercial buildings.

	Relative Impact (★)	Passive Heating	Passive Cooling	Passive Ventilation	Daylighting
High-performance insulation	★★	•	•		
High-performance windows	★★★	•	•		•
Window to wall area ratio <50%	★★★	•	•		•
Double facades	★★	•	•	•	•
External shading	★★★		•		•
Narrow forms	★		•	•	•
Thermal mass	★	•	•	•	
Nocturnal ventilation	★★		•	•	
Pre-cooled ventilation air	★★		•	•	
Air- and moisture-tight envelope	★★	•			

These features were added to the parametric model one at a time to clearly illustrate the compounding benefit of each. Refer to modeling results in Appendix E.

3.7 Modeling Summary

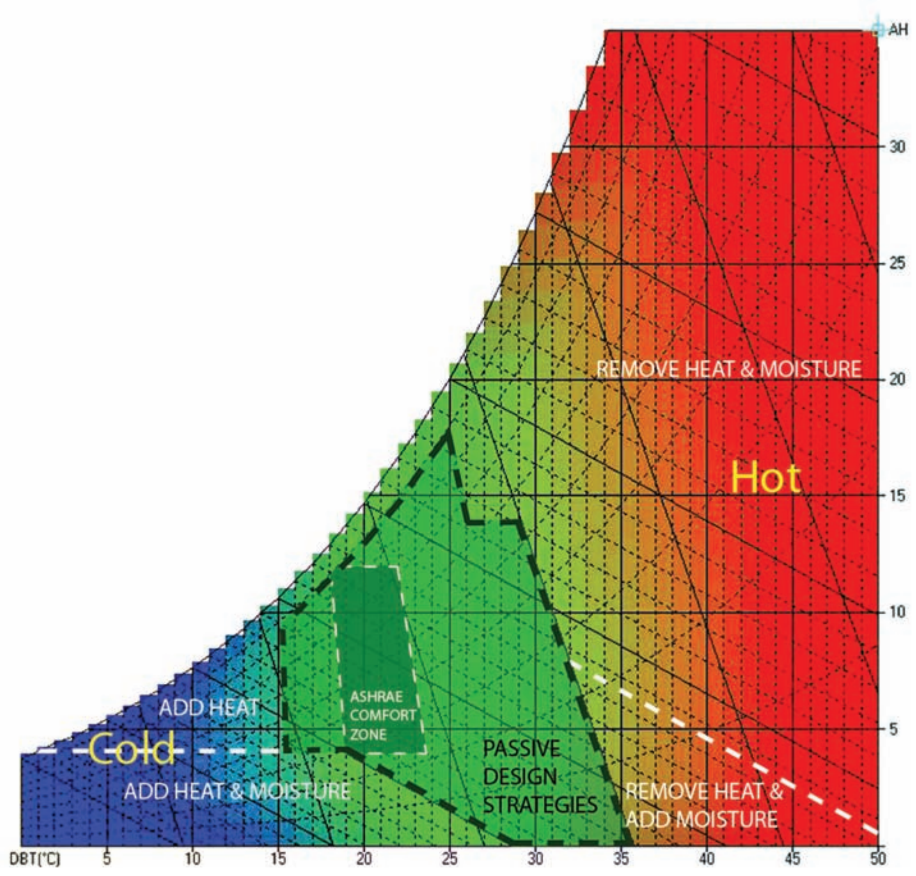
Our modeling results indicate that incorporating passive elements and strategies effectively expands the range of outdoor conditions under which buildings can remain comfortable without active systems.

The figure below shows this effect of passive design strategies relative to the ASHRAE Comfort Zone. When outdoor conditions fall within the extended passive zone, a building that incorporates all of these passive strategies will be comfortable without mechanical heating or cooling; when conditions fall outside of the zone, the building must rely on active systems to maintain thermal comfort.

In conclusion, passive design enables buildings to maintain occupant comfort throughout more of the year using less energy.

For the quantitative impact of individual passive elements and strategies, refer to Appendix E.

Figure 7: ASHRAE Comfort Zone and Achievable Extended Comfort Range by Passive Design Strategies in Vancouver Climate




Liu Institute for Global Issues Photo: Stantec/Arthur Erickson

4 Passive Design Elements

O^2 in Vancouver Photo: Merrick Architecture

The primary objective of passive design strategies is to reduce or even eliminate the need for active mechanical systems while maintaining or even improving occupant comfort. The passive design strategies discussed in Section 3 integrate the complementary passive design elements that follow to minimize heating and cooling loads. Performance of each individual passive element is discussed here in Section 4. They are presented in the general order a designer would encounter them throughout a design.

- Site and Orientation
- Building Shape and Massing
- Landscape Considerations
- Space Planning
- Buffer Spaces
- Windows
- Solar Shading
- Thermal Mass
- Thermal Insulation
- Air and Moisture Tightness

4.1 Site and Orientation

4.1.1 Overview

Many site considerations can affect the passive design approach, including urban design opportunities and constraints, building orientation on the site, shade from other buildings, wind patterns, proximity to industry, noise, and urban character. These all need to be considered to optimize the integration of passive design strategies and some may pose design conflicts. On the other hand, the integration of site considerations such as landscaping, wind and microclimate can influence the local architectural expression of a building.

Building facade orientation is one of the key elements for many passive design strategies. Facade orientation affects the energy and comfort implications of solar shading, window to wall area ratio, window position and performance, and choice of exterior colour.

A building's orientation determines the amount of solar radiation it receives. The roof surface receives the greatest intensity, but it is normally opaque and well-insulated. Building facades, which can have a significant window to wall area ratio, also receive sun in various amounts. The south facade will capture desirable solar gains during winter when the sun angle is low, making it ideal for passive solar heating during winter. On the other hand, window should be carefully placed on the east and west facades since they receive the second highest radiation intensities. Excessive solar heat gains on the west side can be particularly problematic as maximum solar intensity coincides with the hottest part of the day.

The primary objective of passive design strategies is to reduce or even eliminate the need for active mechanical systems while maintaining or even improving occupant comfort.

Figure 8: Vancouver's Two Distinct Grid Orientations

Figure 9: Seasonal Sun Paths

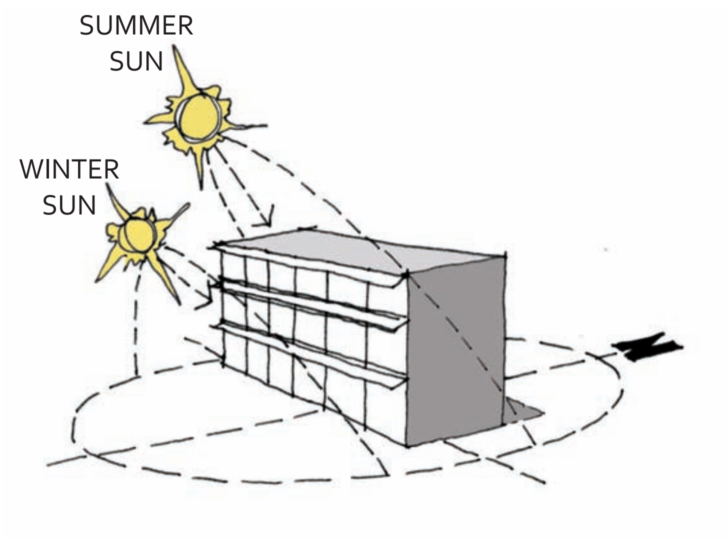
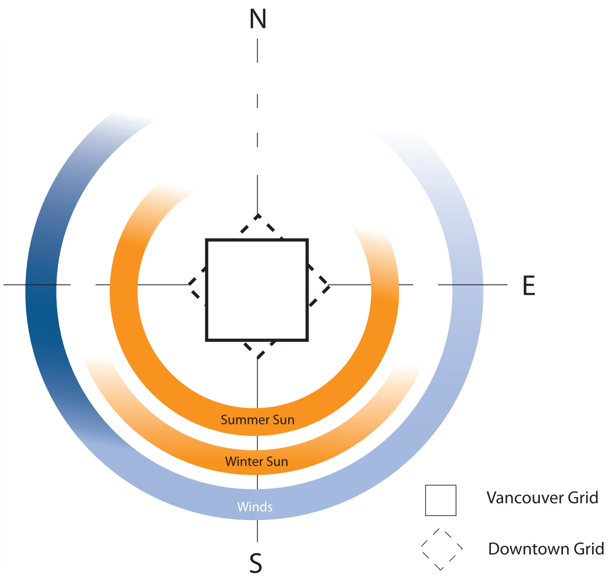


Figure 10: Facade Considerations



4.1.2 Benefits

- Can greatly improve heating and cooling performance when optimized.
- Can greatly improve daylighting when optimized.

4.1.3 Limitations

- Designing to optimal orientation is not always possible, and can be limited by roads, existing development, urban design context, lot size, and lot orientation.

- Heritage conditions and related design guidelines may create opportunities for unique responses in the delivery of a passive design solution.

4.1.4 Synergies

Since many passive design strategies are affected by orientation, responding to the different conditions of each facade is the most fundamental design decision a project team can make to passively design a building. For example, orientation and daylighting are very much linked. Optimum orientation will provide adequate daylight without glare or excessive solar gain.

4.1.5 Vancouver Applications

Orientation that allows winter solar gains is desirable; therefore south-facing orientation is appropriate provided that it is well-shaded during summer.

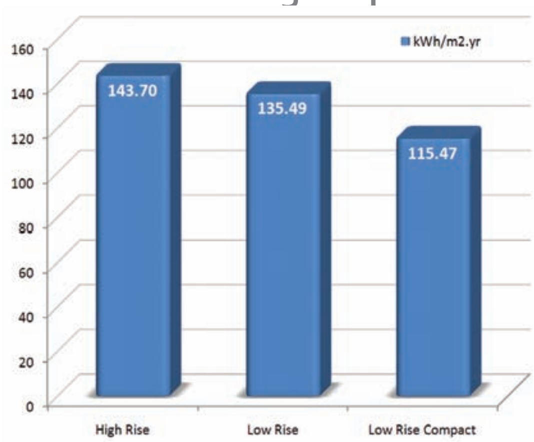
Orientation will often not be optimum in the downtown grid. However, responding to the various facade conditions will significantly increase thermal comfort and decrease active mechanical system requirements.

4.2 Building Shape and Massing

4.2.1 Overview

Building shape and massing[8] have great potential to reduce building energy intensity, but they often fall under the influence of a complex array of factors (planning considerations, building type and use, feasibility and initial cost). Certain common building shapes greatly increase envelope area to volume ratio (e.g., thin high-rise towers), which can decrease building energy performance in heating dominant buildings. With a similar square footage, buildings with a smaller exterior envelope area will achieve better energy-efficient performance. A compact building shape significantly reduces the building's energy intensity and reduces the need for active mechanical systems as demonstrated in the modeling results shown below in Figure 11.

Figure 11: Energy Intensity and Building Shape



CASE STUDY

Turn to page 103 to learn how the Pacific Institute for Sports Excellence's unique building shape provides solar shading.

Building shape and massing have great potential to reduce building energy intensity.

8 "Massing" is used in this section to describe the overall geometry of the building. It is not to be confused with "thermal mass" (see Section 4.8).

Massing optimization can significantly improve passive performance, often without increasing the capital cost.

As one of the first design considerations, the massing of a proposed building must account for orientation and other site-specific conditions. Section 4.1 discusses orientation and its critical effects on massing and other passive design elements.

4.2.2 Benefits

- Reduced heating and cooling energy consumption.
- Reduced peak heating and cooling loads.

4.2.3 Limitations

- Must be carefully considered so as to not compromise the livability of the interior spaces provided (e.g. compromised daylighting; see Synergies).
- Must consider potential urban design conflicts related to street conditions, view corridors and other urban planning considerations.

4.2.4 Synergies

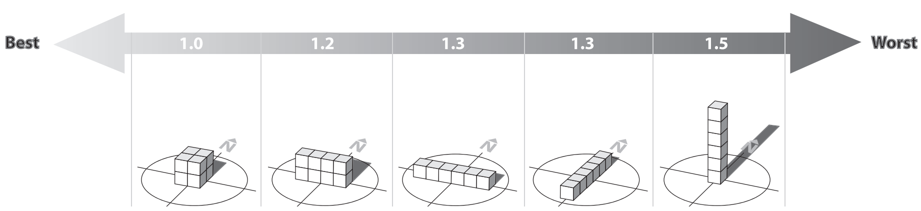
Building massing functions in close relationship with other basic architectural passive design parameters such as orientation, envelope performance (including window location) and solar shading.

Massing must also be considered alongside daylighting needs and natural ventilation, which tend to improve in buildings with narrower profiles, courtyards and other features that increase envelope area.

4.2.5 Vancouver Applications

- Heating-dominant residential buildings should be as compact as possible to improve their energy performance.
- Cooling-dominant commercial buildings should favour a longer shape along an east-west axis with more potential for passive cooling strategies.
- Buildings with compact form can be designed with features such as light wells and atria to facilitate natural ventilation and daylighting.

Figure 12: The Effect of Envelope to Volume Ratio on Energy Efficiency



4.3 Landscape Considerations

4.3.1 Overview

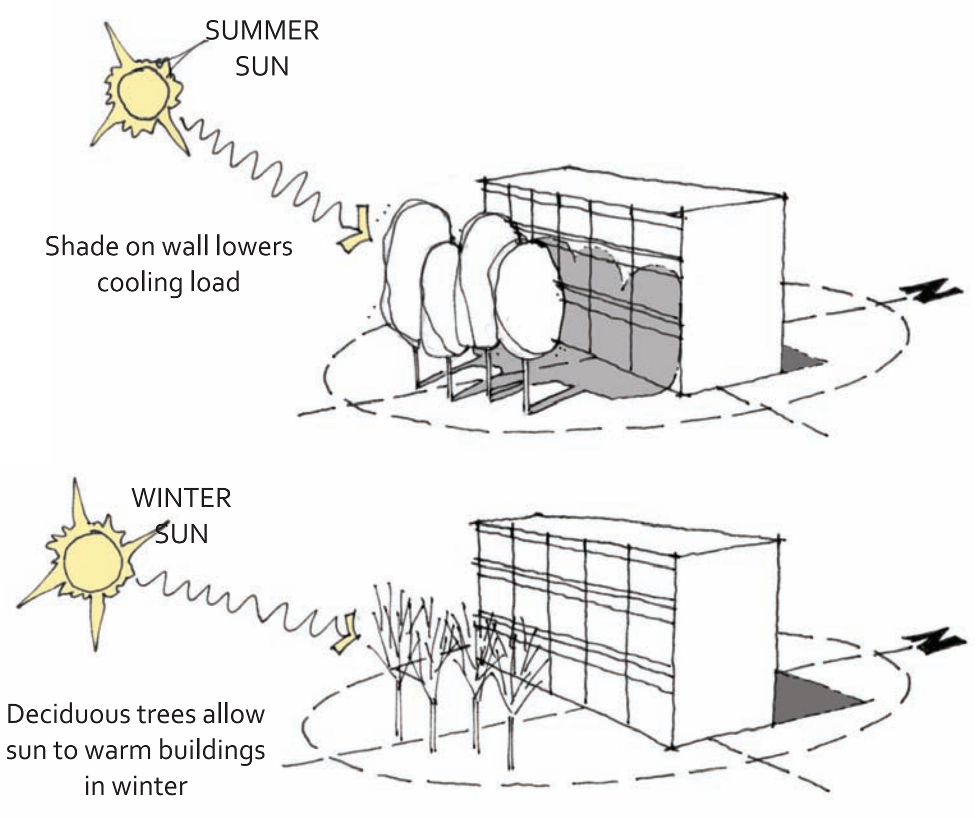
Many landscape considerations happen very early on in the design process. Set backs, street trees, street alignment and use of landscape buffer zones can be guiding elements of many site planning decisions. Therefore, careful consideration of landscaping is critical to successfully implementing the passive approach at the early stages of design. The integration of landscape strategies requires an active IDP where energy and thermal comfort goals are discussed and understood within the design team. Vegetation can help in many ways:

- Reducing ambient temperature and limiting the heat island effect around buildings, thus reducing the cooling load.
- Protecting the building from sun, wind and precipitation.
- Reducing solar intensity by introducing vegetated 'green' roofs and walls.

CASE STUDY

Turn to page 108 to learn how the new Butchart Gardens Carousel building will take advantage of its surrounding landscape.

Figure 13: Landscape Strategies for Passive Solar Heating and Daylighting Control



Deciduous trees provide cooling shade in the summer and after shedding their leaves allow for warm sun to enter the building in the winter.

Figure 14: Reducing Solar Intensity with a Green Wall (Aqua-quest at Vancouver Aquarium)

4.3.2 Benefits

- Deciduous planting provides desirable shading during summer and allows desirable solar gains during winter while adding aesthetic appeal.
- See Synergies.

4.3.3 Limitations

- Landscaping strategies are often limited by the available space.
- Many landscaping strategies require maintenance and irrigation.
- Incorporating landscaping strategies in higher buildings can be challenging due to maintenance and increasing challenges such as weight, wind pressure and irrigation.

4.3.4 Synergies

- Landscaping strategies can assist mechanical ventilation systems by contributing to ventilation air pre-cooling.
- Landscaping strategies can contribute to daylighting controls by reducing glare.
- Landscaping strategies can facilitate passive heating by allowing solar heat gain during winter and providing shade during summer.

4.3.5 Vancouver Applications

- Vancouver's mild, seasonal climate is very conducive to deciduous trees whose leaves provide desirable shading during summer and fall to allow desirable solar gains during winter.

4.4 Space Planning

4.4.1 Overview

Matching the program requirements with orientation and massing (building geometry) can further decrease energy use and increase thermal comfort. Building functions with particular thermal requirements should be placed in areas of the building that can provide those conditions (or come closest) without mechanical intervention. For example, computer labs or other rooms that have large internal heat gains and thus require mostly cooling should be placed on north or east-facing facades to minimize energy use from mechanical cooling.

By accounting for the thermal comfort requirements of a particular space use and matching them to suitable building characteristics, the design team can use passive design strategies to reduce building energy demand and maintain occupant comfort.

4.4.2 Benefits

- Locating spaces in their ideal thermal location in the building reduces mechanical heating and cooling energy by taking advantage of the building's natural thermal responses.
- Strategic space planning can reduce glare and improve comfort.

4.4.3 Limitations

- In many cases, such as residential units facing only one direction, it may be difficult to program the building to avoid having uses that will be negatively affected by solar gain.

4.4.4 Synergies

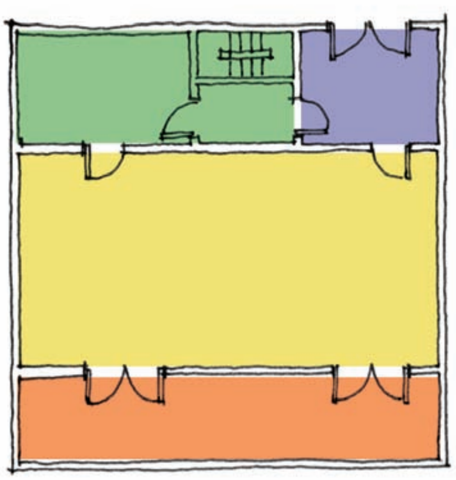
- Space planning considerations are directly linked to orientation and massing and the ability of the design team to provide, when possible, appropriate thermal conditions within the buildings.

CASE STUDY

Turn to page 105 to learn how careful space planning helps Surrey's Revenue Canada building.

Locating spaces in their ideal thermal location in the building reduces mechanical heating and cooling energy.

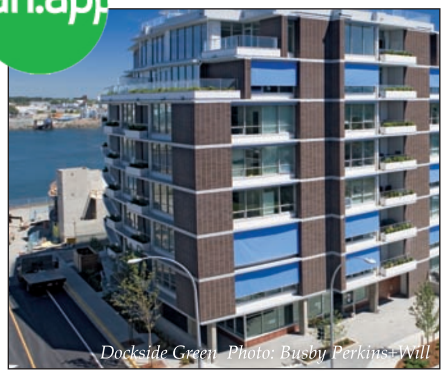
Figure 15: Example of Strategic Space Planning



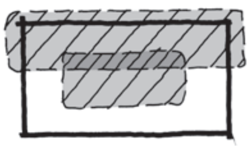
- North Facing Service/Transition Zone
- North Facing Buffer Zone Entry/Vestibule
- Primary Occupied Zone
- South Facing Buffer Zone Passive Solar Heating

- When possible, incorporating buffer spaces to increase thermal conditions of the program areas should influence space planning decisions.

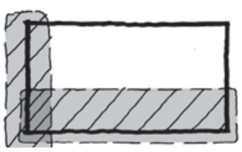
4.4.5 Vancouver Applications


Dockside Green Photo: Busby Perkins+Will

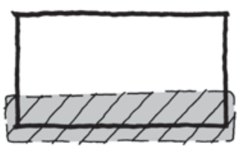
In the Vancouver climate, space planning should target the following conditions:



- Locate cooling dominant spaces on the north or in the centre of the building away from any perimeter solar gain.



- Locate heating dominant spaces on the south or west, avoiding over-exposure to west solar radiation.



- Locate residential spaces on the south exposure whenever possible.

4.5 Buffer Spaces

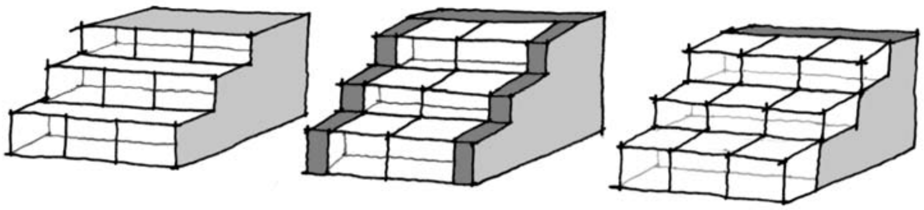
4.5.1 Overview

Buffer spaces such as double facades and sunspaces are located along the building perimeter and can be occupied or unoccupied, as well as semi-conditioned or unconditioned. They improve building energy performance by widening the range of outdoor temperatures in which thermal comfort can be maintained in the building with low mechanical energy consumption. Especially helpful during winter, buffer spaces create another insulation layer in front of the envelope, slowing the rate of heat loss between the outdoors and the indoor conditioned space. Ideally, they should be convertible to fully exterior space during summer to aid in ventilation and cooling of the adjoining occupied space.

Buffer spaces are a key component of many passive solar designs when they are oriented on the sunny side of the building.

South- and west-facing buffer spaces can be designed to act as occupied sunspaces, providing both passive solar heat gain and a functional occupied space. Sunspaces function like passive solar collectors, trapping solar gains like a greenhouse. Thermal storage is most effectively provided in the thermal mass of the floor and/ or walls of the sunspace structure itself. Stored heat can either reach the building passively through the walls between the sunspace and the interior, or be distributed by an active mechanical system. The design and construction of sunspaces varies widely. In general, they can have open or closed ends, single or multiple slopes, and various arrangements of storage mass in the floor and walls.

Figure 16: Examples of Possible Sunspace Configurations



In passive heating applications, sunspaces must be designed so the solar gains are greater than the heat losses through the windows.

Integrating occupied buffer spaces as transition spaces is ideal because a wider thermal comfort range is acceptable in spaces like corridors and entryways, as opposed to other, more tightly conditioned spaces such as residential, classroom or office areas. Entryway vestibules, a mandatory requirement for many buildings under the Vancouver Building Bylaw, are also maintained at wider thermal comfort ranges, which also help to reduce the mechanical system energy consumption by limiting the loss of heated air during winter and cooled air during summer. They also improve comfort in the adjacent space by reducing or even eliminating drafts.

Unoccupied buffer spaces, such as double facades or Trombe walls, are cavities between an exterior window layer and a secondary wall or window layer, typically with controllable openings between the outdoors and the interior spaces. The openings are adjustable to either ventilate the cavity, or to transfer air between the indoors and outdoors. Double facades can also be designed to induce stack effect and passively ventilate the occupied space. During winter the cavity can preheat ventilation air. During summer, the cavity openings can be adjusted to draw exhaust air out of the building. In the shoulder seasons, a double facade can increase the amount of time that natural ventilation can satisfy occupant comfort requirements.

4.5.2 Benefits

- Energy savings with reduced heat losses, infiltration at entries, and/or preheated ventilation air.
- Improved thermal comfort due to more stable interior space surface temperatures, reduced draft, and increased application of natural ventilation.
- Protects interior wall surface from the elements.
- Reduces building heating energy requirements via passive heating.

4.5.3 Limitations

- Buffer spaces increase the area of the building, but the space is not always usable for occupants.

- Buffer spaces may increase capital costs.

4.5.4 Synergies

Many synergies are possible with buffer spaces such as double ventilated facades. Buffer spaces in south facing double ventilated facades can be used to aid natural ventilation for example. Other passive building strategies can also work well with these types of facades such as night cooling and solar shading.

4.5.5 Vancouver Applications

Vancouver's temperate climate makes buffer spaces an excellent design option, because they could potentially eliminate the need for mechanical cooling and dramatically reduce the amount of time the mechanical heating system operates. In addition, they can serve as seasonally convertible habitable spaces. Buffer spaces can also provide additional rain screen protection for the building envelope resulting in longer life and fewer moisture problems for the external wall assembly.

Buffer spaces create another insulation layer in front of the envelope.

Figure 17: Example of Double Facade as Buffer Space (Summer Performance)

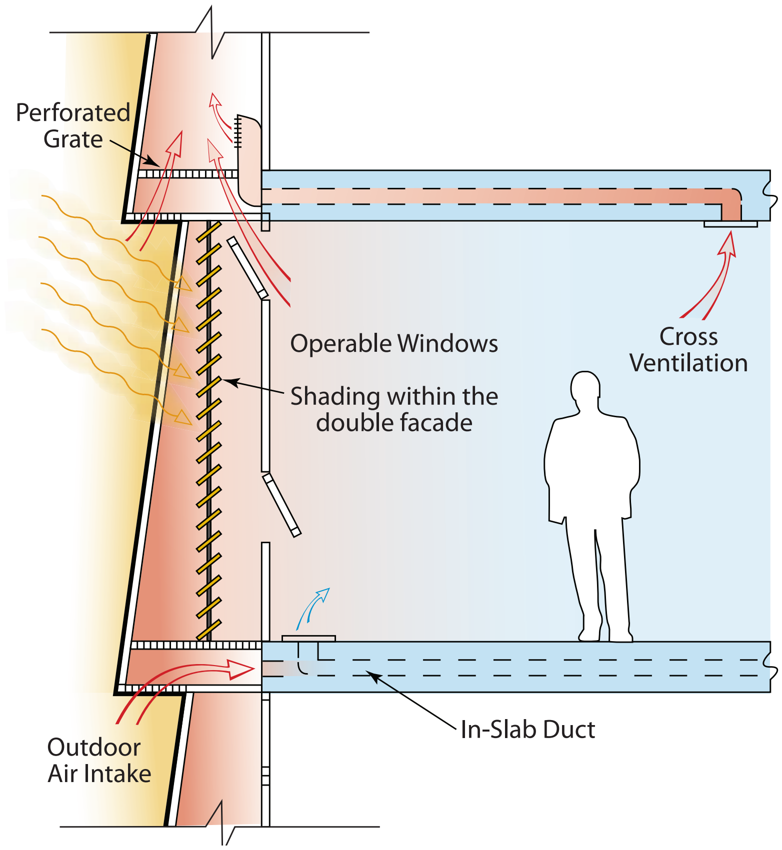
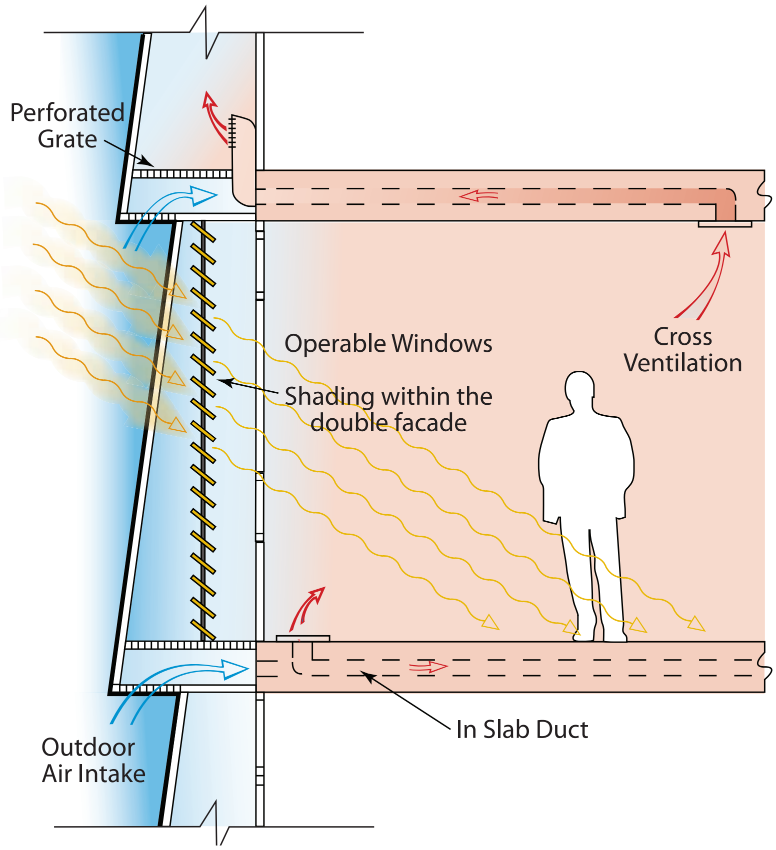


Figure 18: Example of Double Facade as Buffer Space (Winter Performance)



Window assemblies are the weakest thermal links in a building's insulated envelope.

4.6 Windows

4.6.1 Overview

Windows (glazing) are necessary envelope elements in any building as they provide access to views and daylight and can be used for natural ventilation. However, window assemblies are the weakest thermal links in a building's insulated envelope, and the window design approach has a significant impact on occupant thermal comfort and building energy consumption.

In general, windows affect a building's thermal state by transmitting solar radiation directly into the conditioned space, where it stays trapped inside and heats the interior surfaces (i.e., the greenhouse effect). This heat gain is beneficial during winter and undesirable during summer when it can overheat the space.

With respect to windows, the design requirements of heating, cooling, aesthetics and daylighting often conflict; an energy efficient design uses window materials, sizes and framing design that balance aesthetics and overall energy performance. Annual building simulations can help to identify

CASE STUDY

Turn to page 106 to learn how the White Rock Operations Centre uses different window to wall area ratios on different facades.

this optimal combination; however they cannot replace a proper understanding of how window characteristics affect the building.

Window design characteristics fall into two categories: thermal and optical.

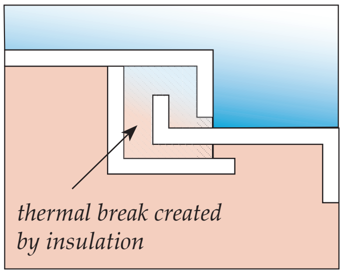
The thermal characteristics are the insulation or U-value, the framing type, overall area of windows, and the amount of framing.

- The number of panes of glass and the gas or vacuum void between them defines the amount of insulation provided by the windows, referred to as U-value. The U-value affects the amount of heat that is transferred between the interior and exterior, as well as the window interior surface temperature. Glass that insulates better traps more heat in the building and keeps a higher internal surface temperature, which is beneficial during winter and undesirable during summer.

- The overall window to wall area ratio is the window characteristic with the most significant impact on building energy consumption. Even the best performing glass insulates poorly when compared to an insulated wall. On east, south, and west exposures, greater window areas will admit more solar gain during winter. However, in the Vancouver climate, the net annual effect of any window to wall area ratio greater than 10% is still a thermal energy loss, even with the higher level of solar gains (see simulation results in Appendix E).

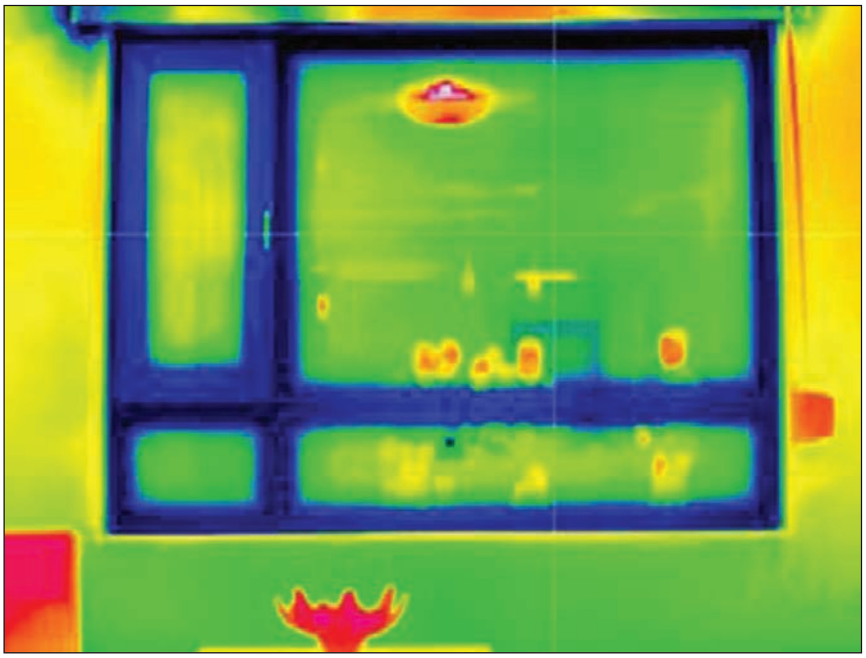
- Frames hold the glass panes and link them with the wall. They are usually made of highly conductive metal, creating thermal bridges between the interior conditioned space and the outdoors, further speeding heat loss through the window assembly. Frames can be made of less conductive materials, such as wood and vinyl. "Thermally broken" frames have an insulating spacer to slow the rate of heat transfer through the frame. However, even with a thermal break, frame material and design always limits the thermal performance of the overall window assembly. The minimum amount of framing structurally required is directly proportional to the area of windows; in addition to the minimal structural requirements, framing design is also guided by the envelope aesthetic, sometimes resulting in more framing than is necessary. The effects of thermal bridging should be minimized by reducing the amount of framing wherever possible. The thermal photo in Figure 20 demonstrates the effect of thermal bridging in window framing.

Figure 19: Thermal Break



"Thermally broken" frames have an insulating spacer to slow the rate of heat transfer through the frame.

Figure 20: Thermal Image Showing Thermal Bridging in Window Framing



The optical characteristics of windows are defined by the glass material and the location of surface treatments such as coatings, tinting or colours. The overall optical performance of windows is typically described by the shading coefficient or solar heat gain coefficient, representing the amount of light and heat the window transmits, absorbs, and reflects. (A window with a low shading coefficient value blocks a high amount of solar radiation.) As these are fixed characteristics that can not be modified with the seasons, they have to strike a balance between the desirable shading during summer and the benefits of solar gains during winter.

The size, location, type and detailing of windows affects the thermal comfort and supplemental heating and cooling energy consumed by the building. Therefore, window design must consider and balance the desire for floor to ceiling glass and the ongoing energy consumption that will be created by such window area and material characteristics.

Benefits

- Good insulation values reduce heating energy consumption.
- Optimized shading properties reduce cooling loads in commercial building.
- Optimized insulation values and framing design reduce heat losses and condensation in residential and high-humidity applications (i.e. food preparation).

- Optimized window to wall area ratios result in greater levels of thermal comfort from smaller cold/hot surface areas.

- Optimized window to wall area ratios can reduce both heating and cooling energy demands.

- Smaller window areas make better quality windows more feasible economically.

Limitations

- Higher capital cost of high performance glass.

- Window to wall area ratios of greater than 50% (including floor-to-ceiling glass) will greatly challenge the energy efficiency of a building. Buffer spaces should be explored in this design scenario.

Synergies

- High performance windows should be combined with natural ventilation strategies to relieve heat gains.

- Window to wall area ratio impacts decisions on shading, window performance, thermal insulation, thermal mass, orientation and programming.

Vancouver Applications

For residential buildings the most effective combination involves a double-pane window assembly with a low-e coating for good winter performance in combination with external shading elements (rather than windows with a low shading coefficient) for good summer performance.

Commercial buildings with high internal heat gains will benefit from double pane windows with a low shading coefficient and a low-e coating.

From a building energy perspective, windows should be located to admit solar radiation during winter to aid the mechanical heating system and be designed to limit the amount of heat lost due to the poor insulating value of glass.

4.7 Solar Shading

4.7.1 Overview

Solar shading elements can be applied to the exterior or interior side of the windows.

External solar shading is the use of overhangs, blinds, louvers, trellises, or anything else that blocks the sun's rays from heating the building envelope and entering the building through windows.

Internal solar shading features, typically internal blinds, are any material that blocks the sun's rays at the perimeter but inside the building.

The distinction between internal and external shading is important because, although both systems block solar radiation, they have

CASE STUDY

Turn to page 107 to learn how the Dockside Green development uses exterior solar shading.

different effects on the building aesthetic, day lighting, comfort, and building energy system requirements.

External shading devices intercept, absorb and/or reflect solar radiation before it reaches the exterior surface of the building envelope. When used in front of opaque envelope assemblies, external shading results in lower external surface temperatures and less heat gain through the envelope. When used on transparent envelope assemblies (i.e., windows), shading reduces the amount of direct solar gain in the space, reduces both the external and internal surface temperatures of affected windows, floors and walls, and reduces glare in the space.

Internal shading also blocks solar radiation from penetrating into the conditioned space; however the solar energy is still transmitted through the window assembly. Once inside, it heats the internal surface of the glass and the blinds. These warm surfaces will heat the interior space and occupants through radiant and convective heat transfer (i.e., greenhouse effect). If mechanical cooling is used, this heat gain needs to be removed by the system.

Effective shading design requires a balance between admitting desirable solar gains during winter and blocking undesirable solar gains during summer. The optimal shading strategy would be adjustable for different times of the year. Fixed features such as horizontal overhangs are designed to admit low-angle winter sun and block high angle summer sun.

Figure 21: Effects of Internal and External Shading

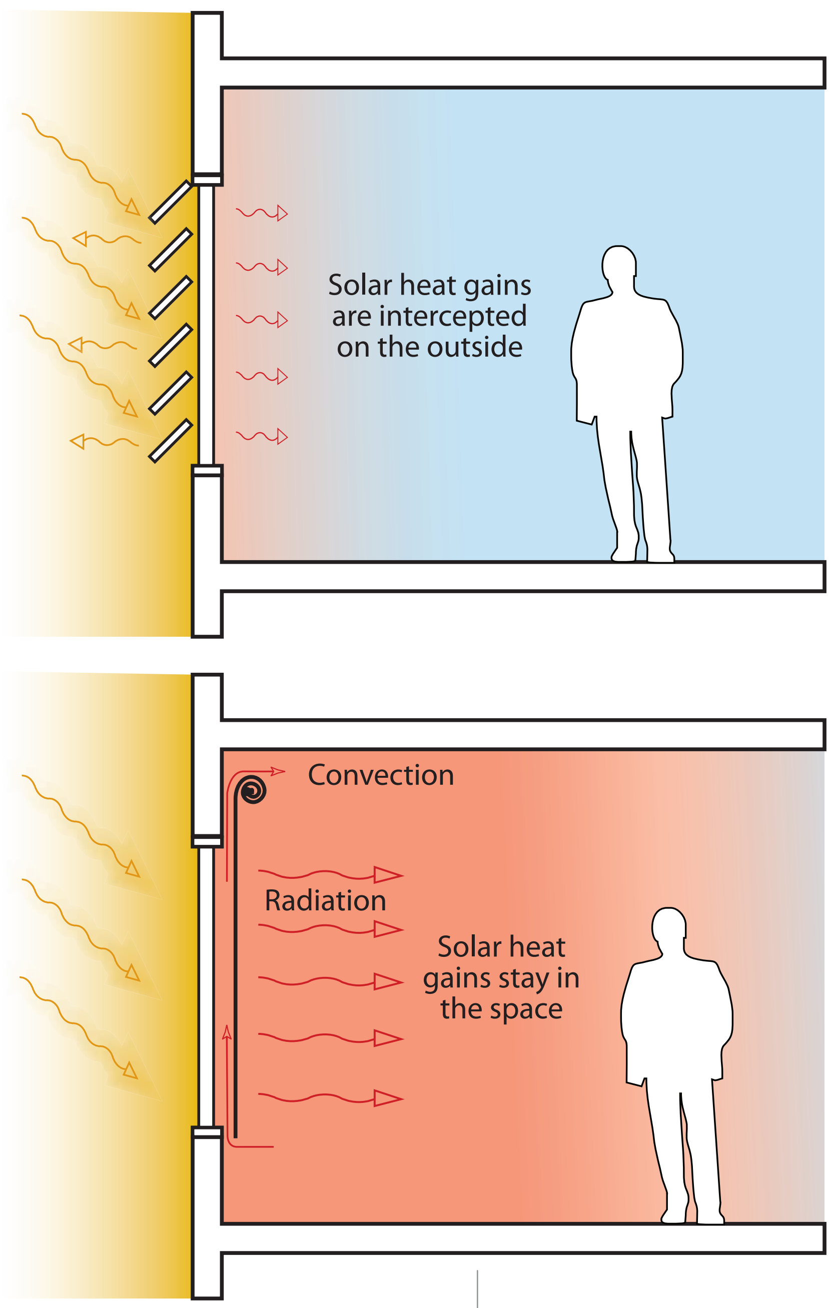
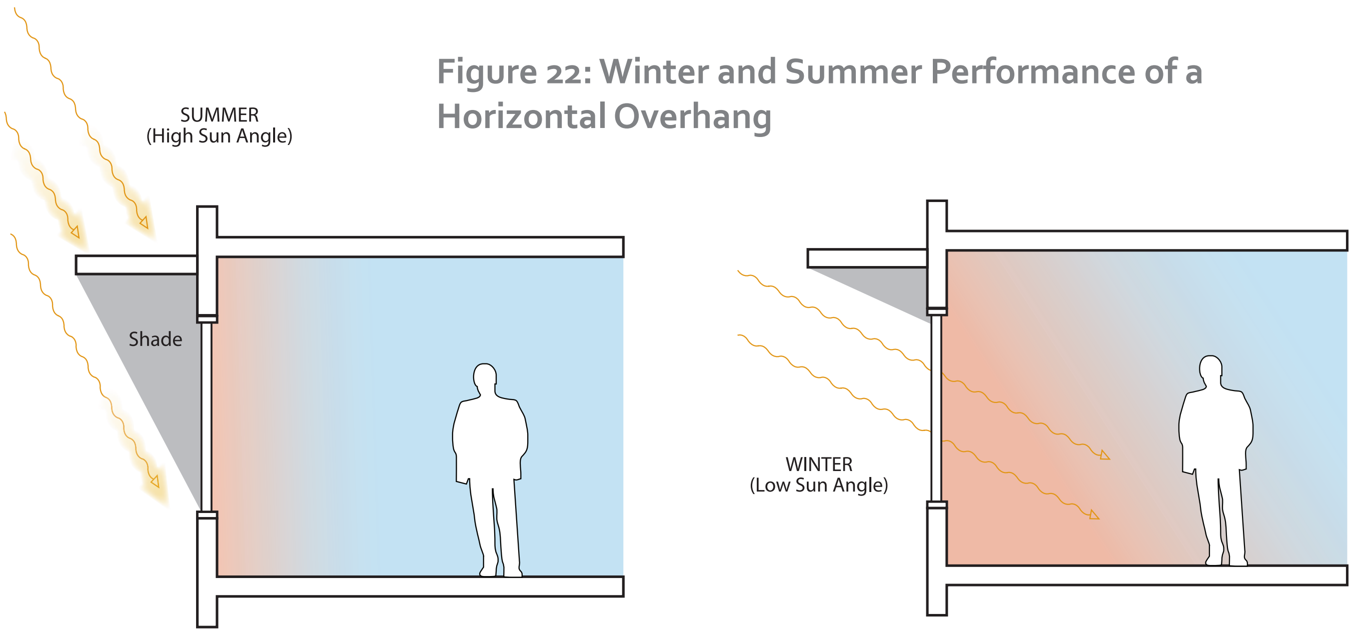


Figure 22: Winter and Summer Performance of a Horizontal Overhang



4.7.2 Benefits

- Reduced demands on, and potentially eliminates the need for, active cooling systems.
- Reduced glare and improves thermal comfort by blocking direct solar gains.

4.7.3 Limitations

- The benefit of blocking direct solar gains in summer must be balanced with the desired benefit of solar heat gains in winter.
- Designers must consider practical issues such as window washing.

4.7.4 Synergies

- Building Orientation
- Daylighting

4.7.5 Vancouver Applications

van:app

- Shading elements should be designed according to their particular facade orientation and keeping in mind seasonal temperature variations and the changing angle of the sun.
- When designing fixed shading devices, it is important to consider how they will provide the appropriate performance to meet both winter heating and summer shading/cooling requirements.

4.8 Thermal Mass

4.8.1 Overview

All matter has thermal mass, however when used in reference to a building, thermal mass generally means materials capable of absorbing, holding, and gradually releasing heat (thermal energy). Thermally massive materials absorb

CASE STUDY

Turn to page 104 to learn how UBC's Liu Institute for Global Issues takes advantage of thermal mass.

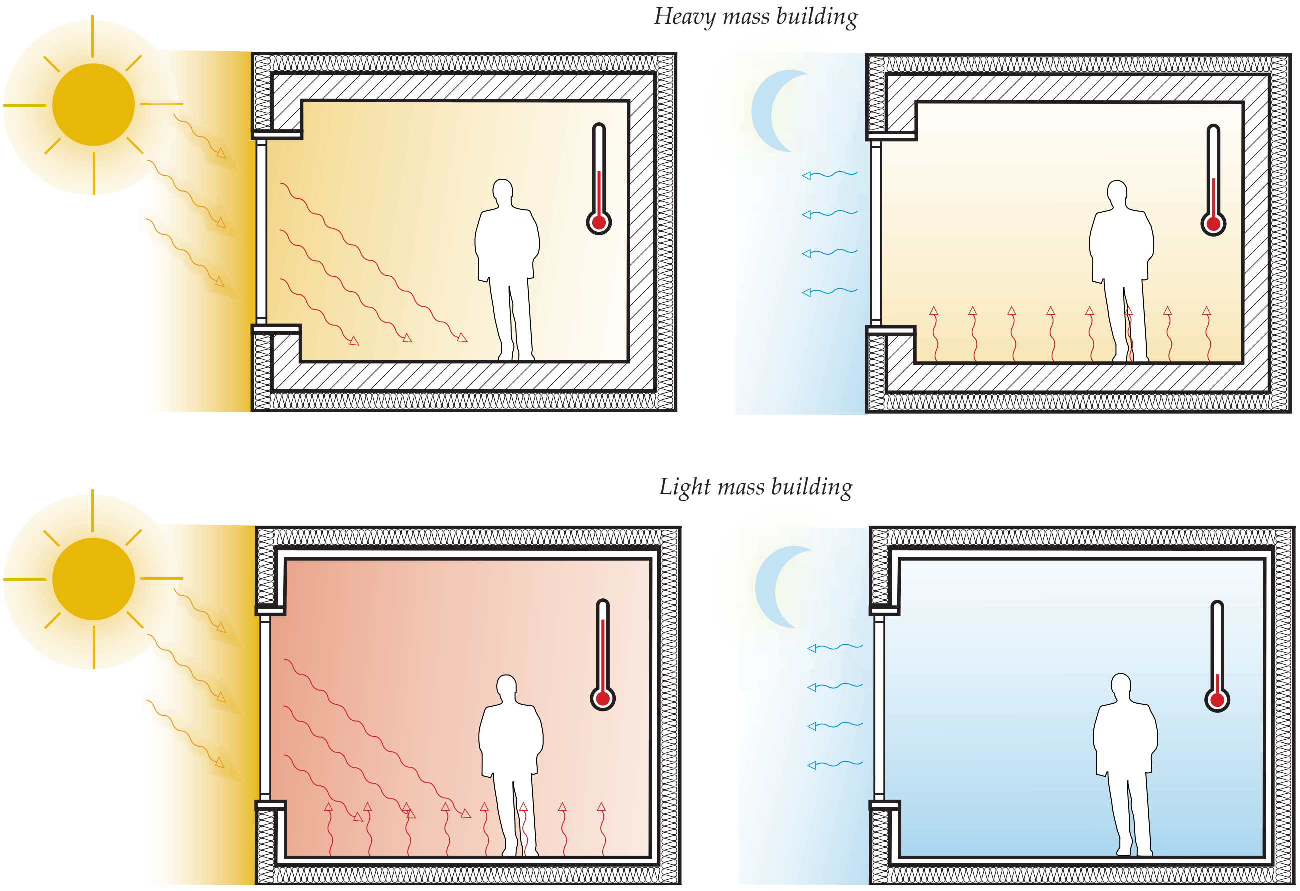
heat and slowly release it when there is a temperature difference between the mass and the surrounding space. When incorporated in a wall, for example, the mass acts as a heat sink, absorbing the heat and slowing its transfer through the wall.

Heavy, dense building materials with high specific heat like stone, concrete, brick, or adobe have high thermal mass. Lightweight, porous materials such as wood, insulation, and glass have low thermal mass.

During summer, thermal mass exposed to the interior absorbs heat from the space, including solar gains, and lowers the load on the mechanical cooling system. A thermally massive floor in a day-occupied building, for example, can be cooled overnight with cooler outdoor air. In the morning the cool mass will absorb solar and other heat gains from the space, providing the sensation of coolness from the floor. This has been shown to delay the onset of daily mechanical cooling and in some cases reduce or even eliminate the peak cooling demand. This delay is referred to as "thermal lag."

Thermally massive materials absorb heat and slowly release it when there is a temperature difference between the mass and the surrounding space.

Figure 23: Effects of Thermal Mass



Thermal mass can have a negative impact on energy performance in some cases, where there is no opportunity to release heat into ambient air (in climates with no diurnal swing) or there is no opportunity for solar gains to be absorbed and stored (in climates with cold temperatures and low solar incidence).

4.8.2 Benefits

- Reduced annual energy use.
- Reduced peak demand.
- Maintains a more stable internal environment.
- Increased acoustic insulation of assemblies.
- Improved fire ratings of assemblies.

4.8.3 Limitations

- Without adequate direct solar radiation (i.e., on north-facing facades), thermal mass can result in increased energy consumption from the mechanical system when compared with lightweight construction.

4.8.4 Synergies

- Passive solar heating.
- Passive ventilation.
- Passive cooling and shading.

4.8.5 Vancouver Applications

- Thermal mass construction, when applied to the interior side of the insulation and exposed to the occupants and solar gains, will reduce heating energy requirements in the Vancouver climate.
- Thermal mass construction, when exposed to natural ventilation air flows and the occupants, will reduce cooling energy requirements in the Vancouver climate.
- Thermal mass can allow for natural, controlled moisture absorption and release in the Vancouver climate.

4.9 Thermal Insulation

4.9.1 Overview

Thermally insulating materials are poor thermal conductors that slow the rate of heat losses and gains to and from the outside. Effective thermal insulation is one of the most critical design parameters of building envelope.

This reduction of heat transfer is commonly expressed in terms of R-Value (and the metric equivalent, RSI-Value) and U-Value. Minimum R-Values and maximum U-values for key building envelope components are prescribed by current ASHRAE 90.1 building energy standards.

Thermal insulation also impacts the surface temperature on the

R-Value / U-Value

R-Value and the metric equivalent RSI-Value:
Thermal resistance

How well the material slows down the transfer of thermal energy.

U-Value:
Heat transfer rate

The intensity of heat transfer through the material.

R ≈ 1/U

envelope interior, which directly impacts thermal comfort. Interior envelope surface temperatures must remain high enough during winter to avoid condensation and maintain occupant comfort. Cold surface temperatures (i.e., windows) affect occupant comfort by both radiation and convection.

To achieve consistent thermal insulation of the building envelope, assemblies must be carefully detailed with continuous thermal breaks. Thermal breaks use non-conductive materials to separate conductive materials to avoid degrading the envelope's thermal insulation, a common problem called thermal bridging.

4.9.2 Benefits

- Reduces heating and cooling losses/gains and energy consumption.
- More stable interior surface temperatures increases thermal stability in the conditioned spaces.

4.9.3 Limitations

- Rate of diminishing returns, best investigated with building simulations.

4.9.4 Synergies

- Infiltration and air tightness.
- Window performance.

4.9.5 Vancouver Applications

van:app

- Thermal insulation must be better than the current standard (ASHRAE 90.1 v.2007) in order to maintain comfort with window to wall area ratios optimized for heating and cooling.
- Minimize thermal bridging to ensure the targeted overall R-values (RSI-Values) and U-values of envelope assemblies are achieved.

4.10 Air and Moisture Tightness

4.10.1 Overview

The air and moisture tightness of a building's envelope is a critical factor in its thermal performance and durability. It is also indirectly related to the building's ventilation system.

Undesirable air movement through the envelope can occur in either direction: infiltration is movement of exterior air into the building, and exfiltration is leakage of interior air to the exterior. Infiltration and exfiltration can occur at the same time through different unintentional paths such as cracks around windows and doors or improperly sealed construction joints. They are caused by air pressure and temperature differences across the building envelope due to differences in air density between warm and cold air. Greater differences in pressure and temperature cause greater rates of infiltration and exfiltration.

Indoor air and outdoor air are not only different temperatures most of the time, but they also contain different amounts of moisture in the form of water vapour, which diffuses with the air. In the Vancouver climate this diffusion is predominantly from the warmer, more humid interior side (due to internal moisture gains) toward the cooler, less humid exterior side. If moisture is allowed to diffuse through the envelope, it will eventually reach the colder portion of the envelope assembly, where it will condense as the envelope temperature drops below the dew-point temperature (see Appendix C.2).

An incorrectly detailed building envelope with undesirable air and moisture diffusion typically has the following negative effects:

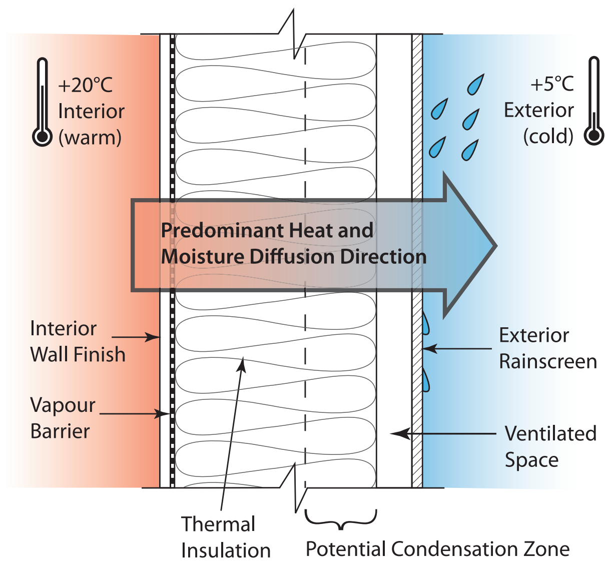
- Reduced thermal insulating value of the envelope resulting in excessive heat losses and increased heating energy requirements.
- Uncontrolled air and moisture exchange between the exterior and interior.
- Potential condensation within the envelope.
- Physical damage of the envelope components from condensation (e.g., corrosion of metals, rotting of wood).
- Potential occupant health impact associated with mildew and fungus growth resulting from the trapped moisture within the envelope.

To avoid these negative impacts, a building's envelope must be completely air- and moisture-tight. Depending on the envelope type, different approaches to achieve air and moisture tightness are required:

1. Lightweight envelope

For most conventional lightweight envelope assemblies (e.g., steel or wood frame), air and moisture tightness is best achieved by applying both a continuous vapour barrier on the interior side of the envelope, at or just behind the finished surface layer, and a continuous rain screen on the exterior face of the envelope with a narrow, vented air gap separating it from the insulation. This configuration keeps the moist air in the space and precipitation on the outside. (The interior moisture is removed by proper ventilation.) Provided the continuity of the vapour barrier and rain screen is achieved (by careful design and installation), the resulting envelope is completely air- and moisture-tight and thus avoids negative impacts such as the risk of condensation and reduced thermal insulation value.

Figure 24: Air- and Moisture-tight Envelope (Conventional, Lightweight Assembly)



2. Heavy-weight envelope

High-performance heavy-weight envelopes should have "sandwich-like" assemblies with a relatively thick layer of concrete or masonry facing the interior and a layer of thermal insulation with a protective vented rain-screen facing the exterior. The dense and massive concrete or masonry layer is sufficiently air tight to keep infiltration and exfiltration at acceptable levels. Unless the interiors have consistently high humidity levels, as might be the case in a commercial kitchen, vapour barriers (e.g., waterproof coating, membrane, ceramic tile, etc.) on the interior surface may not be essential. As massive materials are also porous to a certain degree, they can absorb and release moisture from the indoor air. When combined with continuous exterior thermal insulation to keep the mass temperature above the dew point, the massive layer can absorb and release moisture safely without risk of condensation and its related negative impacts. This continuous thermal insulation on the exterior side is critical to both improving energy performance and avoiding condensation. (Proper application of air and vapour barriers must be considered with a qualified building envelope consultant on a project-specific basis.)

Insulating heavy mass envelope from the inside requires a vapour barrier, since the potential condensation zone extends all the way to the insulation. Inside insulation also creates undesirable thermal bridges at floor-to-wall interfaces that are prone to condensation and compromise the thermal insulation value of the envelope.

Traditional non-tight envelopes had high infiltration/exfiltration rates (often more than 1 air change per hour, or ACH) that were actually—and unintentionally—high enough to meet ventilation requirements. However, this undesirable, uncontrolled ventilation increased heating energy requirements and often caused condensation and its related negative impacts. Although in Vancouver's mild climate the energy penalty for a non-tight envelope is not as severe as in the rest of Canada, uncontrolled air and moisture diffusion through the envelope is still undesirable. Properly designed and built air- and moisture-tight envelopes typically limit uncontrolled air exchange to less than 0.2 ACH. As a result, the space ventilation must be provided by separate means to provide sufficient fresh air for building occupants.

Buildings in Vancouver should have properly detailed and constructed air- and moisture-tight envelopes.

Space ventilation can be fully active with fans and heat recovery ventilation (HRV) units, fully passive with operable windows, or a mixed-mode system that combines the two. Most locations at Vancouver's latitude have harsher climates with much greater heating-dominant requirements. In these climates, year-round reliance on fully active HRV is typically recommended as the most energy-efficient means of providing ventilation in air-tight buildings. However, in Vancouver's milder climate, the most energy-efficient solution is the mixed-mode ventilation approach, relying on HRV during heating season only and relying on passive ventilation strategies for the rest of the year. (See Appendix E - Energy Modeling for modeling results that illustrate the greater efficiency of a mixed-mode system in the Vancouver climate.)

4.10.2 Benefits

- A properly detailed and installed air- and moisture-tight envelope improves building energy performance and mitigates the risk of condensation and its related negative effects.

4.10.3 Limitations

- Tighter envelopes require greater care to avoid leaks from face seals.
- An inadequately detailed and/or installed air- and moisture-tight envelope can result in cumulative moisture and condensation buildup within the envelope. This will result in compromised energy performance and other negative effects.

4.10.4 Synergies

- Passive and mixed-mode ventilation strategies.
- Certain shading devices can also serve as additional rain protection for the envelope.

4.10.5 Vancouver Applications

Buildings in Vancouver should have properly detailed and constructed air- and moisture-tight envelopes. Passively designed buildings should also incorporate a mixed-mode ventilation approach, relying on HRV during heating season only and relying on passive ventilation strategies for the rest of the year.

Appendix A – Glossary of Key Terms

Annual Heating Plant Energy	The annual total of the heating energy consumed by the heating plant, measured in kWh.
Annual Space Heating Energy	The annual total of the heating energy delivered to the space, measured in kWh.
Annual Ventilation Heating Energy	The product of the instantaneous ventilation heating loads (kW) and the duration for which it is required (h), measured in kWh.
Annual Ventilation Cooling Energy	The product of the instantaneous ventilation cooling loads (kW) and the duration for which it is required (h), measured in kWh.
Computational Fluid Dynamics (CFD)	Complex numerical analysis using fluid mechanics theory to analyze fluid flow and heat transfer conditions within the defined space boundaries. In many cases results are available in a graphical display.
Cooling Design Temperature	The outdoor temperature equal to the temperature that is exceeded 1% of the number of hours during a typical weather year.
Distribution System Energy	The energy consumed by all the equipment making up a mechanical system, excluding the heating and cooling generating equipment. This value is the product of the rated power of each piece of equipment (kW) and the operating duration (h) and is measured in kWh.
Efficiency	The ratio of the quantity of useful energy generated by a system to the quantity of energy put into the system.
Energy Intensity	A normalized unit to measure the amount of energy used per unit area, allowing energy performance comparisons between different buildings, usually measured in kWh/m^2 year.
Free Run Temperature	The natural space temperature inside the building operating in an entirely passive mode with no mechanical systems to heat, cool, or ventilate.
Heat Transfer	Heat energy moves in one direction - from hot to cold. Heat transfer occurs in three ways; conduction, i.e., touching a stove element; convection, i.e., warm air flows up from the stove element; or radiation, i.e., the heat you feel next to the stove element. In a building, all three modes of heat transfer occur and impact the comfort level inside.
Heating Design Temperature	Outdoor dry bulb temperature equal to the temperature that is exceeded at least 99.6% of the number of hours during a typical weather year.
Mean Radiant Temperature	A measure of an occupant's perception of radiant temperature from all surfaces in the space.
Peak Operating Efficiency	All mechanical equipment has an efficiency curve that is dependent on the capacity that is required. For example, a boiler is designed to provide 100 kW of heating. The boiler will be most efficient when 100 kW of heating are required. If only 20 kW of heat are required, the boiler will operate at a reduced efficiency and will consume excess fuel energy for the amount of heat it can produce.
Peak Space Heating Load	The instantaneous amount of heat the building will require during the coldest time of the year in order to maintain a specific indoor temperature, measured in kilowatts, kW. This is the amount of heat that the system must be able to provide to the space to make up the heat loss through the windows, walls, floors and roof.

Peak Ventilation Load	The instantaneous amount of heat energy required to bring ventilation (outdoor) air to the temperature required for delivery to the occupied space, measured in kW.
Resultant Temperature	The average of the mean radiant temperature and the air temperature. This measurement is the best indication of the temperature perceived by an occupant. Also known as Operative Temperature.

Appendix B – Thermal Comfort

B.1 Parameters

Table 3: Factors Influencing Thermal Comfort Perception

Environmental Factor	Heat and Mass Transfer Process	Portion of Total Perception of Thermal Comfort
Air temperature	Conduction (direct contact)	6%
Temperature of the surrounding surfaces	Radiation (rays)	50%
Air velocity and air movement distribution	Convection (movement of a fluid)	26%
Air humidity	Evaporation (heat removed in phase change from liquid to gas, e.g., sweat)	18%

There are other factors influencing comfort which are just as important as the factors listed above, however, they are seldom considered during building and system design. They include radiant asymmetry, vertical air temperature gradient, and thermal stability. Radiant asymmetry refers to uncomfortable conditions caused by two nearby surfaces having very different temperatures. Too large a vertical air temperature gradient, the difference in temperature from head to toe, can also cause discomfort. Finally, comfortable conditions require thermal stability (i.e., relatively constant thermal conditions over time).

If neglected, these factors can result in perceived discomfort and unnecessary energy consumption even though the building fully meets the primary conditions. For example, the localized radiant effects of a cold or hot window surface (winter/summer) cause thermal discomfort even though the space air temperature is maintained within the design comfort range by the mechanical system. This condition cannot be corrected by simply adjusting the space air temperature. Instead, it requires careful design of the building fabric to better control the surface temperatures.

B.2 Fanger Model

The Fanger Thermal Comfort Model (named after Danish researcher Ole Fanger) is the most widely used model. It determines comfort as a function of a limited set of parameters: air temperature, relative humidity and air motion in relation to the occupant's activity level (i.e., metabolic rate) and clothing.

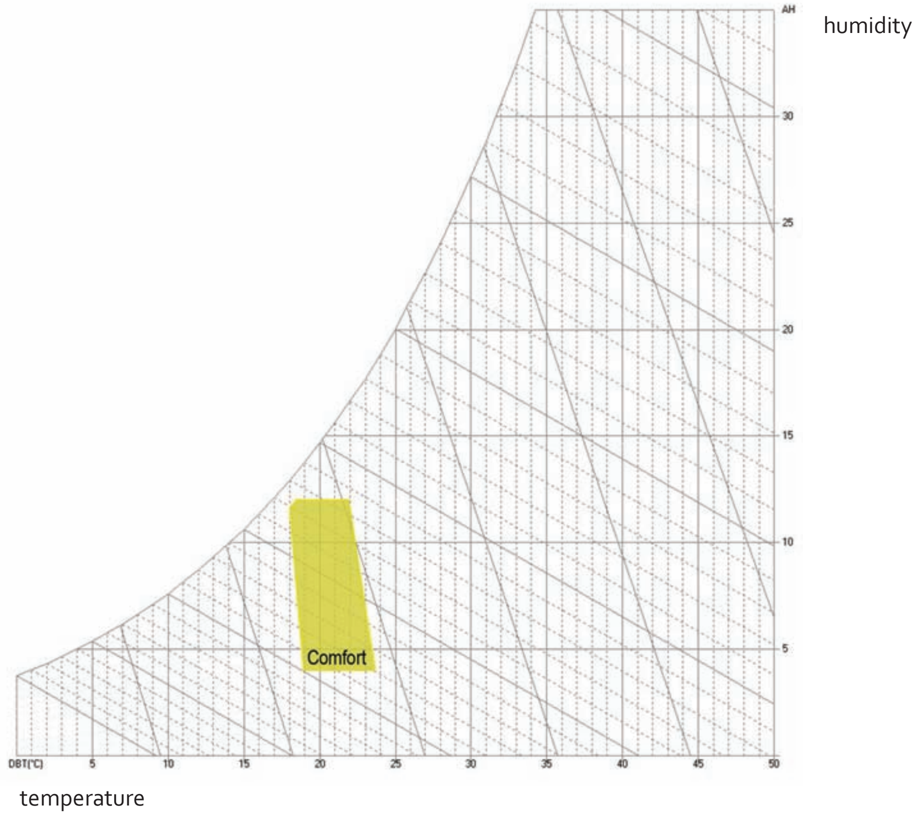
The Fanger Model was developed from the results of controlled laboratory experiments. It prescribes a relatively narrow range of acceptable thermal comfort parameters, most often defined in a further simplified relationship between only two parameters; the operative temperature and relative humidity (see Figure 25 below). The acceptable indoor conditions do not vary with outdoor conditions on a daily or yearly basis. The prescribed range of acceptable conditions falls within a relatively narrow range (i.e., 20°C at 30% RH for heating, and 22°C at 60% RH for cooling year round). This results in heavy reliance on active mechanical systems regardless of the outdoor climatic conditions, which can lead to unnecessary energy consumption.

Although this comfort model clearly identifies two separate comfort regions for heating and cooling seasons, respectively, the majority of current buildings are designed to a fairly narrow comfort zone representing the winter performance, which is maintained by mechanical systems year round.

B.3 Adaptive Model

While the Fanger Model is widely used and it is appropriate for mechanically conditioned and ventilated buildings, it does not adequately define thermal comfort when passive conditioning and natural ventilation are introduced.

Figure 25: ASHRAE Comfort Zones as Defined by the Fanger Model



As such, it eliminates many passive systems from the design. Furthermore, it does not always reflect occupant comfort perfectly. Therefore, another model; the Adaptive Thermal Comfort Model, has been developed from surveys of acceptable thermal comfort conditions in actual buildings. The Adaptive Thermal Comfort Model correlates outdoor conditions with indoor conditions and allows a wider range of acceptable thermal parameters within its definition of comfort, making it more suited to buildings with passive conditioning and natural ventilation.

The conditions defining human perception of thermal comfort are not fixed, but are subject to gradual drift in response to changes in both outdoor and indoor thermal environment. The human body is able to adjust its metabolic rate in response to changes in climate throughout the year, and as a result, occupants' definition of comfort actually changes based on the season and location. For example, a sudden change of temperature is likely to provoke discomfort and complaint, while a similar change, occurring gradually over several days or longer, would be compensated by a gradual corresponding change of clothing and adaptation to the new thermal conditions and would not provoke a complaint. For passively designed and operating buildings the observed comfort temperature proved to be almost linearly dependent on the past outdoor temperature.

The fundamental assumption of the adaptive approach to thermal comfort is expressed by the adaptive principle: "If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort". People will make adjustments to their activity, clothing, posture, and/or adjust required elements of their surrounding (i.e., open or close windows, pull down blinds, etc.) to improve their thermal comfort. In addition to these adjustments, they acclimatize to the new thermal conditions. Therefore, in addition to the optimized passive building design, adequate provisions and ways for occupants to adjust their thermal environment need to be provided.

In a well-designed passive building operating in Free Running mode (see Section 2.2.3 and Appendix B.4), indoor thermal conditions change only gradually in response to changes in the weather. In the mild Vancouver climate, it is possible to achieve a passive building design that would be able to maintain acceptable thermal comfort conditions within the parameters of the Adaptive Model for the majority of the year, with the exception of the coldest outdoor temperatures during winter. With the proper passive design, the building's reliance on active mechanical systems and resulting energy requirements can be significantly reduced.

The required strategies to achieve such passive performance are discussed in Section 3 of this toolkit.

B.4 Free Run Temperature

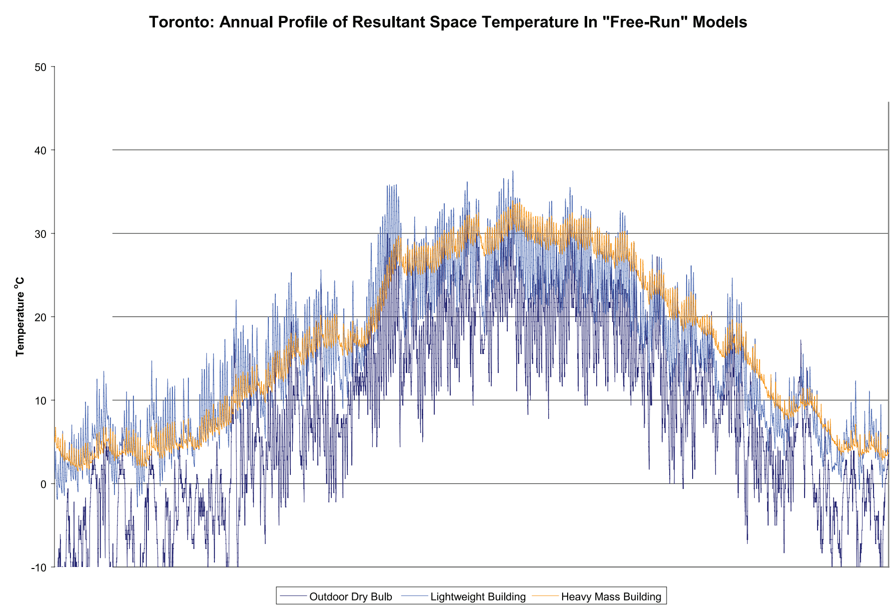
The original FRT methodology was developed at the Swiss Federal Institute of Technology. It is based on the notion that "any building in any climate develops its own temperature behaviour pattern under the influence of its passive building components and the climate alone".

The FRT methodology can serve as a valuable tool during the early stages of building design. Widespread availability and use of powerful advanced building energy simulation tools make generating a detailed FRT profile relatively easy.

The FRT methodology is one of the most effective and accurate means for optimizing passive building design strategies.

Figure 26 below displays an example of FRT profile results. In this case, the two simulated buildings were identical except for the amount of mass in their building constructions. The temperature difference during peak summer conditions represents the potential energy savings from reduced peak load. That is, by lowering the temperature the building reaches on its own, without any mechanical systems, the peak demand on the mechanical systems is lowered.

Figure 26: Example of a FRT Profile



Appendix C – Vancouver Climate Characteristics

C.1 Overview

Detailed weather data is necessary for the concept analysis of shading, envelope, passive and active solar heat gain, building system energy and plant capacities. Comprehensive hourly data, required for envelope, building system energy and plant capacity analysis, is only available for Vancouver International Airport, which is located just southwest of the city, on the shore of Georgia Strait.[9]

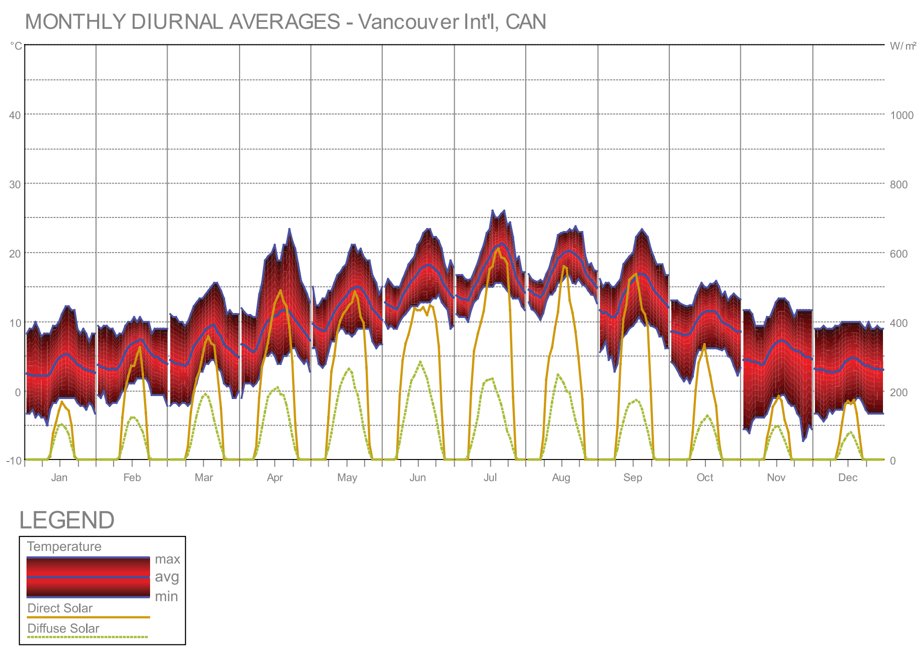
The following graph shows the typical daily weather profile for each month from the Vancouver weather file.

C.2 Air Temperature and Humidity

There are several ways to express the moisture properties of air. The psychrometric equations relate dry bulb temperature, absolute humidity (moisture quantity in the air expressed in grams of water per kilogram of air), relative humidity, wet-bulb temperature and dew point.

The relative humidity, expressed as a percentage, is commonly used when discussing the moisture content of air. However, this parameter is easily misinterpreted, especially in cold

Figure 27 : Monthly Diurnal Averages



9 Energy simulations and any hourly analysis done with computer software require a weather file containing various data sets, such as air temperature and wind speed. The file from Canadian Weather for Energy Calculations (CWEC) is used throughout this analysis. It is publicly available and is a derived file covering 30 years of historical data.

conditions. High relative humidity is often mistaken for high humidity under any conditions, but this is not the case. For example, 10°C air with 80% relative humidity has a humidity ratio of 7 g water/kg air, whereas 30°C air with 80% relative humidity has a humidity ratio of 22 g water/kg air – more than three times greater. This is especially relevant to Vancouver; our high relative humidity levels at our corresponding low air temperature represent only mild levels of absolute moisture quantity in the air.

Furthermore, cold outdoor air with high relative humidity becomes dry indoor air once passed over sensible heating coils; the amount of moisture remains constant, but the volume of the air increases and therefore the relative humidity percentage drops. For this reason, the relative humidity of the ambient outdoor air is not always the best indicator of indoor air conditions for this climate.

With the detailed relative humidity and dry bulb temperature data in the weather file, other air moisture properties can be calculated using the psychometric relationships. In this report, we use the dew point temperature to help guide the passive design process, not the relative humidity. Dew point temperature represents the temperature at which condensation occurs. Dew point temperature is important when assessing building envelope construction, internal surface temperatures, ventilation air humidification/dehumidification, and mechanical systems such as radiant cooling. The annual dew point temperature profile was generated using weather data from Vancouver International Airport. The annual maximum dew point temperature is 18°C, and occurs early in September, because Vancouver summers are relatively warm and dry.

Figure 28: Summer Dry Bulb Temperature and Relative Humidity Profile

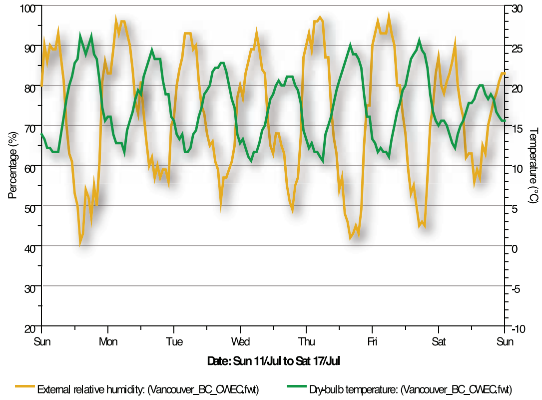


Figure 29: Annual Dry Bulb Temperature and Relative Humidity Profile

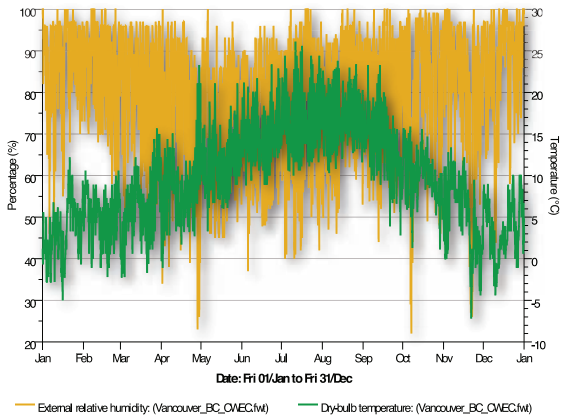


Figure 30: Annual Dry Bulb Temperature and Dew Point Temperature Profile

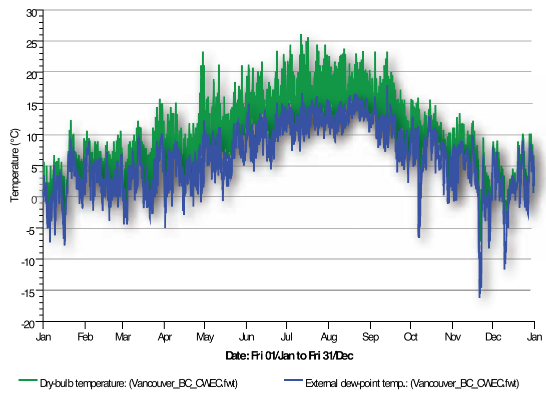


Figure 31: Dry Bulb Temperature and Dew Point Temperature Profile: Second Week of July

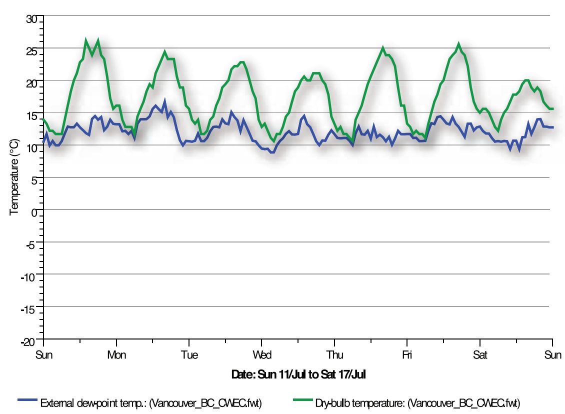


Figure 32: Dry Bulb Temperature and Dew Point Temperature Profile: Last Week of November

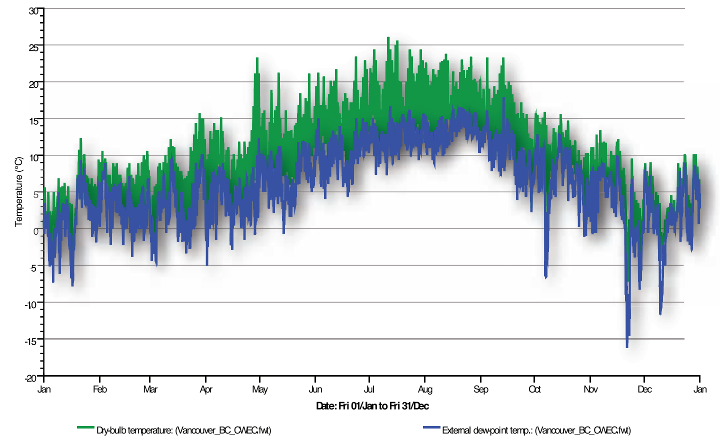
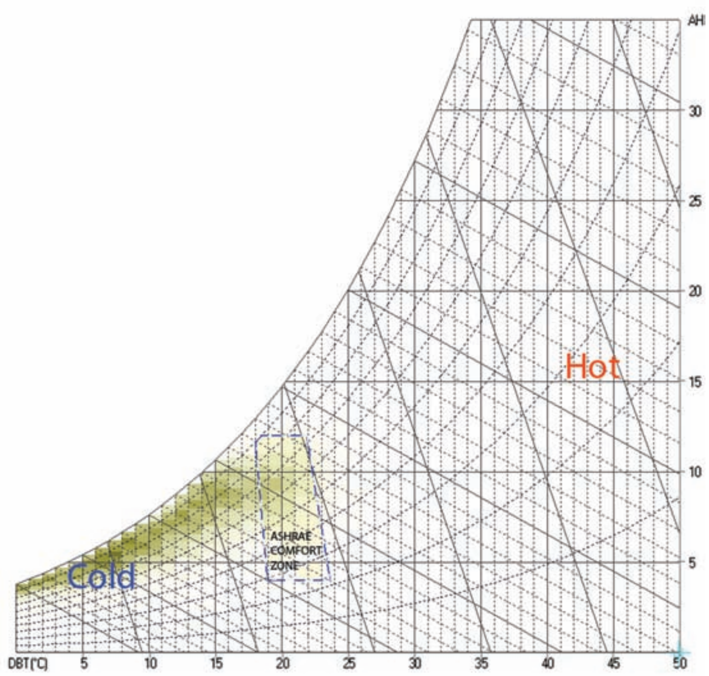


Figure 33 below shows the annual and seasonal outdoor air conditions in Vancouver on a psychrometric chart. The blue box indicates the ASHRAE standard 55 comfort range. Data points to the left and below this range indicate times when outdoor air is cooler than the desired operating temperature. Data points to the right and above are times when the air is warmer.

Figure 33: Annual Cumulative Frequency of Outside Air Conditions in Vancouver



When no passive design features are implemented, the data points outside the comfort range (i.e., the blue box) represent times when mechanical heating or cooling is required.

Incorporating passive design features expands the range of outdoor conditions during which indoor comfort conditions can be maintained without mechanical heating or cooling. (See also Figure 7.)

C.3 Solar Radiation

Many days during spring receive up to 450 W/m^2 of global radiation (on a horizontal flat plane), and the maximum value during summer is 880 W/m^2.

Solar radiation affects the design of thermal mass, solar shading, window parameters, and active solar energy systems (i.e., photovoltaics and hot water heating).

The average daily solar radiation profile for each week in the year is shown in Figure 35, extracted from the Vancouver weather file.

Figure 34: Seasonal Cumulative Frequencies of Outside Air Conditions in Vancouver

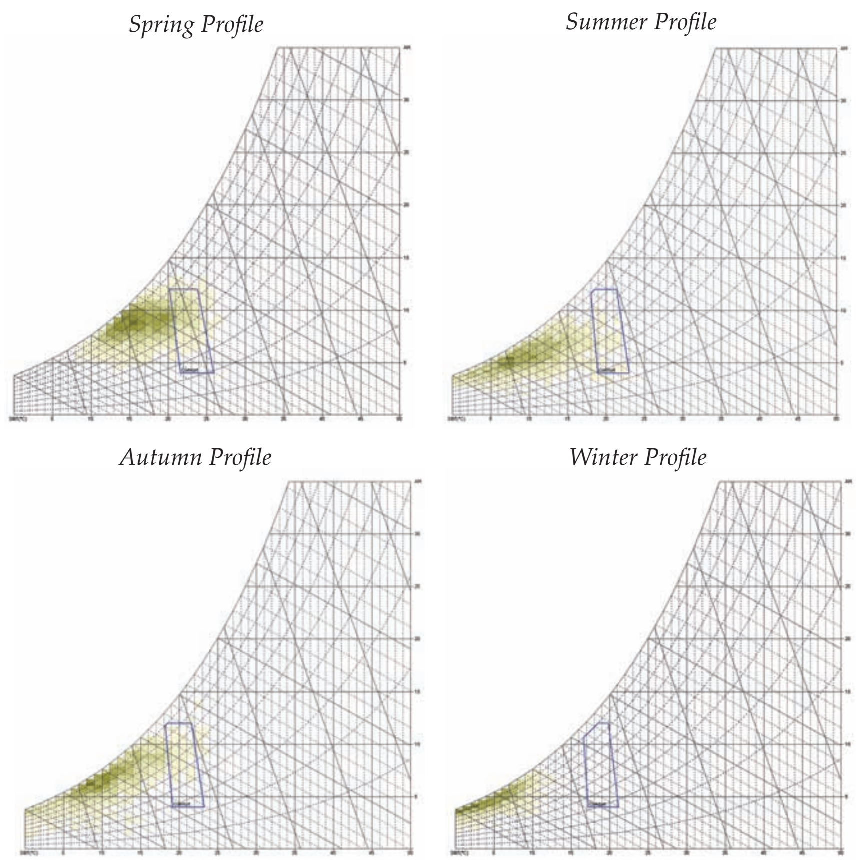
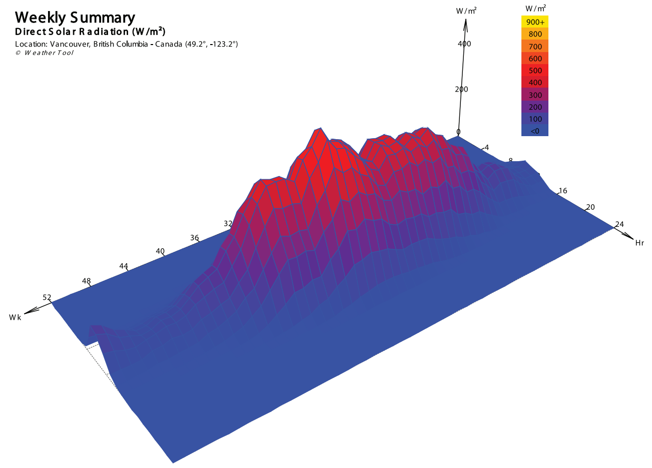


Figure 35: Direct Solar Radiation (W/m²)



Sun Up/Down December 21st: 8:05 PST to 4:17 PST (8 hours and 12 minutes of daylight)
Sun Up/Down June 21st: 5:07 PSD to 21:22 PSD (16 hours and 15 minutes of daylight)

C.4 Wind

Wind data is important when designing naturally ventilated buildings, operable window and louver placement, and local wind power generation.

Wind is specific to a site's surroundings and is strongly influenced by adjacent buildings and terrain, open fields or bodies of water, and even parking lots and trees. If advanced natural ventilation designs are pursued, a weather station is set up on the site as early as possible to collect real, site-specific wind conditions and patterns for use in design and energy simulations.

Figure 36 : Annual Wind Cumulative Frequencies

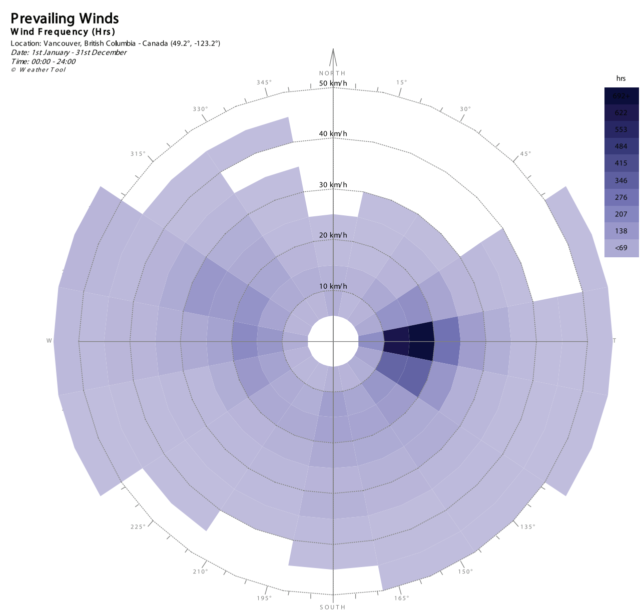
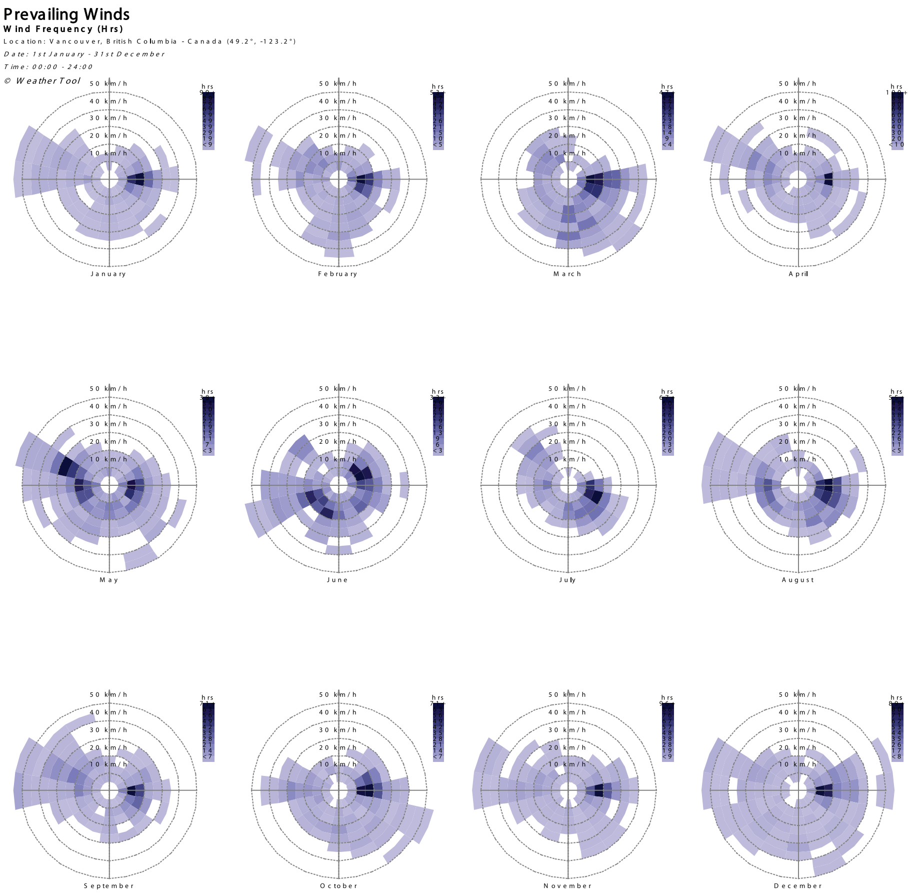


Figure 37 : Monthly Wind Cumulative Frequencies



C.5 Precipitation

The average total precipitation in Vancouver ranges from a low of 39 mm in August to a high of 180 mm in November. The average monthly total rainfall is 96 mm, and most of the annual rainfall occurs between October and March. Considering rainfall is important when assessing rainwater harvesting and storm water management.

Vancouver receives an average of 48 cm of snow per year, with a maximum depth accumulated in January averaging at 16.6 cm deep. Snowfall is an important consideration when exploring active solar systems using solar collector panels.

C.6 Outdoor Design Temperatures

Historical weather data for Vancouver indicates an extreme minimum temperature of -17.8°C in 1950 and an extreme maximum temperature of 33°C in 1960. Site microclimate will also influence outdoor air temperatures, and it is possible that a particular site could experience even higher air temperatures during summer. However, when establishing heating and cooling design temperatures for a building, it is not reasonable to design to these extremes, as the resulting systems and equipment will be dramatically oversized and operate at low efficiency most of the time. Rather, it is common practice to use established design conditions as defined by the BCBC and ASHRAE Standard 90.1. The published Vancouver design conditions appear in Section 2.3.

Appendix D – Energy Performance Targets

Neither of the common North American building standards defines building energy performance targets in measurable energy units. Instead they establish the energy performance of active components such as HVAC equipment (not systems), service water heating efficiency and lighting power density in terms of equipment efficiencies.

This methodology essentially creates a non-existent target for energy performance. There is no established benchmark of energy performance in easily comparable energy units. With no clear target to aim for, it becomes difficult for the proposed design to achieve its low-energy goals.

The modeling protocol required by the standards further complicates the situation by requiring detailed data on active systems before any energy analysis can be performed. These parameters are seldom clearly defined at early design stages, so the focus tends to shift to optimizing the active system components without adequate consideration for first optimizing passive features.

Millennium Water Photo: Merrick Architecture

Appendix E – Energy Modeling

E.1 Introduction

Advanced building energy simulation software was used to calculate the effects of the passive building design elements discussed in this toolkit. Each element was simulated on a control building to find the amount of energy needed to maintain comfort in the occupied space year round. The models were set to isolate the interaction between the building and climate from other variables. These results represent parametric ideal situations useful for demonstrating the thermal principles and relative energy performance of each measure.

In a realistic building multiple elements may be installed and often the elements will interact with each other. Both the potential synergies and complications are discussed in the relevant element's results discussion. Also, to further explore this interaction, passive heating and cooling strategies comprised of multiple elements were simulated.

The assumptions, simulation inputs, results and analysis are provided in this appendix. The study conclusions are summarized in the main body of the report.

E.2 Study Cases

Calculate the annual heating and cooling energy required at the space level in a control building to demonstrate the effect of the following passive building elements and strategies:

Passive Building Elements

1. Building Orientation
2. Space Planning
3. Window to Wall Area Ratio
4. Window Performance
5. Solar Shading
6. Thermal Mass
7. Thermal Insulation
8. Infiltration and Air tightness

Passive Building Strategies

9. Passive Heating
10. Passive Cooling
11. Residential Applications
12. Commercial Applications

E.2.1 Assumptions and Inputs

The baseline parametric model is a 3 storey square building with 9 square spaces per floor and in all cases is simulated using the same Vancouver CWEC weather file.

This geometry was selected to provide equal comparison between facades and to provide simulation result data in all three typical floor scenarios: floors in contact with the ground; floors that have roof surfaces exposed to the outdoors; and, the most typical arrangement in Vancouver's high rise market, both floor and ceiling in contact with an adjacent occupancy.

The building is aligned square north-south in all of the element and strategy simulations, with the exception of the orientation study.

As this study investigates the passive response of the building features the variable and subjective simulation parameters of internal heat gains and mechanical systems were intentionally omitted. Results are presented in terms of the energy intensity in kWh/m^2 yr and represent the space heating and cooling energy requirement at the space level. Other building energy flows such as domestic water heating, fan and pump power were also omitted from the analysis and no systems or efficiencies were included.

Ventilation air tempering in the baseline model is generally omitted from the analysis where passive envelope features are studied.

Where the performance of the passive element has an effect on, or may be affected by ventilation a separate base case with ventilation was created and the presented results include the energy required to temper the ventilation air.

In cases where it is believed the internal heat gains will play a role in the interpretation of the results and application of the measure a commercial office building schedule was assigned. Those cases are noted as commercial schedule and a separate base case with the commercial schedule was created.

Tables outlining the modeling inputs for the baseline, as well as the passive element and strategy studies, are presented in the following sections.

E.2.2 Methodology

The overall study methodology consists of the following steps:

1. The baseline model was simulated for one year and was calibrated by comparing the results with published energy use data for actual buildings in British Columbia as well as previous modeling experience.
2. Each passive element was simulated independently on a copy of the baseline building. Iterations were conducted on several of the measures to produce data ranges to identify trends and patterns.
3. The results of each element were analyzed and potential combinations of elements were identified.
4. These element combinations defined the strategies proposed for the Vancouver climate and those strategies were simulated to demonstrate the compounding effect as each measure was added.

Additional notes on the methodology for the simulating each of the elements and strategies are noted in the respective sections.

E.2.3 Results and Conclusions

The simulation results and conclusions are presented in the following sections. Results for all spaces in each simulation are available; however only results for specific spaces were presented for the purpose of this study.

Typically results are presented for the most relevant extreme spaces, however the entire data set could be provided upon request.

E.3 Baseline Model

The baseline model is the simplest model and is simulated for comparison between passive envelope elements. The settings represent current market practice in Vancouver with envelope assemblies meeting the Vancouver Building By-law (2007) requirements. Internal heat gains and ventilation air tempering are not included to isolate the passive building behaviour.

E.3.2 Methodology

1. Simulate the baseline model for one full year.

2. Extract and record the annual heating and cooling results.

E.3.3 Results

The baseline results were not generated to act as a prescriptive energy target because the variable and subjective inputs of internal gains, ventilation rates and mechanical systems were not included. Rather, the results are intended to be used in the relative comparison of the effects of the

E.3.1 Assumptions and Inputs

Wall RSI value:	R2.3 (ASHRAE 90.1) exterior wall with 100mm concrete outside	m^2K/W
Roof RSI value:	R2.6 (ASHRAE 90.1)	m^2K/W
Window U value:	U2.3 double pane windows	W/m^2K
Window total shading coefficient:	0.7 clear glass	
Window to wall area ratio:	60%	
Infiltration	0.5	ACH
Room resultant temperature set points :	21 - 24	°C
RH:	0-100 not controlled	%
Internal heat gains from people, lighting, or equipment:	Not included	
Ventilation:	Not included	

While most of Vancouver is aligned to a north south grid, downtown Vancouver is aligned at a 45° angle from north-south.

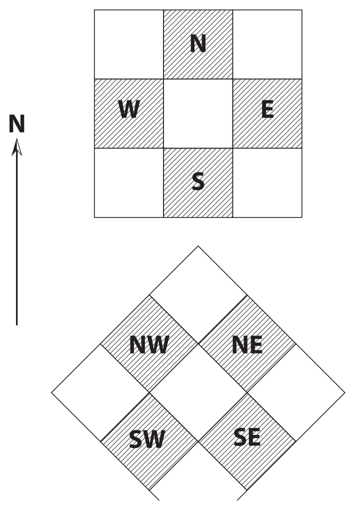


Figure 38: Model orientation for the north-south aligned model, at top, and the 45° aligned model to represent Vancouver's downtown peninsula.

various passive measures and are presented as such in the following sections.

E.4 Orientation

This set of simulations compared four spaces on the middle floor of the parametric model in two different orientations. The first orientation represents most of Vancouver, oriented with the street grid aligned north south.

The second orientation represents the downtown peninsula aligned at an angle roughly 45° from north-south. The simulation results represent an identical space with one external wall in 8 different orientations.

E.4.2 Methodology

1. Simulate the baseline model aligned square to the north.
2. Simulate the baseline model aligned 45° from north.
3. Extract results for the mid-facade space of the middle floor in each model, for a total of 8 sets of results.

E.4.1 Assumptions and Inputs

Wall RSI value:	R2.3 (ASHRAE 90.1) exterior wall with 100mm concrete outside	m^2K/W
Roof RSI value:	R2.6 (ASHRAE 90.1)	m^2K/W
Window U value:	U2.3 double pane windows	W/m^2K
Window total shading coefficient:	0.7 clear glass	
Window to wall area ratio:	60%	
Infiltration	0.5	ACH
Room resultant temperature set points :	21 - 24	ºC
RH:	0-100 not controlled	%
Internal heat gains from people, lighting, or equipment:	Not included	
Ventilation:	Not included	

E.4.3 Results

Figure 39: Annual heating and cooling energy intensity for mid-wall spaces on the middle floor, each space has one external wall exposed to the direction noted (Building aligned north-south).

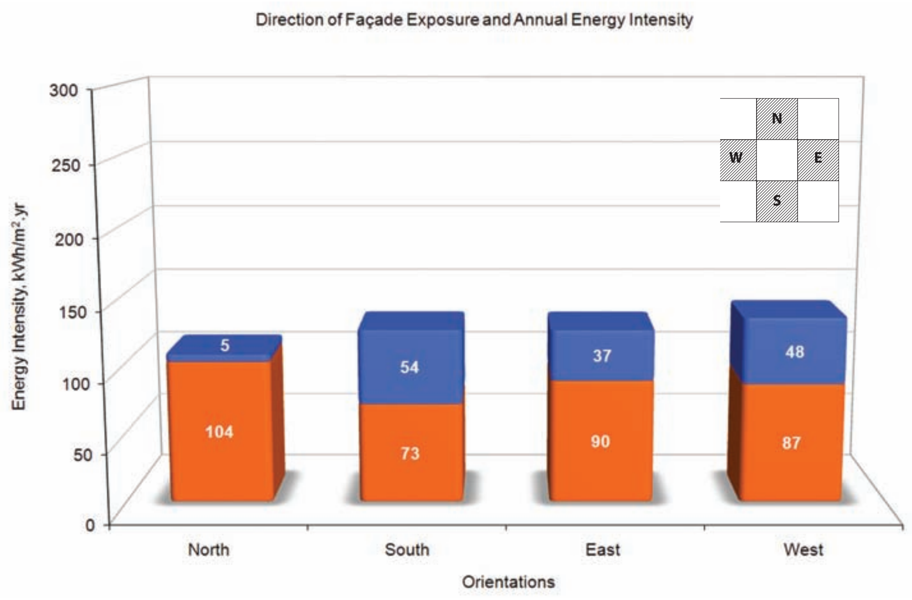
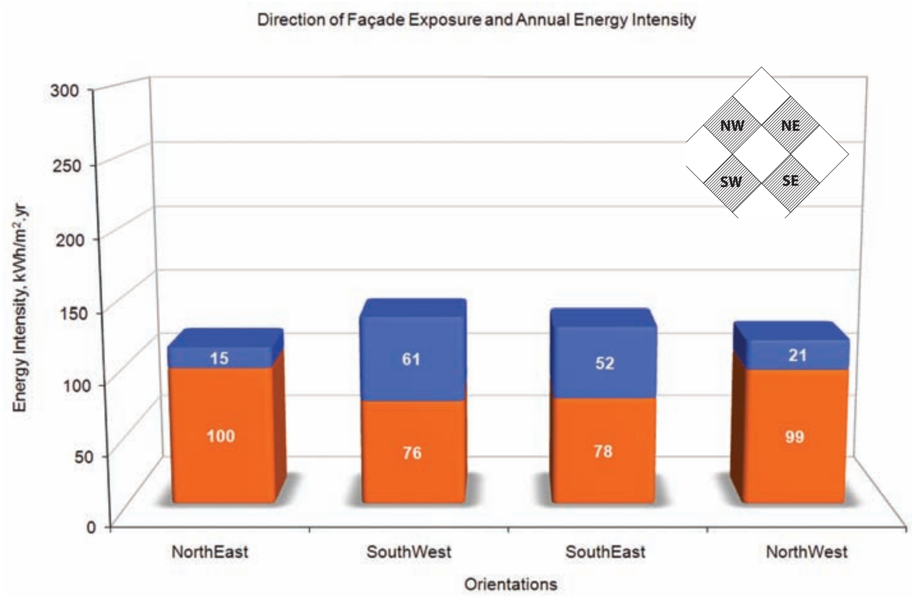


Figure 40: Annual heating and cooling energy intensity for mid-wall spaces on the middle floor, each space has one external wall exposed to the direction noted (building aligned 45 degrees from north).



E.4.4 Conclusions

- Spaces with southwest exposure have the highest total energy requirement; however they have the lowest heating energy requirement as the direct effect of the solar gain.

- North, northeast and possibly northwest exposures can be designed to be sufficiently comfortable without space cooling, especially if additional passive cooling elements such as natural ventilation are provided.

- All facades were simulated with the same window to wall area ratio. The energy consumption could be more evenly distributed in the building if different window to wall area ratios were applied to the different exposures.

- Internal heat gains and orientations do interact as discussed in the programming section of this report. No simulations were conducted for programming as the discussion is sufficient for the purpose of this toolkit and programming is highly building specific. Building specific modeling must be conducted to assess the building energy performance of programming layouts with respect to facade exposure.

- Though it appears that the downtown pattern has generally higher energy requirements than the north-south alignment, corner space results are not presented. When the whole building annual energy use is compared between the two orientations the results show that the difference is negligible (0.04%) as the parametric building is symmetrical. Buildings which are not symmetrical would produce different results.

E.4.5 Recommendations for Orientation

- Design each facade specific to its orientation.

- Minimize east and west exposures to avoid unwanted solar gains.

- The 45° vs. 90° orientation makes little difference on overall energy performance on a symmetrical building with identical facades.

E.5 Balcony Buffer Space

In this study the baseline parametric model was adjusted to have enclosed, unconditioned balconies on all the exterior facades. Apertures were assigned to ventilate the balconies and to allow air transfer between the balcony space and conditioned space. The buffer space aperture controls were optimized to relieve heat gains from the buffer zone in order not to induce a cooling load in the adjacent space. Also, apertures between the balcony and adjacent space were opened when the air temperature was sufficient to passively offset the need for heating or cooling.

The balcony concept provides an additional level of insulation between the conditioned space and the exterior when closed, preheats ventilation air, or relieves solar heat gains before they negatively affect the conditioned space. Balconies and their openings can be configured to increase the total building surface area to enhance cooling with the windows open and maintain a more compact form to minimize envelope surface area with the windows closed.

Dockside Green - Photo: Enrico Dagostini / Busby Perkins+Will

E.5.1 Assumptions and Inputs

Wall RSI value:	R2.3 (ASHRAE 90.1) exterior wall with 100mm concrete outside	m^2K/W
Roof RSI value:	R2.6 (ASHRAE 90.1)	m^2K/W
Window U value:	U2.3 double pane windows	W/m^2K
Window total shading coefficient:	0.7 clear glass	
Window to wall area ratio:	60% with 50% of windows operable	
Infiltration	0.5	ACH
Room resultant temperature set points :	21 - 24	ºC
RH:	0-100 (not controlled)	%
Internal heat gains from people, lighting, or equipment:	Not included	
Ventilation:	Not included	
Balcony Depth:	915mm	
Balcony Windows:	100% glass wall with 50% operable single pane glass	
Window Controls:	Buffer space open to occupied space when the outdoor air temperature greater than 19 ºC less than 21 ºC; Balcony exterior window controlled by balcony air temperature > 20 ºC	

E.5.2 Methodology

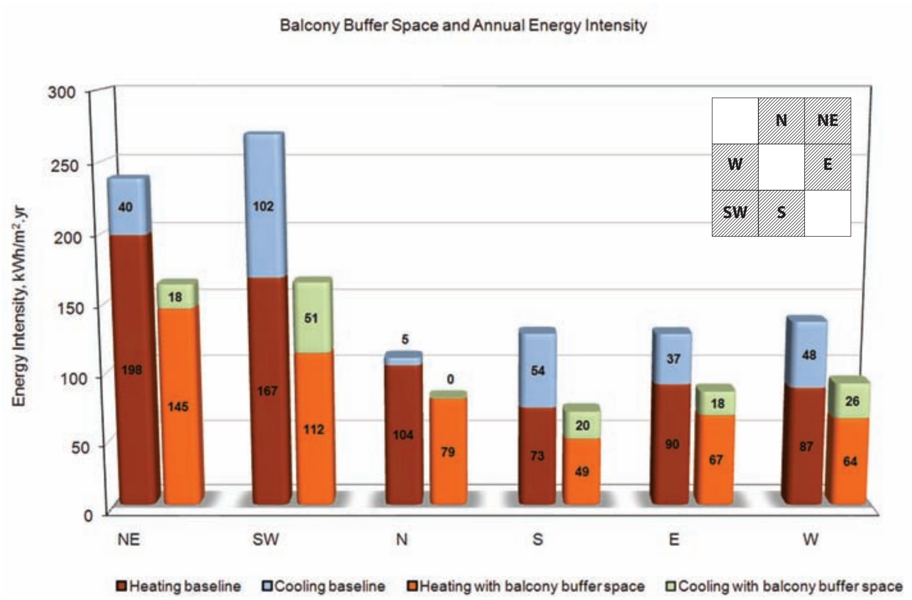
1. Revise a copy of the baseline model to have 915mm deep exterior balconies on all facades and maintain external wall and glass properties in the wall dividing the balcony from the conditioned space. Corner spaces have two balconies, one on each facade. Assign single pane windows to balcony exterior wall and typical floor construction to the balcony floors/ceilings. Assign the opaque external wall construction to the partition walls between balconies.

2. Add operable windows to both the balcony exterior walls and the wall between the balcony and the adjacent space.

3. Extract the results for both extreme corner spaces as well as the mid-facade spaces facing each of the four cardinal directions on the middle floor of the model.

E.5.3 Results

Figure 41: Annual heating and cooling energy intensity with balcony buffer spaces as compared with the baseline building fully sealed without buffer, shown for the middle floor SW and NE corners and mid-facade rooms in all four cardinal directions.



E.5.4 Conclusions

- The buffer space effectively reduced both the heating and cooling energy in all cases. The corner spaces have higher demands because they have greater envelope exposure areas, and for the same reason see the greatest reduction in energy consumption with the addition of the buffer space.

- The buffer space reduces the cooling energy by half in most of the spaces and completely eliminates the cooling energy in north facing spaces. In absolute values, the buffer space has the greatest impact on the southwest corner, south, west and northeast corner spaces.

- The buffer space reduces the heating energy in all spaces by values ranging between 24% in the north and 33% in the south facing spaces.

- The balcony floor, ceiling, and partition walls were simulated with opaque constructions. These elements also act as fixed shading blocking solar gains from entering the conditioned space when compared with the baseline. This shading effect is embodied in the overall results and analysis.

- The results show that significant energy savings can be achieved though the application of unconditioned buffer spaces to the building facade.

- Though comfort conditions are not extracted from the simulations, the reduced heating and cooling energies indicate more stable internal temperatures in the conditioned space. The unconditioned balcony would be comfortable during most of the year for most activities with the exception of sleeping.

- Buffer spaces were not simulated with a commercial schedule however the overall effect is expected to be similar. With internal heat gains a buffer space would expand the range of outdoor temperatures during which natural ventilation could be applied, thus reducing the cooling energy demands. In commercial applications a buffer space would most likely consist of a double facade or atrium spaces.

E.5.5 Recommendations for Buffer Space

- Incorporate buffer spaces on all exposures whenever possible to optimize comfort and reduce both peak load and overall heating and cooling energy requirements.

E.6 Window to Wall Area Ratio

One of the most significant passive building features affecting Vancouver's building energy consumption is the extensive use of windows in place of exterior walls.

This study iterates through various window to wall area (GWA) ratios on the baseline building and presents the trends in annual space heating and cooling energy required for the north-east corner and south-west corner rooms.

Note on ASHRAE Standard 90.1: Section 5.2 states that for a building to comply with the standard the prescriptive values can only be applied to buildings with 50% window to wall area ratio, or less. Envelopes with greater window to wall area ratios must comply with the standard through the building envelope trade-off method of Appendix C. Section C3.3 states that the baseline building will have a window to wall area ratio that is the same as the proposed building, or 40%, whichever is less. Therefore any building with a GWA greater than 50% is measured against the performance of a building with 40% window to wall area ratio and often the trade-off calculation results in lower U-value requirements (high performance windows).

E.6.1 Assumptions and Inputs

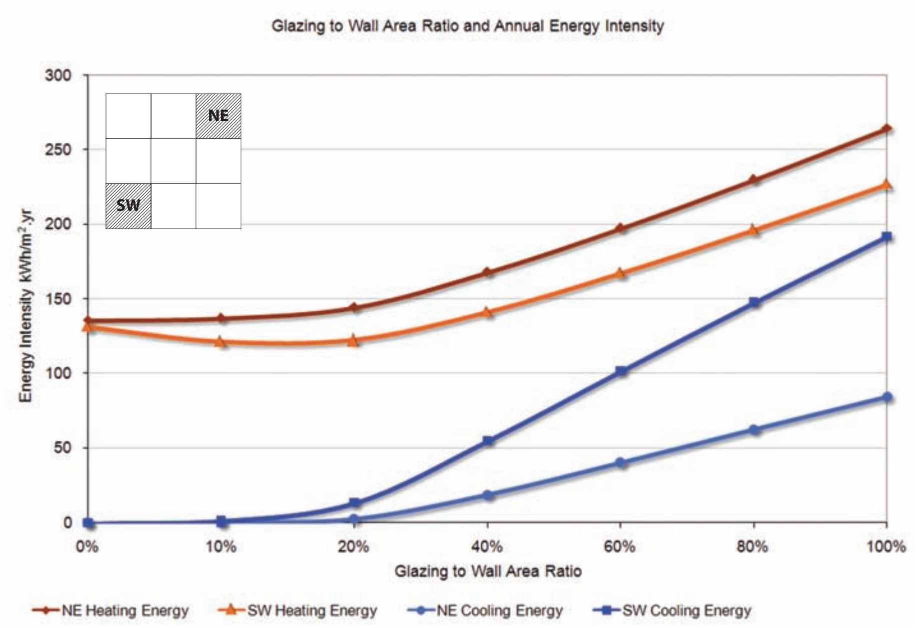
Wall RSI value:	R2.3 (ASHRAE 90.1) exterior wall with 100mm concrete outside	m^2K/W
Roof RSI value:	R2.6 (ASHRAE 90.1)	m^2K/W
Window U value:	U2.3 double pane windows	W/m^2K
Window total shading coefficient:	0.7 clear glass	
Window to wall area ratio:	0%, 10%, 20%, 40%, 80%, 100%	
Infiltration	0.5	ACH
Room resultant temperature set points :	21 - 24	°C
RH:	0-100 (not controlled)	%
Internal heat gains from people, lighting, or equipment:	Not included	
Ventilation:	Not included	

E.6.2 Methodology

1. Adjust a copy of the baseline model for a range of window to wall area ratios. In each case apply the window ratio to all four facades.
2. Extract results for the northeast and southwest corner spaces on the top floor of the model.

E.6.3 Results

Figure 42: Annual heating and cooling energy intensity with varying window to wall area ratios in the SW and NE corner spaces.



E.6.4 Conclusions

- Significant heating and cooling energy consumption begins occurring after the 40% window to wall area ratio threshold. Heating energy is increased because although the greater window area allows more solar heat to enter the space, the overall insulation value provided by the envelope (window plus wall) is low and the heat loss overwhelms the solar heat gain.

- Little to no cooling energy is required below the 20% window to wall area ratio in this model because there are no internal heat gains. If there were internal heat gains a slight cooling energy requirement may be observed.

- In the southwest corner space GWA ratios between 10% and 30% result in lower heating energy consumption that the same space without any windows, showing that annually the solar heat gain offsets the heat losses through the envelope on this exposure. Note that this trend is not the same for the northeast corner space, where any amount of windows increases the annual heating energy consumption.

- The southwest corner space cooling energy requirement increases dramatically beyond 30% window to wall area, and the heating energy increases as well, thus showing that window areas greater than 30% on this type of exposure have an adverse effect on the energy performance. The lowest total heating and cooling energy requirement in the southwest space occurs between 10% and 20% window to wall area ratio.

- The resulting trend is not unique between different building types; it is a consistent trend that the extent of windows being used currently in Vancouver is resulting in unnecessarily high energy consumption in all building types, those with heating only as well as those with both heating and cooling systems.
- Any building proposed to have a window to wall area ratio greater than 50% must prove overall energy consumption at or below that of the ASHRAE standard building at 40%. In the southwest corner space, for example, the cooling energy doubles when the ratio increase from 40% to 60% and the heating energy increases as well. This increased energy consumption must be compensated for in other areas of the building envelope and systems, and would likely require higher insulating values in the windows and other envelope components.

E.6.5 Recommendations for Window to Wall Ratio

For optimum passive performance, do not exceed 50% windows on any facade and limit windows to 30% whenever possible, taking into account other aesthetic and livability criteria.

If higher window to wall area ratios are desired, incorporate high performance windows or double facade and optimize shading.

E.7 Window Performance

Window assemblies are specified by several factors which describe their insulating effect and the amount of solar heat and light it transmits and reflects. In this study a range of window insulation values were simulated in both a residential and commercial schedule (without and with internal gains, respectively). The selected values represent greater and poorer performance than the value prescribed by ASHRAE 90.1. The shading coefficient was also studied, but on the residential schedule only.

Note on ASHRAE Standard 90.1: Section 5.2 states that for a building to comply with the standard the prescriptive values can only be applied to buildings with 50% window to wall area ratio, or less. Envelopes with greater window to wall area ratios must comply with the standard through the building envelope trade-off method of Appendix C. Section C3.3 states that the baseline building will have a window to wall area ratio that is the same as the proposed building, or 40%, whichever is less. Therefore any building with a GWA greater than 50% is measured against the performance of a building with 40% window to wall area ratio and often the trade-off calculation results in lower U-value requirements (high performance windows).

E.7.1 Assumptions and Inputs

Wall RSI value:	R2.3 (ASHRAE 90.1) exterior wall with 100mm concrete outside	m^2K/W
Roof RSI value:	R2.6 (ASHRAE 90.1)	m^2K/W
Window U value*:	3.5 and 0.8 double pane and 4-element pane windows	W/m^2K
Window total shading coefficient:	0.3 and 0.5 clear glass	
Window to wall area ratio:	60%	
Infiltration	0.5	ACH
Room resultant temperature set points :	21 - 24	°C
RH:	0-100 (not controlled)	%
Residential Internal heat gains from people, lighting, or equipment:	Not included	
Ventilation:	Not included	
Commercial Internal heat gains: People: Lighting: Equipment:	7am to 8pm, with night thermostat setback to 15 - 28 7 11 5	 °C $people/100m^2$ W/m^2 W/m^2
Ventilation:	10	L/s/person

** Note that the lower U-value has a higher insulating value. Properly applied low-e coatings decrease the U-value thereby increasing the insulation value.*

E.7.2 Methodology

1. Test the effect of window insulation by adjusting a copy of the baseline model for two window performance cases representing: a low quality, double pane window assembly with U=3.5 W/m^2K, and a very high performing 4-element window assembly with U=0.8 W/m^2K. Maintain the baseline shading coefficient at 0.7 to represent clear glass. Apply the same parameters to all facades.

2. Extract and compare the results for the northeast and southwest corner spaces.

3. Generate a commercial baseline model that has the commercial occupancy schedule.

4. Repeat steps 1 and 2 with the commercial occupancy schedule.

E.7.3 Results: U-value

Figure 43: Annual heating and cooling energy intensity with various window insulation values for residential schedule with no heat gains.

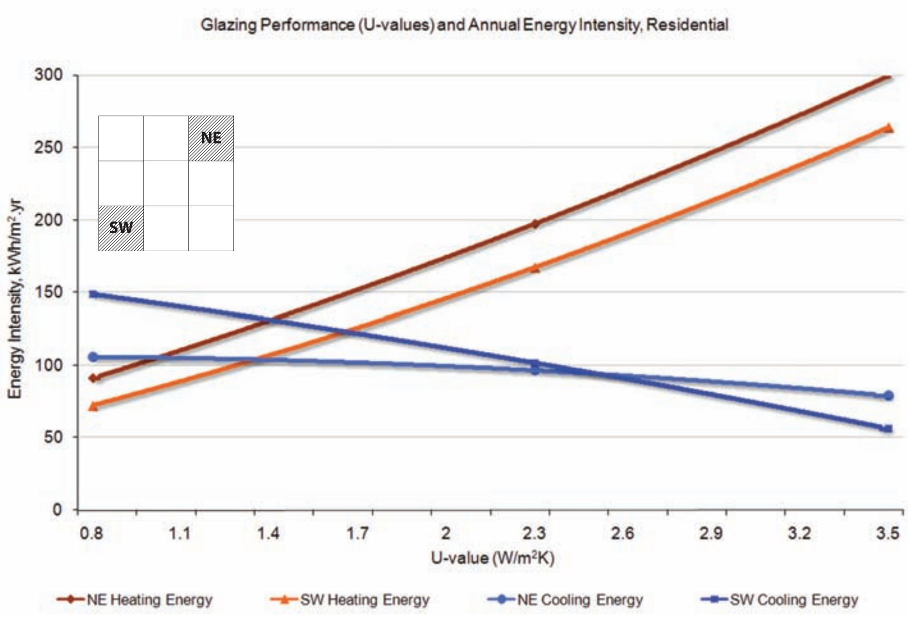
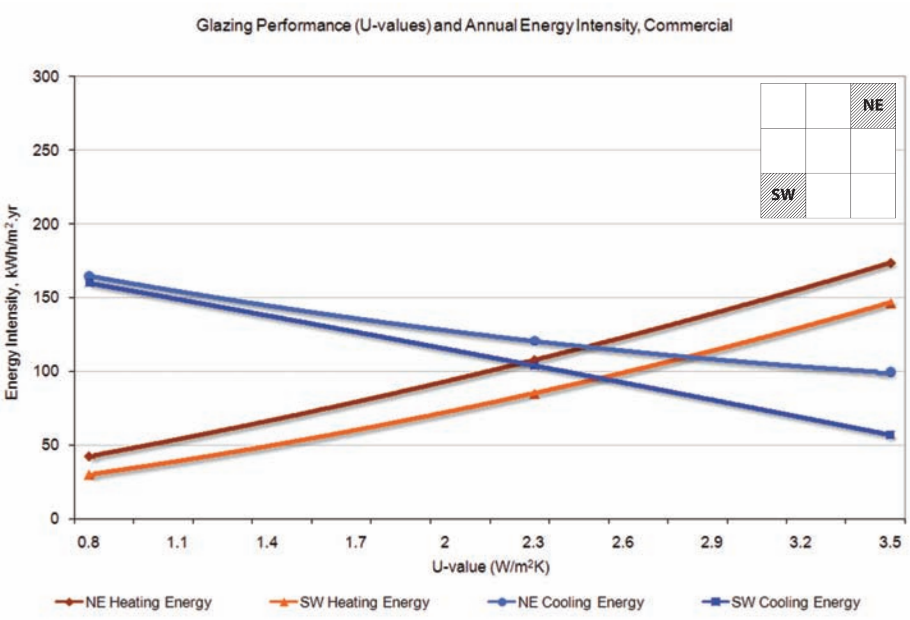


Figure 44: Annual heating and cooling energy intensity with various window insulation values for commercial building schedule.



E.7.4 Conclusions: U-value

- When the U-value is low (high insulating value) the heating energy intensity is low and the effect of lowering the window performance is significant because of the extent of windows on the building (60% window to wall area ratio).

- When the heating energy performance is optimized the cooling energy performance is adversely effected because this study assumes a sealed building and the heat accumulated during the day does not leave the building as quickly as with a glass with higher U-value. Passive cooling strategies such as natural ventilation and operable external shading should be used to counteract this effect instead of reducing the thermal performance of the windows.

- This effect on the relative heating and cooling energy is more pronounced with the commercial schedule because there are internal heat gains and night setback on the thermostat, thus lower heating energy demands and higher cooling energy demands overall.

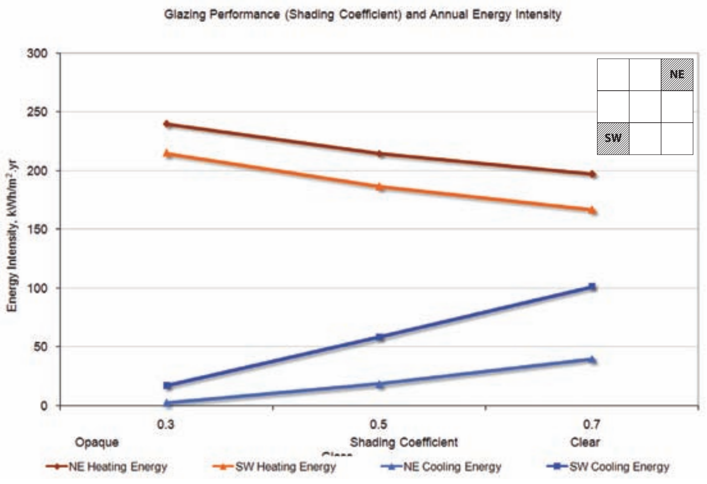
- This result suggests that in a commercial building if no passive cooling features can be applied, a life cycle costing analysis[2] may be required to determine an optimal window U-value which results in the minimum total primary energy used for space heating and cooling.

- Even the highest performing glass assemblies have relatively poor thermal performance when compared with a built up insulated wall, and cannot compensate for large GWA ratios.

- In buildings with greater than 50% window to wall area ratio, lower U-value window (higher insulating value than the standard) and passive cooling features will be required to compensate for the increase in total energy consumption associated with the high window areas.

E.7.5 Results: Shading Coefficient

Figure 45: Annual heating and cooling energy with various shading coefficients on the windows with no internal heat gain schedule.



2 Life cycle cost analysis requires building energy simulations and system level calculations to determine the amount of primary energy used and accounts for system and plant energy conversion efficiencies, which are not factored into the passive results analysis in this study. The results presented in this study represent the space level heating and cooling demands as discussed in the Introduction to this appendix.

E.7.6 Conclusions: Shading Coefficient

- The low shading coefficient glazing (dark tinted) blocks solar radiation all year long which reduces the cooling energy intensity in the building but increases the heating energy intensity.
- In a residential application the impact of the low shading coefficient on the heating energy performance is not preferred over the resulting benefit in cooling. High shading coefficients (less tinted glass) are preferred and can be coupled with passive cooling strategies to optimize energy consumption and comfort.
- In commercial applications where the cooling energy represents a greater proportion of the overall energy consumption, a low shading coefficient may reduce the annual total primary energy consumption, and building specific energy simulations should be used to determine the appropriate glazing product for the project.
- ASHRAE 90.1 prescribes shading coefficients for window to wall area ratios up to 50%. The Canadian MNECB does not prescribe shading coefficients in recognition of the fact that this permanent passive feature has an inverse effect on the building in heating mode, and instead allows the designer to determine which is most suitable for the project application.

E.7.7 Recommendations for Window Performance

For residential buildings, use clear glass with good insulating value (low U-value with low-e coating). Mitigate unwanted solar gains with external shading and passive cooling by natural ventilation.

For commercial buildings, use either clear glass with effective external shading elements or dark or reflective glass (low shading coefficient) to control unwanted solar gains. Regardless of shading option, the glass should have good insulating value (low U-value with low-e coating). Remove internal heat gains with other passive elements (e.g., natural ventilation).

E.8 Solar Shading

In this study two different shading approaches were tested. In the first set of simulations the baseline case was compared with fixed exterior overhangs of various lengths. In the second simulation the baseline case was compared with an operable external blind that can be opened to admit solar gains when they can offset heating energy and be closed to block solar gains when cooling is required.

E.8.1 Assumptions and Inputs

Wall RSI value:	R2.3 (ASHRAE 90.1) exterior wall with 100mm concrete outside	m^2K/W
Roof RSI value:	R2.6 (ASHRAE 90.1)	m^2K/W
Window U value:	U2.3 double pane windows	W/m^2K
Window total shading coefficient:	0.7 clear glass	
Window to wall area ratio:	60%	
Infiltration	0.5	ACH
Room resultant temperature set points :	21 - 24	°C
RH:	0-100 (not controlled)	%
Internal heat gains from people, lighting, or equipment:	Not included	
Ventilation:	Not included	
Fixed External Overhangs Window Height: Overhang Depth:	 2,400mm 300mm, 900mm, and 2,400mm 7°, 21°, and 45° angle between the bottom of the window and edge of overhang	
Operable External Blinds Description: Controls:	 50% transparent blind Blinds closed when space resultant temperature exceeds 22 °C	

E.8.2 Methodology

1. Generate 3 copies of the baseline model and add fixed exterior overhangs at the top edge of the 2,400mm high glazing on the east, south and west facades. Simulate 3 models with 300mm, 900mm and 2,400mm overhangs respectively. These cases represent shade angles of 7°, 21 °, and 45° angle measured between the bottom of the window and edge of overhang.
2. Generate an additional copy of the baseline model and assign 50% transparent operable external blinds to the east, south, and west windows. Control the blinds to reduce the cooling energy consumption with minimal effect on the heating energy consumption.
3. Extract and compare the results for northeast and southwest corner spaces on the top floor of the model.

E.8.3 Results: Fixed External Overhangs

Figure 46: Annual heating and cooling energy with fixed external shading of various depths in the top floor northeast and southwest corner spaces. Shade angle is measured from the bottom edge of the window to the outer edge of the overhang.

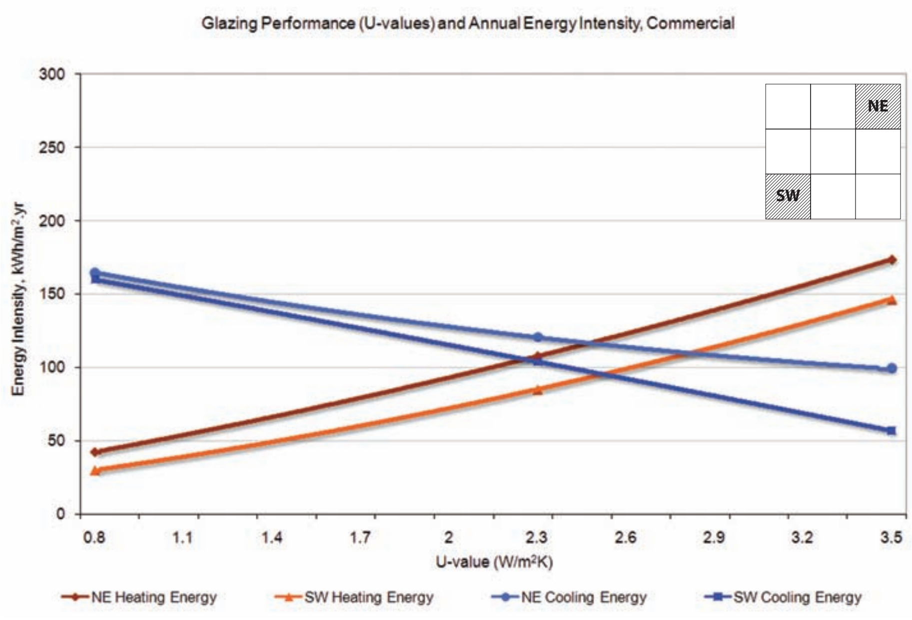
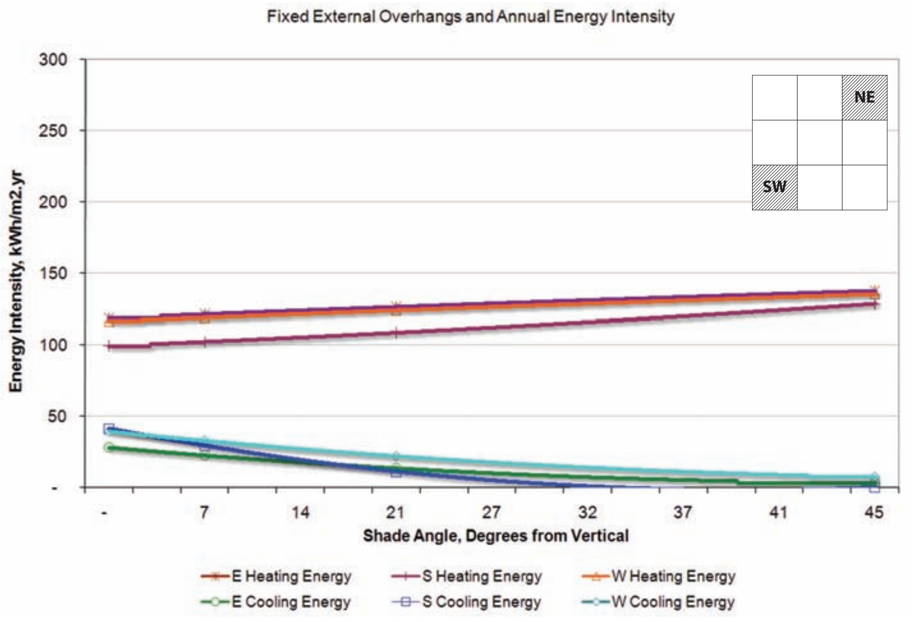


Figure 47: Annual heating and cooling energy with fixed external shading of various depths in the top floor east, south and west mid-facade spaces. Shade angle is measured from the bottom edge of the window to the outer edge of the overhang.



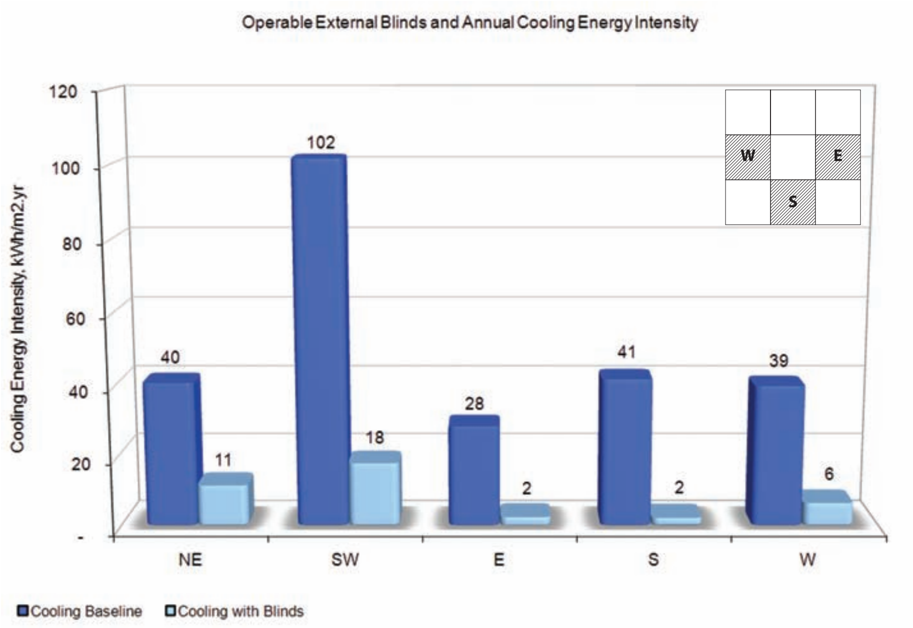
E.8.4 Conclusions: Fixed External Overhangs

- The external overhangs have the greatest impact on the southwest corner and the south mid-facade space.
- Overhangs with shade angles less than 10º (shade depths less than 300mm) have little impact on the space cooling energy overall and in the mid-facade spaces increase the heating energy by about the same amount as the cooling is reduced.
- Overhangs with shade angles greater than 35º eliminated the cooling energy requirement in the south mid-facade space with a marginal increase in space heating energy.
- When the shade angle is between 7º and 15º (depth between 300mm and 600mm) the cooling energy is reduced with minimal impact on the space heating energy in all cases.
- At depths between 21º and 45º(depth between 900mm and 2,400mm) the cooling energy is dramatically reduced in the corner and south mid-facade space, however the annual heating energy consumption increases.

Revenue Canada Offices
Photo: Busby Perkins+Will

E.8.5 Results: Operable External Blinds

Figure 48: Annual heating and cooling energy with operable external blinds controlled to close when the space temperature exceeds 22°C in the northeast and southwest corner spaces, S, W, E mid facade spaces on the top floor.



Dockside Green - Photo: Enrico Dagostini / Busby Perkins+Will

E.8.6 Conclusions: Operable External Blinds

- The external blinds effectively reduce cooling energy consumption on all three facades and nearly eliminate the cooling energy consumption in the east and south mid-facade spaces.
- External blinds are more effective than overhangs on the east and west facades because they successfully block low angle sun (early morning and evening) where no length of fixed overhang is effective.
- The external blind control can be optimized in a way that has no impact on the annual heating energy.

E.8.7 Recommendations on Shading

- Incorporate overhangs providing shading angles of 20°-30° off vertical (measured from the bottom window sill to the edge of the overhang) on south-facing windows.
- Incorporate operable external shading on east-, south- and west-facing windows.

E.9 Thermal Mass

This set of simulations investigated the effect of thermal mass construction on the annual heating and cooling energy of the passive, residential space with no internal heat gains. The baseline case has thermal mass in the exterior wall construction; however it is exposed to the environment and not the conditioned space. The baseline building was adjusted to create two new massing cases. The first case maintained the baseline concrete floor thickness with a lightweight external wall construction. The second case had increased concrete thickness in the floor and external wall with the location revised to the interior side of the insulation. Each case was tested with two window to wall area ratios, 60% as per the baseline model and 40% to demonstrate and discuss the synergy between these two passive elements.

E.9.1 Assumptions and Inputs

Wall RSI value: Baseline Lightweight Heavy Mass	R2.3 (ASHRAE 90.1) exterior wall with 100mm concrete outside exterior wall, steel frame with batt insulation exterior wall with 200mm concrete inside	m^2K/W
Floors: Baseline & Lightweight Heavy Mass	100 mm concrete 200 mm concrete -	
Roof RSI value:	R2.6 (ASHRAE 90.1)	m^2K/W
Window U value:	U2.3 double pane windows	W/m^2K
Window total shading coefficient:	0.7 clear glass	
Window to wall area ratio:	60% and 40%	
Infiltration	0.5	ACH
Room resultant temperature set points :	21 - 24	ºC
RH:	0-100 (not controlled)	%
Internal heat gains from people, lighting, or equipment:	Not included	
Ventilation:	Not included	

E.9.2 Methodology

1. Generate two copies of the baseline model to test the two construction weights with 60% window to wall area ratio. Assign both construction weights to both models, respectively.

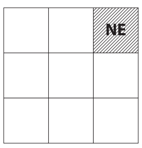
2. Generate a copy of each construction weight model and adjust the window to wall area ratio to 40%.

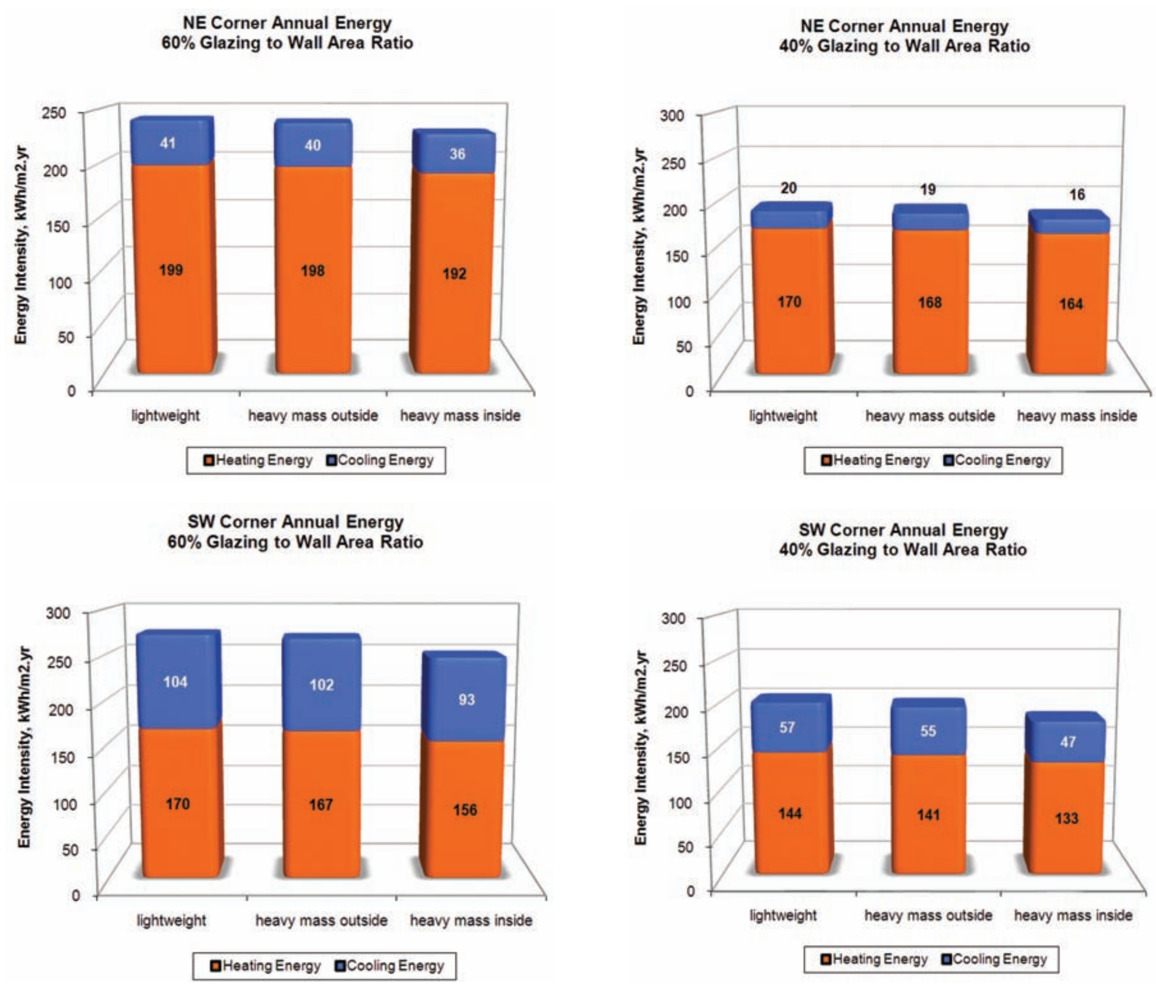
3. Extract and compare the results for northeast and southwest corner spaces on the top floor of the model.

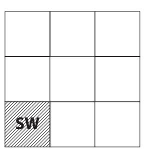
Leigh Square Photo: Boldwing Continuum

E.9.3 Results

Figure 49: Annual heating and cooling energy for various construction weights, in the northeast corner space with a) 60% and b) 40% window to wall area ratios and the southwest corner space with c) 60% and d) 40% window to wall area ratios.







E.9.4 Conclusions

- Thermal mass in the external wall is more effective at reducing both heating and cooling energy consumption when exposed to the interior conditioned space in all cases.
- The overall impact is greater with the lower window to wall area ratio, because there is more total external wall surface area and, therefore, more thermal mass.
- Even in the southwest corner space the benefit of increased window area and resulting additional solar heat gain does not exceed the negative impact of the greater window area's heat loss showing that lower window ratios result in better energy performance.

E.9.5 Recommendations on Thermal Mass

Use thermal mass that is exposed to the conditioned space and combine it with other passive elements to achieve its full energy-savings and comfort potential.

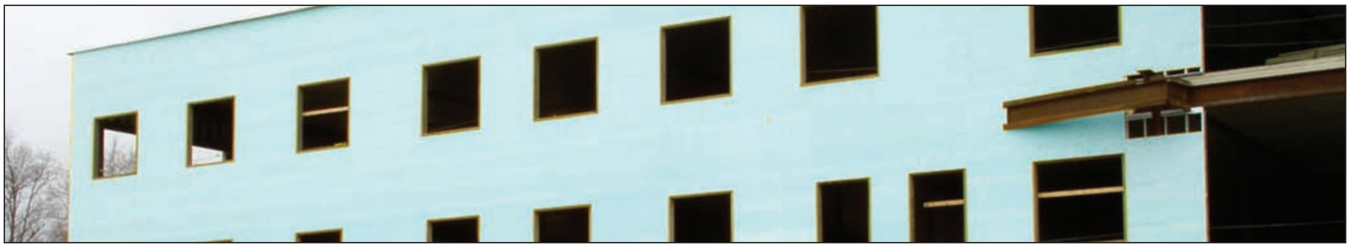
E.10 Wall Insulation

This study tested a range of insulation thicknesses within the exterior wall assembly. The minimum case tested consisted of 100mm concrete with 15mm gypsum wall board (RSI 0.4 m²oK/W) and no insulation. Insulation was added between the concrete and wallboard at various thicknesses up to 175mm to provide an overall RSI value of 7 m²oK/W. The simulation results are presented for the northwest corner spaces and the southeast corner spaces. This study was conducted without internal heat gains

E.10.1 Assumptions and Inputs

Wall RSI value:	RSI 0.4, 0.9, 5.3, 7 exterior wall with 100mm concrete outside various insulation thickness	m²K/W
Roof RSI value:	R2.6 (ASHRAE 90.1)	m²K/W
Window U value:	U2.3 double pane windows	W/m²K
Window total shading coefficient:	0.7 clear glass	
Window to wall area ratio:	60%	
Infiltration	0.5	ACH
Room resultant temperature set points :	21 - 24	oC
RH:	0-100 (not controlled)	%
Internal heat gains from people, lighting, or equipment:	Not included	
Ventilation:	Not included	
Commercial Internal heat gains: People: Lighting: Equipment	7am to 8pm, with night thermostat setback to 15 - 28 7 11 5	 oC people/100m² W/m² W/m²
Ventilation:	10	L/s/person

Detailed commercial schedule provided at the end of this appendix.



E.10.2 Methodology

1. Copy the baseline model which has an exterior wall assembly consisting of 100mm concrete, insulation, and 15mm of gypsum wall board.

2. Adjust the insulation thickness in each case as required to provide a range of insulating values, from RSI 0.4, which has no insulation to RSI 7 which has 175mm insulation.

3. Compare the results with the baseline case which meets the minimum prescriptive requirement of ASHRAE 90.1 which is RSI 2.3 m^2oK/W.

4. Generate a commercial baseline model with the commercial occupancy schedule.

5. Repeat steps 1 to 3 with the commercial occupancy schedule.

6. Extract and compare the results for northeast and southwest corner spaces on the top floor of the model.

E.10.3 Results

Figure 50: Annual heating and cooling energy intensities for the NE and SW corner spaces with varying insulation thicknesses for a residential building.

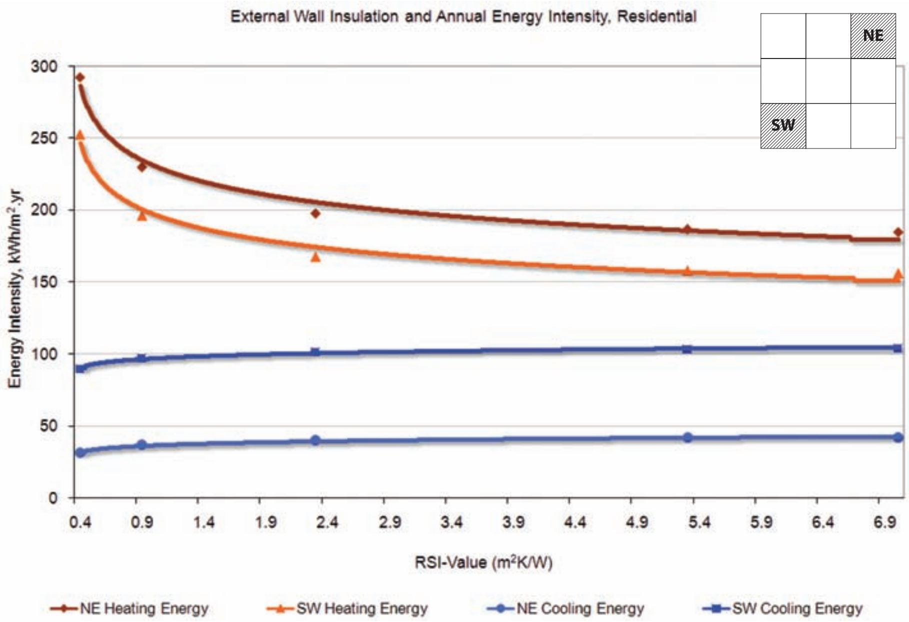
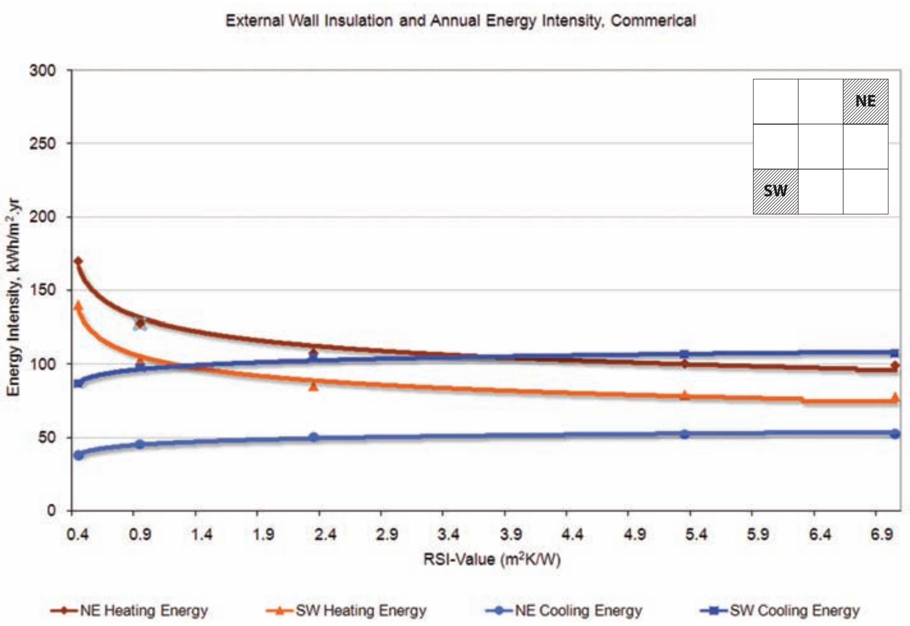


Figure 51: Annual heating and cooling energy intensities for the NE and SW corner spaces with varying insulation thicknesses for a commercial building.



E.10.4 Conclusions

- Wall insulation values below the RSI 2.3 value prescribed by ASHRAE significantly increase the space heating energy required in both residential and commercial spaces.

- Values between RSI 2.3 and RSI 5.3 yield some energy benefits and should be explored in building specific simulations. The curve between these two points indicates that significant energy benefits could be achieved even up to RSI 3.8.

- Increasing the wall insulation value beyond RSI 5.3 results in little to no net energy benefit.

- The increased insulation value increases the amount of cooling energy required in both space types, however the impact is greater in the commercial space because there are internal heat gains. This result is because the added insulation slows the rate of heat loss through the envelope during the summer in the cooler evening hours when the air temperature is lower than the space temperature. This result is unique to an airtight building, and should be counteracted with other passive cooling strategies.

- These results were generated with a 60% window to wall area ratio to represent the baseline for the Vancouver current market. ASHRAE standard 90.1 prescribes wall insulation values up to and including a 50% window to wall area ratio. Beyond that point, the building envelope trade-off method must be used to prove compliance, in which other energy features must be improved to offset the negative effects of large window areas. In this case, wall, roof and window insulation values greater than the prescribed value would likely be required.

E.10.5 Recommendations on Insulation

Target overall wall assembly RSI values between 2.3 (ASHRAE minimum) and 2.9. Use modeling to assess project-specific benefits, as the impact of insulation depends greatly on window to wall area ratio.

E.11 Infiltration

This portion of the study isolated the effect of the building construction air tightness. The baseline model was adjusted twice, to represent a well constructed air tight building with 0.2 Air Changes per Hour (ACH) infiltration rate and to represent a leaky building with 1.0 ACH. The simulation software calculates the infiltration rate hourly based on temperature differentials and wind speeds. The settings represent the amount of air infiltration at peak conditions as determined in the simulation.

E.11.1 Assumptions and Inputs

Wall RSI value:	R2.3 (ASHRAE 90.1) exterior wall with 100mm concrete outside	m^2K/W
Roof RSI value:	R2.6 (ASHRAE 90.1)	m^2K/W
Window U value:	U2.3 double pane windows	W/m^2K
Window total shading coefficient:	0.7 clear glass	
Window to wall area ratio:	60%	
Infiltration	0.2, 0.5, and 1.0	ACH
Room resultant temperature set points :	21 - 24	ºC
RH:	0-100 (not controlled)	%
Internal heat gains from people, lighting, or equipment:	Not included	
Ventilation:	Not included	

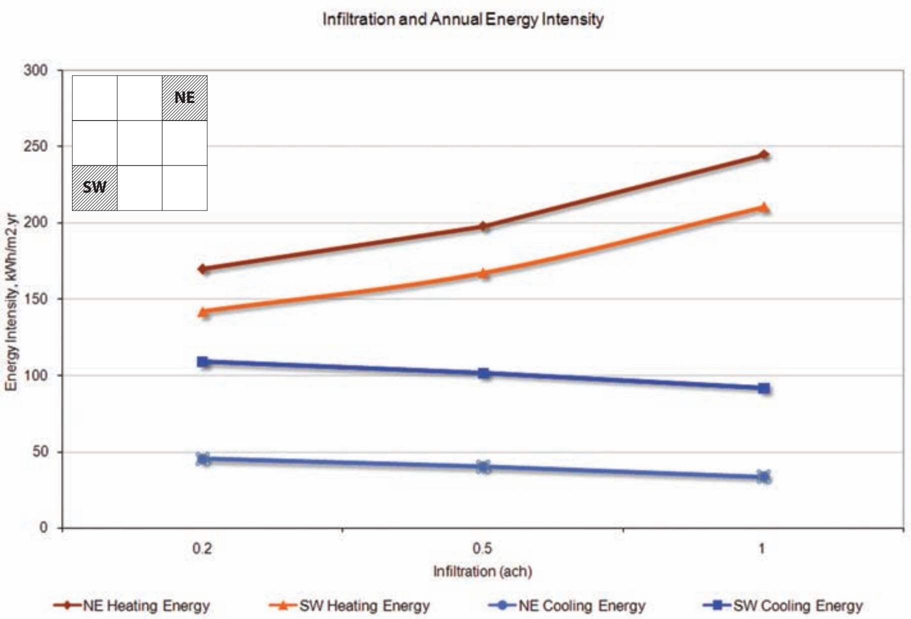
E.11.2 Methodology

1. Create two copies of the baseline model and adjust the infiltration rate in each to 0.2 ACH and 1.0 ACH respectively.

2. Extract and compare the results in the top floor northeast and southwest corner spaces.

E.11.3 Results

Figure 52: Annual heating and cooling energy for top floor northeast and southwest corner spaces with various rates of infiltration. 0.2 ACH represents a well constructed airtight building, 0.5 ACH represents average construction and 1.0 ACH represents a building.



E.11.4 Conclusions

- Increased infiltration rates increase the heating energy consumption and reduce the cooling energy consumption.

- The infiltration rate has a greater effect on space heating than on space cooling due to the temperature difference between the Vancouver climate and the indoor air set point.

- In this model the effect of infiltration is the same regardless of exposure (both SW and NE corner trends are consistent with each other). However, wind

Example of an HRV unit

pressure affects infiltration and spaces that have exterior surfaces exposed to high wind pressures may experience increased heating energy demands depending on the quality of construction. In the case of infiltration the space orientation is relevant to the prevailing winds rather than the solar angles.

- Increased infiltration rates reduce the cooling energy because the air exchange provides free cooling. However, this is not a recommended approach because the air leakage is uncontrolled and could be perceived as uncomfortable drafts for occupants as well as increase heating energy demands. Other passive cooling elements should be applied to reduce cooling energy consumption.

E.11.5 Recommendations on Infiltration

Use air-tight envelope to minimize uncontrolled infiltration.

E.12 Heat Recovery Ventilation

This part of the air tightness study compared the combined effects of infiltration rates, heat recovery ventilation and natural ventilation. One well recognized energy saving approach in North America is to maintain an airtight envelope year round and rely entirely on heat recovery ventilation equipment to provide energy savings. The energy performance of the parametric building with this strategy is compared with a case without the heat recovery system as well as a case that includes the HRV during the winter months only and has a less airtight envelope during the summer months with natural ventilation openings.

As this study includes ventilation air tempering energy in the results interpretation, a revised baseline model was generated to include ventilation throughout the year. The presented results include both space tempering and ventilation air tempering energy requirements.

E.12.1 Assumptions and Inputs

Wall RSI value:	R2.3 (ASHRAE 90.1) exterior wall with 100mm concrete outside	m^2K/W
Roof RSI value:	R2.6 (ASHRAE 90.1)	m^2K/W
Window U value:	U2.3 double pane windows	W/m^2K
Window total shading coefficient:	0.7 clear glass	
Window to wall area ratio:	60%	
Infiltration	0.2, 0.5	ACH
Room resultant temperature set points :	21 - 24	ºC
RH:	0-100 (not controlled)	%
Internal heat gains from people, lighting, or equipment:	Not included	
Ventilation:	Not included	
Residential Schedule Internal heat gains: People: Lighting:	24h/day 2 0 0	 people/room W/m^2 W/m^2
Ventilation: Heat Recovery Efficiency:	10 55%	L/s/person

E.12.2 Methodology

1. Generate a ventilation baseline model with 2 people per space, 10 L/s/person operating 24 hours per day. This baseline is referred to as Case A.

2. Copy this ventilation baseline model and adjust the infiltration rate to represent a well constructed air tight envelope with 0.2ACH; Case B.

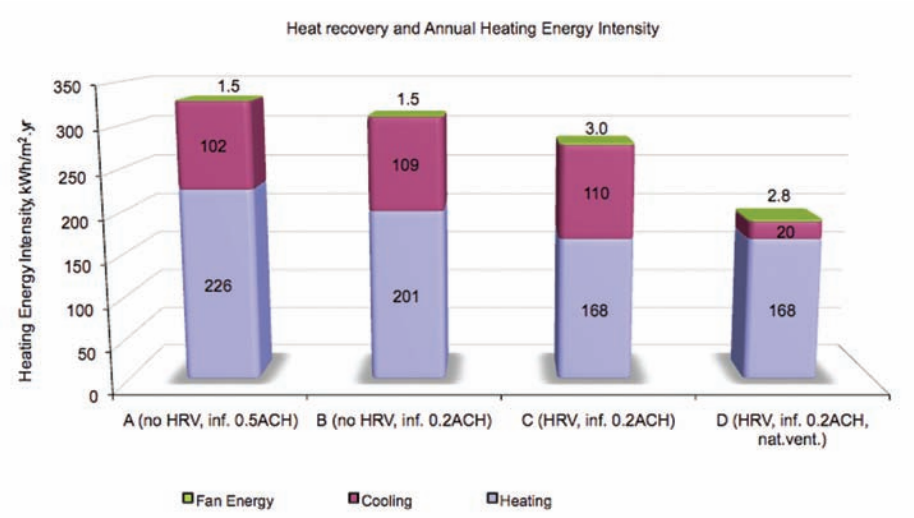
3. Copy the Case B model and add heat recovery to calculate the amount of heat energy that can be recovered from the ventilation air flow rate as it is exhausted from the space, Case C. The heat recovery unit seasonal efficiency is conservatively assumed to be 55% and no allowance is made for bypassing the heat exchanger during summer conditions, the resulting heat transfer increases the ventilation air cooling load.

4. Copy case C and add natural ventilation apertures and control to provide ventilation air to the space when outdoor air conditions are within the desired temperature range and/or can provide space cooling, Case D.

5. Extract and compare the results for the top floor southwest corner space.

E.12.3 Results

Figure 53: Annual heating and cooling energy for both space and ventilation air tempering for the southwest corner space on the top floor with various applications of air tightness and heat recovery ventilation.



E.12.4 Conclusions

- The simple HRV system (without summer bypass) reduces the total ventilation air heating energy consumption but slightly increases the ventilation air cooling energy.

- Increased air tightness decreases the space heating energy and increases the space cooling energy.

- The combined effect of increased air tightness and simple HRV reduces the total annual energy consumption when compared with the base case, and this result (Case C) represents a standard approach to energy savings.

- Case D shows that the combination of all three factors results in the best energy performance overall. Not accounted for in this case is also the wider range of acceptable comfort conditions in spaces with natural ventilation as discussed in the natural ventilation section below, which would further reduce the energy consumption of Case D.

- So far in the studies mechanical systems and electrical energy have been omitted from the analysis to isolate the passive building response. However, fan energy must be addressed when discussing HRV. An HRV unit has an additional return fan when compared with a basic air handling unit system where ventilation air is exhausted by small distributed fans or by exfiltration. The annual fan energy consumption is therefore higher with an HRV system over the basic alternative.

- Natural ventilation reduces the number of hours the fans operate and thus reduces the annual fan energy consumption as well as the space cooling energy. Natural ventilation also bypasses the HRV unit eliminating the unwanted summer heat exchange that would occur otherwise.

- Fan energy was calculated for the parametric model based on the ventilation air volume and though the HRV cases consume more electric fan energy, the absolute values are very low compared with the space heating and cooling energy consumption and were omitted from the charts.

E.12.5 Recommendations on Heat Recovery Ventilation

For optimum passive performance, use heat-recovery ventilation during heating season only, and design for natural ventilation and cooling by natural ventilation throughout the rest of the year.

E.13 Natural Ventilation

To simulate a simple natural ventilation strategy operable windows and controls were added at the external walls of all the spaces. The corner spaces have two facades and are cross ventilated with no model adjustments. To cross ventilate the mid-facade spaces the core was connected on all three levels and extended above the roof to represent a wind tower or an atrium. Apertures were added between the core and mid-facade spaces, as well as on the external walls of the core above the roof level. All of the apertures were controlled by the comfort conditions in the occupied spaces and the windows were closed when supplemental mechanical heating or cooling was needed to temper the space.

Hesquiat School
Photo: Marceau Evans Johnson Architects

The thermostat settings in the occupied spaces were adjusted to a wider deadband when natural ventilation was simulated. This assumption is based on ASHRAE Standard 55 Figure 5.3 and the adaptive comfort model approach which states that occupants will be comfortable in a wider range of temperatures, which are more closely related to outdoor conditions, when they have access to operable windows.

As ventilation energy is relevant to the natural ventilation discussion, ventilation base cases were generated for both residential and commercial occupancy. The natural ventilation model was simulated with both schedules.

E.13.1 Assumptions and Inputs

Wall RSI value:	R2.3 (ASHRAE 90.1) exterior wall with 100mm concrete outside	m²K/W
Roof RSI value:	R2.6 (ASHRAE 90.1)	m²K/W
Window U value:	U2.3 double pane windows	W/m²K
Window total shading coefficient:	0.7 clear glass	
Window to wall area ratio:	60%	
Infiltration	0.2	ACH
Room resultant temperature set points :	19 - 26	ºC
RH:	0-100 (not controlled)	%
Residential Internal heat gains: People: Lighting:	24h/day 2 0 0	 people/room W/m² W/m²
Ventilation:	10 6am to 6pm	L/s/person
Commercial Internal heat gains: People: Lighting: Equipment	7am to 8pm, with night thermostat setback to 15 - 28 7 11 5	 ºC people/room W/m² W/m²
Ventilation: *Detailed commercial schedule provided at the end of this appendix*	10	L/s/person
Window Opening Controls:	Windows open based on outdoor air temperature 18°C < outdoor air < 23°C	
Window Operable Area:	50% (1/2 of the 60% window area is operable)	
Core Ventilation Tower: Cross Ventilation	Core space connected and extended above roof surface by 2.7m to act as ventilation shaft Apertures added between mid-facade spaces and core dimension 1.5m x 6m	

E.13.2 Methodology

1. Generate a residential ventilation baseline model with the inputs noted in the table above.

2. Copy the residential ventilation baseline model and provide operable windows and controls at all of the exterior wall windows.

3. Connect the core spaces vertically and extend beyond the roof to simulate a ventilation shaft or wind tower.

4. Add apertures and controls to the wall between the mid-facade perimeter spaces and the new core ventilation shaft. Also add apertures and controls to the exterior walls of the ventilation shaft above the roof level.

5. Extract and compare the cooling energy results for the middle floor southwest and northeast corner spaces, which have corner cross ventilation within the space as well as all 4 mid-facade spaces, which have cross ventilation through to the core ventilation shaft.

6. Repeat steps 1 through 5 with a commercial baseline and the commercial schedule assigned in all spaces.

E.13.3 Results

Note: Mechanical ventilation is accounted for in all cases.

Figure 54: Annual cooling energy intensity with and without natural ventilation on the middle floor for the northeast and southwest corner spaces as well as mid-facade spaces in each cardinal direction with residential occupancy.

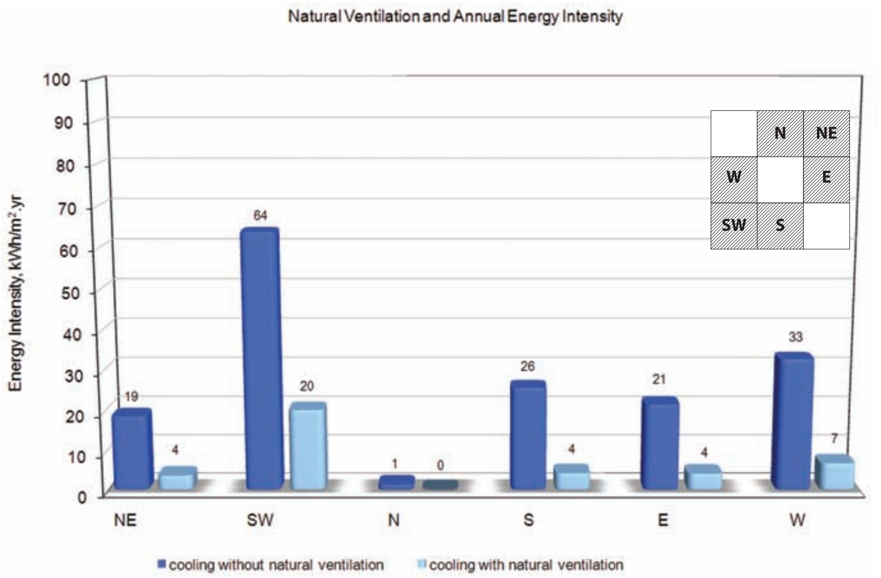
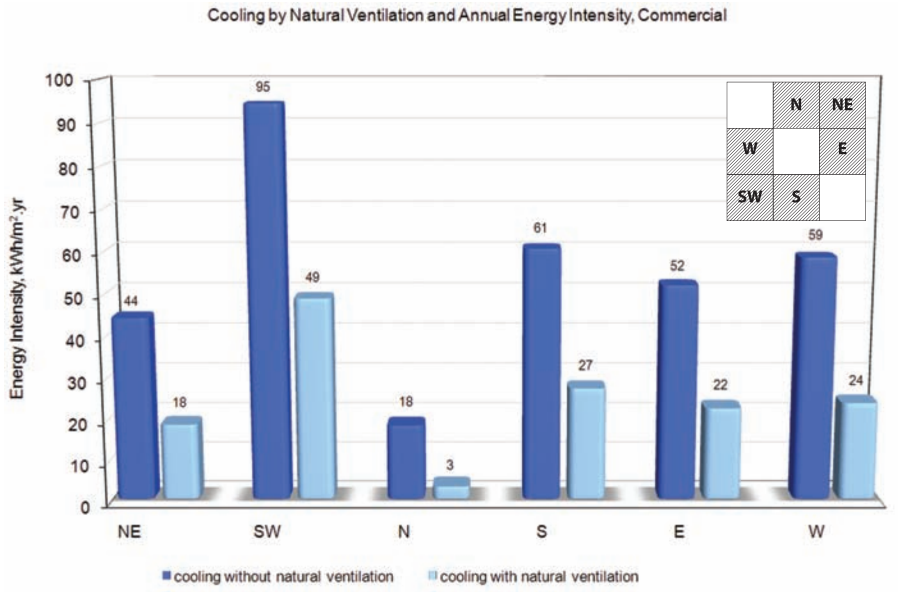


Figure 55: Annual cooling energy intensity with and without natural ventilation on the middle floor for the northeast and southwest corner spaces as well as mid-facade spaces in each cardinal direction with commercial schedule.

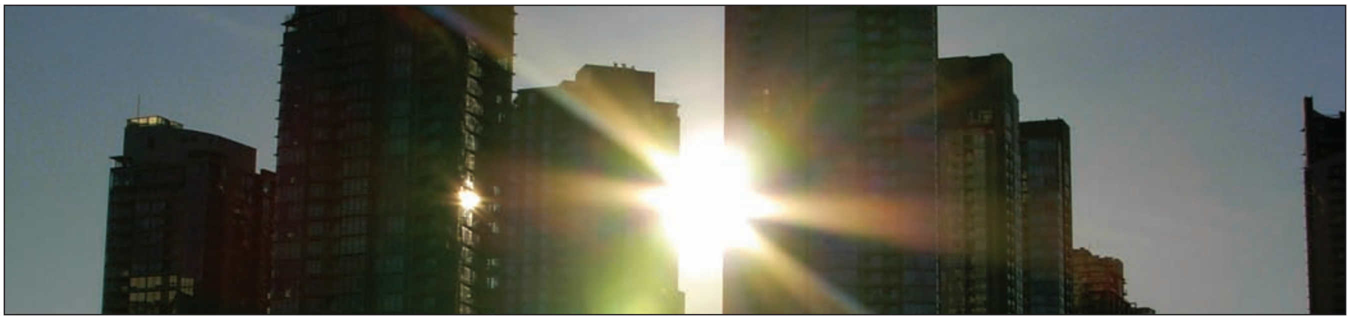


E.13.4 Conclusions

- Natural ventilation reduces the annual cooling energy in all cases, and by a significant amount.
- In the residential spaces cooling energy is reduced by 69% to 100%, 82% on average across the middle floor.
- In the commercial spaces cooling energy is reduced by 48% to 83%, 60% on average across the middle floor.
- In the residential occupancies the space cooling energy is very low in most of the spaces with the exception of the west and southwest corner spaces. These spaces could be treated with other passive cooling elements, such as shading, to reduce or even eliminate the need for mechanical cooling.
- Space and ventilation air heating energy was calculated but is omitted from the chart to focus the discussion on the passive cooling effect. Well controlled natural ventilation has very little impact on heating energy and in the simulations the value remained constant between cases.
- The corner spaces have different type of cross ventilation than the mid-facade spaces, and both strategies are effective, the corner spaces energy savings are only slightly lower than the floor average.

E.13.5 Recommendations on Natural Ventilation

Design for cooling by natural ventilation in all building types.



E.14 Strategy: Passive Heating

This study combined the passive heating elements in a series of simulations to demonstrate their combined effect in an application with no mechanical cooling system. Each measure was added to the baseline model incrementally to demonstrate the compound effect. The simple baseline model was used with no internal heat gains or ventilation energy to isolate the passive thermal response. HRV was not simulated as it does not affect the passive building response or space heating and is adequately addressed in section 12.0.

Two cases were simulated; Case 1 and Case 2, with different combinations of elements and the presented results are the sum of the heating energy requirements in all the perimeter spaces on the middle floor of the model.

E.14.1 Assumptions and Inputs

The following lists the passive element inputs applied to the baseline model as described in the methodology below.

Passive Building Element	Case 1	Case 2	Settings
Building Orientation	√	√	North-south
Buffer Space		√	3ft deep balconies
Window to Wall Area (GWA)	√	√	40%
Window Performance Insulation Shading Coefficient	√	√	U=0.81 W/m²°C clear glass
Solar Shading			
Thermal Mass	√		200mm floor & 200mm interior side of the external wall
Thermal Insulation	√		RSI 5.3
Infiltration	√		0.2
Natural Ventilation			


Leigh Square Community Arts Village Photo: Boldwing Continuum

E.14.2 Methodology

Case 1

The passive heating elements were added to the baseline model in the following order. Each element was added to the previous model, and the simulation results were extracted at each step.

1. Simulate baseline model.
2. Reduce window to wall area ratio to 40%, simulate and record results.
3. Improve window U-value to U=0.81 W/m^2°C, simulate and record results.
4. Increase wall insulation value to RSI 5.3, simulate and record results.
5. Revise floor and wall construction to heavy mass with 200mm concrete inside the insulation, simulate and record results.
6. Improve air tightness to 0.2ACH, simulate and record results.

Case 2

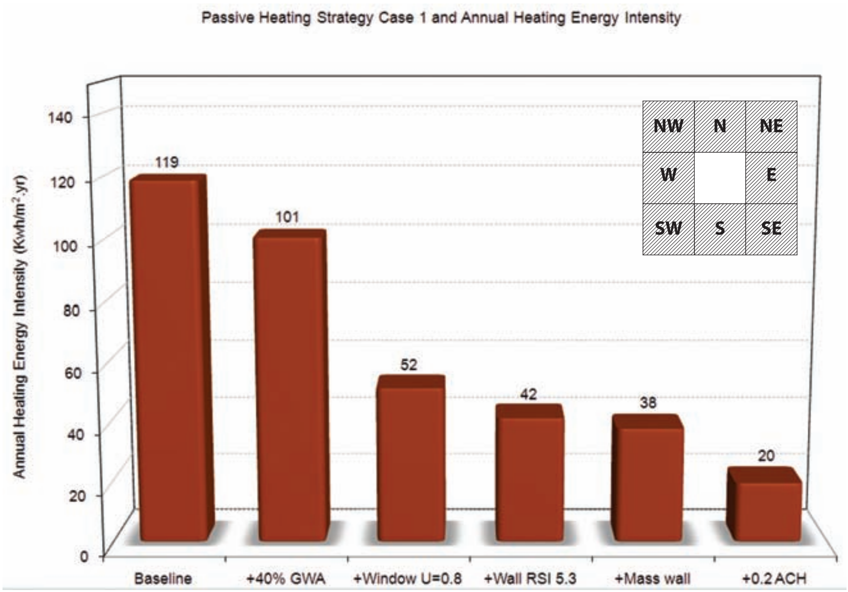
The passive heating elements were added to the baseline model in the following order. Each element was added to the previous model, and the simulation results were extracted at each step.

1. Simulate baseline model.
2. Reduce window to wall area ratio to 40%, simulate and record results.
3. Revise floor and wall construction to heavy mass with 200mm concrete inside the insulation, simulate and record results.
4. Add an enclosed balcony buffer space with no window openings, simulate and record results.
5. Add window openings to the enclosed buffer space, simulate and record results.

E.14.3 Results

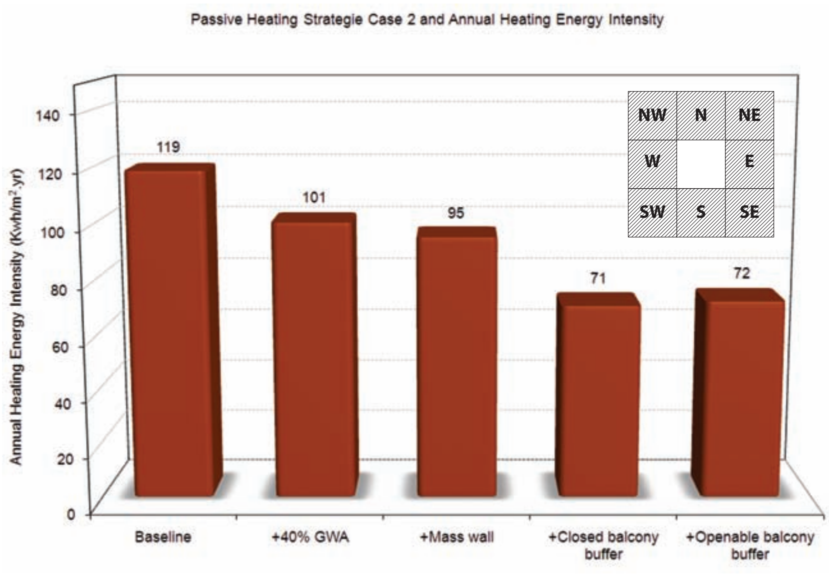
Case 1

Figure 55: Incremental, cumulative effect of the passive heating elements on the annual heating energy intensity summed over all the perimeter spaces on the top floor in the passive heating strategy Case 1.



Case 2

Figure 56: Incremental, compound effect of the passive heating elements on the annual heating energy intensity summed over all the perimeter spaces on the top floor in the passive heating strategy Case 2.



E.14.3 Conclusions

- The elements assigned in Case 1 resulted in significant heating energy savings. The greatest contributions came from the window to wall area ratio, the window U-value and increased air tightness. However, the final result of 20 kWh/m²year is a function of all the elements interacting.

- The elements assigned in Case 2 produced heating energy savings as well, however fewer elements were implemented and the overall savings are not as impressive as in Case 1.

- Two cases were run because when the buffer space was added at the end of Case 1 it was found that the buffer increased the heating energy consumption. This result was investigated and it was found that with the high envelope insulation the buffer space had minimal effect on the heating energy because heat gained via the buffer space was offset by the reduction in solar heat gains resulting from the shading effect created by the balcony.

- The benefit of the enclosed balcony was demonstrated in Case 2 assuming that wall and window insulation improvements were not applied in lieu of the enclosed buffer space, which is a realistic trade-off in actual construction practice.

E.14.4 Recommendations on Passive Heating

- Optimize the effect of passive heating by strategically combining passive elements. (See specific recommendations for each passive element above.)


Millennium Water
Photo: Merrick Architecture

E.15 Strategy: Passive Cooling

This study combined passive cooling elements in a series of simulations to demonstrate their combined effect. A heating system was simulated but the results are not presented in this section as the interaction is discussed in each measure, and the focus of this study is passive cooling only. Each measure was added to the baseline model incrementally to demonstrate the compound effect. The simple baseline model was used with no internal heat gains or ventilation energy to isolate the passive thermal response.

E.15.1 Assumptions and Inputs

Passive Building Element		Settings
Building Orientation	√	North-south
Buffer Space		3ft deep balconies
Window to Wall Area (GWA)	√	40%
Window Performance Insulation Shading Coefficient	√	U=0.81 W/m2°C SC=0.3
Solar Shading	√	External operable blinds
Thermal Mass	√	200mm floor & 200mm interior side of the external wall
Thermal Insulation		
Infiltration	√	0.5
Natural Ventilation	√	Refer to inputs in Section 13.0

E.15.2 Methodology

The passive cooling elements were added to the baseline model in the following order. Each element was added to the previous model, and the simulation results were extracted at each step.

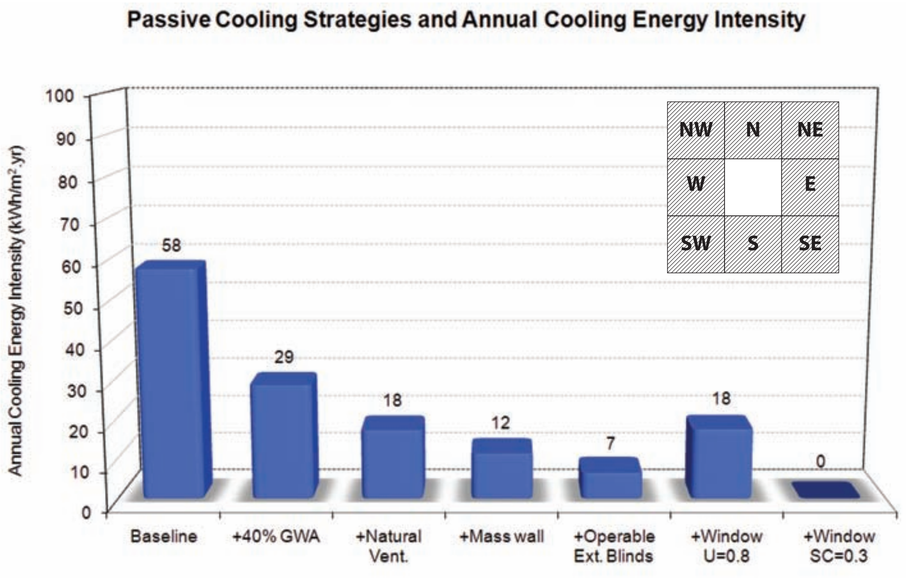
1. Simulate the baseline model.
2. Reduce window to wall area ratio to 40%, simulate and record results.
3. Add natural ventilation strategies in the same way as in the element study; simulate and record results.
4. Revise floor and wall construction to heavy mass with 200mm concrete inside the insulation, simulate and record results.
5. Add external operable blinds in the same way as in the element study; simulate and record results.
6. Improve window U-value to U=0.81 W/m²°C, simulate and record results.
7. Reduce window shading coefficient to 0.3, simulate and record results.

Regent College
Photo: Clive Grout Architects

The Regent College Library wind tower takes advantage of the natural stack effect to passively provide 100% outdoor air to this underground facility.

E.15.3 Results

Figure 57: Incremental, cumulative effect of the passive cooling elements on the annual cooling energy intensity summed over all the perimeter spaces on the top floor in the passive cooling strategy Case 2



E.15.4 Conclusions

- Increasing the window U-value even with operable windows increases the annual cooling energy.
- With all the passive measures applied the cooling load is eliminated; note that this model has no internal heat gains from occupants, equipment or lighting. Internal gains and heating loads are discussed in the commercial approach.
- Depending on the amount of internal heat gains the cooling energy may not be entirely eliminated, however, the passive features successfully eliminate the environmentally induced cooling loads and therefore the cooling system size could be dramatically reduced and be designed to deal with the internal gains only.

E.15.5 Recommendations for Passive Cooling

- Optimize the effect of passive cooling by strategically combining passive elements. (See specific recommendations for each passive element above.)

E.16 Strategy: Residential Approach

Passive building elements were selected that would improve the annual heating and cooling energy performance for a residential building in the Vancouver climate. Each measure was added to the baseline model incrementally to demonstrate the compound effect. The simple baseline model was used with no internal heat gains or ventilation energy to represent a simple residential occupancy.

Cooling energy results are presented even though in many cases residential buildings do not have mechanical cooling systems. However, even if a cooling system is not applied the cooling energy results provide insight on anticipated comfort levels. High annual cooling energy consumption indicates that such a space would overheat more often than a space with low cooling energy consumption.

The results are summed over the perimeter spaces of the middle floor of the parametric model, which represents the majority of residential development in Vancouver.

E.16.1 Assumptions and Inputs

Passive Building Element		Settings
Building Orientation	√	North-south
Buffer Space		
Window to Wall Area (GWA)	√	40%
Window Performance Insulation Shading Coefficient	√	U=0.81 W/m²°C clear glass
Solar Shading	√	External operable blinds
Thermal Mass	√	200mm floor & 200mm interior side of the external wall
Thermal Insulation	√	RSI 5.3
Infiltration	√	0.2
Natural Ventilation	√	Refer to inputs in Section 13.0

E.16.2 Methodology

The passive elements were added to the baseline model in the following order. Each element was added to the previous model, and the simulation results were extracted at each step.

7. Simulate baseline model.
8. Reduce window to wall area ratio to 40%, simulate and record results.
9. Improve window U-value to U=0.81 W/m²°C, simulate and record results.
10. Increase wall insulation value to RSI 5.3, simulate and record results.
11. Revise floor and wall construction to heavy mass with 200mm concrete inside the insulation, simulate and record results.

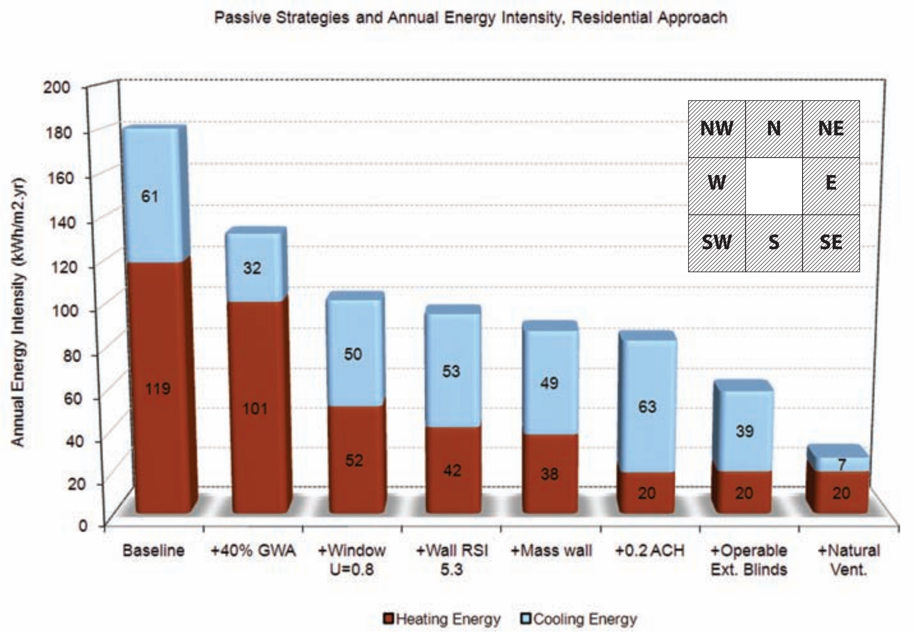
12. Improve air tightness to 0.2ACH, simulate and record results.

13. Add external operable blinds in the same way as in the element study; simulate and record results.

14. Add natural ventilation strategies in the same way as in the element study; simulate and record results.

E.16.3 Results

Figure 58: Incremental cumulative effect on the annual heating and cooling energy intensity for the all perimeter spaces on the middle floor for the passive residential approach.



E.16.4 Conclusions

- The simulation shows that the passive measures successfully reduce the total heating and cooling energy consumption of the residential building.

- The measures which increase the cooling energy, window and wall insulation and improved air tightness, decrease the heating energy and in each case the total energy consumption is lower with the added element. The operable blinds and natural ventilation strategies successfully reduce the cooling energy to be well below that of the baseline.

- The trends follow the results found in the individual element simulations and the combined effect is a dramatic reduction in energy consumption compared with the baseline case.

A.16.5 Recommendations on Residential Approach

- Incorporate as many passive design elements as possible to optimize comfort and minimize overall energy use.

E.17 Strategy: Commercial Approach

Commercial buildings typically operate with higher internal heat gains, greater ventilation requirements and different thermostat controls than residential buildings. As such, commercial buildings typically have higher cooling energy requirements and therefore the passive elements affect their energy performance differently than residential buildings. To demonstrate the effect of passive building elements on both heating and cooling energy performance on this type of building a commercial approach was simulated.

Passive elements were selected with a priority to reduce the annual cooling energy consumption of the building. The results are summed over the perimeter spaces of the middle floor of the parametric model.

E.17.1 Assumptions and Inputs

Passive Building Element		Settings
Building Orientation	√	North-south
Buffer Space		
Window to Wall Area (GWA)	√	40%
Window Performance Insulation Shading Coefficient	√	 U=0.81 W/m²°C clear glass
Solar Shading	√	External operable blinds
Thermal Mass	√	200mm floor & 200mm interior side of the external wall
Thermal Insulation	√	RSI 5.3
Infiltration	√	0.2
Natural Ventilation	√	Refer to inputs in Section 13.0

E.17.2 Methodology

The passive elements were added to the baseline model in the following order. Each element was added to the previous model, and the simulation results were extracted at each step.

1. Simulate the baseline model.
2. Reduce window to wall area ratio to 40%, simulate and record results.
3. Add natural ventilation strategies in the same way as in the element study; simulate and record results.

4. Revise floor and wall construction to heavy mass with 200mm concrete inside the insulation, simulate and record results.

5. Add external operable blinds in the same way as in the element study; simulate and record results.

6. Improve window U-value to U=0.81 W/m²°C, simulate and record results.

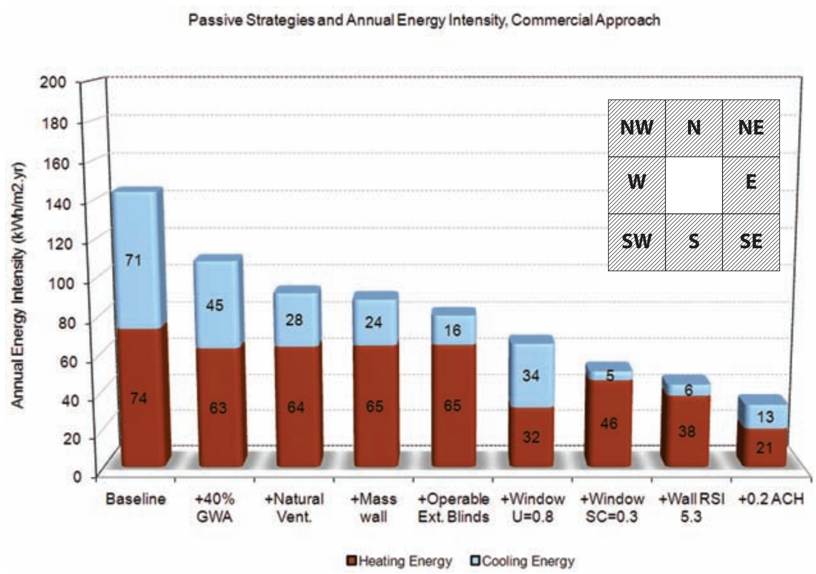
7. Reduce window shading coefficient to 0.3, simulate and record results.

8. Increase wall insulation value to RSI 5.3, simulate and record results.

9. Improve air tightness to 0.2ACH, simulate and record results.

E.17.3 Results

Figure 59: Incremental cumulative effect on the annual heating and cooling energy intensity for the all perimeter spaces on the middle floor for the passive commercial approach



E.17.4 Conclusions

- The passive elements reduce the total annual heating and cooling energy consumption in the commercial building significantly.

- Although the shading coefficient, and mass wall increase the heating energy consumption compared with the previous case, the element's effect on space cooling results in reduction in net annual energy consumption.

- The final result is a significant reduction in both space heating and space cooling energy consumption for the commercial building.

E.17.5 Recommendations on Commercial Approach

Incorporate as many passive design elements as possible to optimize comfort and minimize overall energy use.

E.18 Commercial Schedule

Room set points

	Summer	Winter
Resultant Temp.:	24-28(setback)	15(setback)-21
RH:	0-100%	0-100%

Conditioning schedule (on □ off ■) Set back system setback during weekends

On/off	□	□	□	□	□	□	■	■	■	■	■	■	■	■	■	■	■	■	■	□	□	□	□	□
hr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

People(no people during weekends)

People density:	14.3	m^2 / person
OA requirements:	10	l/s/person
Sensible gain:	73	W / person
Latent gain:	59	W / person

%	0	0	0	0	0	0	50	100	100	100	100	100	100	100	100	100	50	25	0	0	0	0	0	0
hr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Lighting (10% safety lighting during weekends)

Lighting power density:	11	W/m^2

%	10	10	10	10	10	10	100	100	100	100	100	100	100	100	100	100	100	100	1to	10	10	10	10	10
hr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Plug load (no plug load during weekends)

Installed power density:	5	W/m^2

%	0	0	0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100	0	0	0	0	0	0
hr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24


O2 Photo: Merrick Architecture

Appendix F – Case Studies

O^2

Vancouver, BC
Provided by Merrick Architecture

The O^2 project was conceived as the convergence of earth, air and water. O^2 is a residential mixed use project that integrates and responds to the natural elements within the densely populated urban context of Vancouver's West End.

O^2's natural ventilation recalls the proximity of the ocean and takes advantage of the corresponding sea breezes. The building form and strategically placed operable windows assist in optimizing natural cooling and ventilation through the suites.

Passive cooling is also achieved through the use of south- and west-facing shading that controls and reduces excessive solar heat gain. Natural daylighting is maximized through the careful consideration of the depth and layout of the units, integration of interior glazing, and location of external glazing systems.

Millennium Water – Vancouver's Olympic Athlete's Village

Vancouver, BC
Provided by Merrick Architecture

Vancouver's Olympic Village development demonstrates a number of passive design strategies that significantly reduce building energy loads. South facades feature horizontal shading while western exposures feature mechanized external vertical shading devices to control daylighting and solar heat gains. Deep balconies provide shading to the suites below.

Access stairwells are pulled to the perimeter of the building and encased in glass to maximize natural daylighting, encourage the use of stairs, discourage elevator use, and draw light into the public corridors. Natural ventilation is optimized with operable windows. Suites are designed as through-units to allow cross-ventilation with unconditioned exterior hallways. Evaporative cooling ponds located in the courtyards between buildings cool the air as it circulates between the external and interior environments.

Pacific Institute for Sport Excellence, Camosun College

Victoria, BC

Provided by Cannon Design

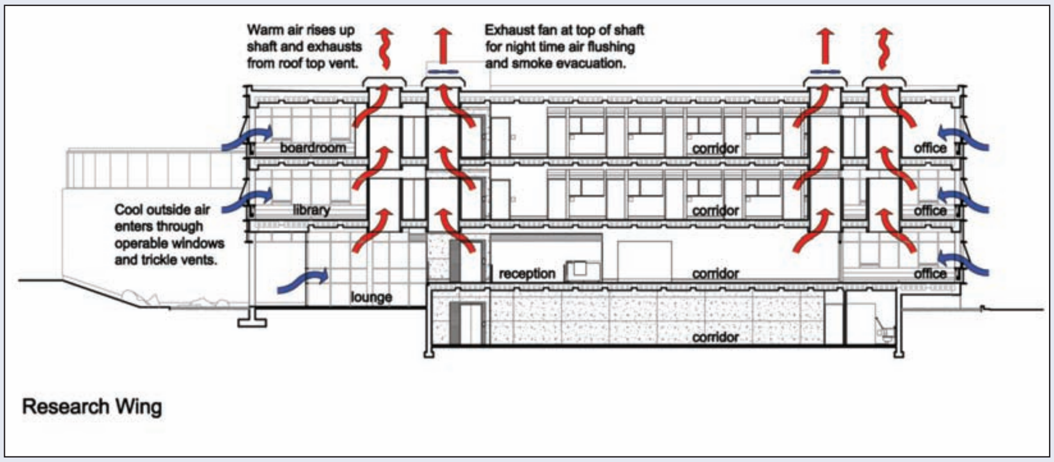
The Pacific Institute for Sport Excellence (PISE) accommodates a complex program of sport education, sport medicine and wellness, and high-performance athletic research and training. It is located on the outer edge of Camosun College's semi-rural Interurban Campus and will ultimately become an important urban landmark within the college's master plan.

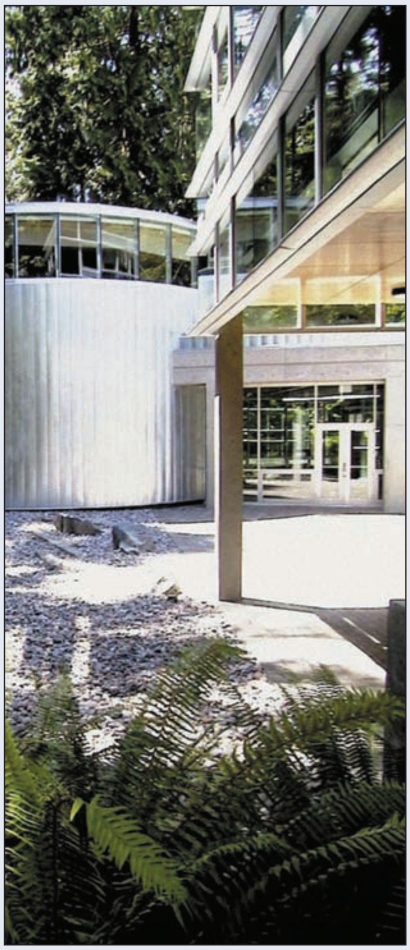
PISE's greatest energy-saving factors are its site orientation and building shape. Tucked into the slope of the hill, first floor service spaces and change rooms are earth-sheltered under an urban plaza. The building's east-west oriented shape maximizes southern exposure on the long, highly glazed 3-storey facade. East and west facades are minimized and have reduced window areas.

A constrained construction budget precluded the implementation of exterior shading devices on the south facade. Instead, the design called for the south facade to slope outward 15 degrees, providing 'self shading' for the interior during summer. This strategy cost only nominally more than a vertical facade, and considerably less than exterior shading devices. This provided a dynamic and highly imageable form to the institution and worked well to accommodate different program areas on the three floors. Most importantly, this strategy helped reduce energy consumption by approximately 45% compared to a conventional facility of this kind.

Liu Institute for Global Issues, UBC

Vancouver, BC
Provided by Stantec





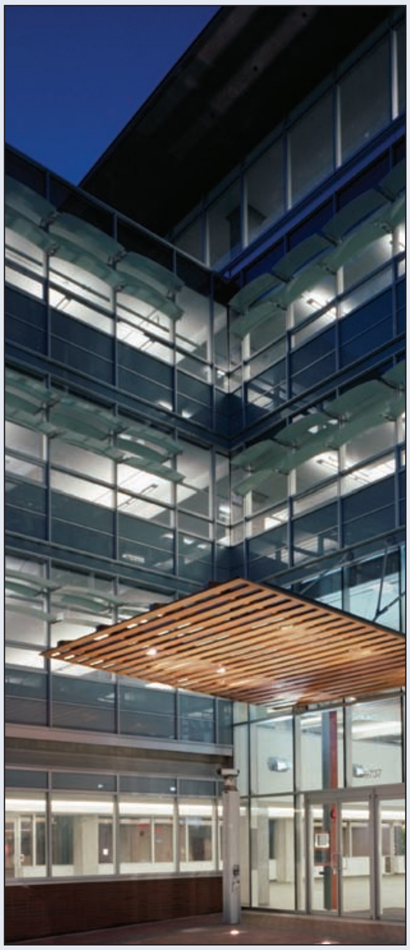
The Liu Institute has two distinct elements: one wing with offices and research and administration space for 72 participants, and one wing with meeting space including a case room, a multi-purpose room, and two seminar rooms. The building site was chosen carefully to maximize the quality of indoor light and take advantage of its natural forest setting. A rare Katsura tree stands in the entry courtyard to the north, while the south courtyard opens to a Zen garden and the forest backdrop beyond.

Passive design strategies include thermal mass in the form of exposed concrete surfaces. The pre-cast concrete is featured as both a structural element and a finish. The building spaces are naturally ventilated through operable windows, trickle vents and stack effect from four thermal chimneys. The adjacent forest provides passive shading for the interior spaces while allowing for extensive daylighting. The forest canopy offers occupants protection from direct solar glare.

Revenue Canada Offices

Surrey, BC

Provided by Busby Perkins+Will



Completed in 1998, the Revenue Canada office building was one of the first to demonstrate the rational and economic benefits of green building and passive design strategies in office buildings. The office spaces are organized around a central core that contains all shared heat-generating equipment, such as printers and photocopiers. This concentration of heat assists in creating the stack effect necessary to draw in fresh air from the perimeter windows for natural ventilation. For the first time, a 100% shading coefficient was implemented, with a two-tier system of exterior shading to block direct summer sun from entering the building. The upper sun shade is paired with an interior light shelf that reflects daylight off white-painted exposed concrete ceilings, allowing the daylight to reach deep into the office space. Through natural ventilation, a raised floor system, thermal mass from concrete flooring, and external solar shading, air-conditioning was minimized and is only used in the height of summer.

Adapted from Busby: Learning Sustainable Design, Janam Publications Inc., March 2007.

Photos: Martin Tessler

City of White Rock Operations Centre

White Rock, BC
Provided by Busby Perkins+Will

Completed in 2003, this 600 m^2 facility houses the public works departments for the City of White Rock, including administration, meeting rooms, lockers and changing rooms for municipal operations field crews. Each facade responds to the natural environment on that side of the building. To the east, a roof overhang and a row of deciduous trees provide summer shade and allow for winter sun penetration. To the south, the roof overhang continues and a projecting horizontal sun shade is added to protect the lower areas of windows. To the west, an exterior horizontal trellis (made of salvaged telephone poles) is supported on projecting fin walls that together provide afternoon protection from solar penetration. In contrast with the other elevations, the north facade is almost entirely solid, with windows covering only 5% of the wall area.

Dockside Green

Victoria, BC

Provided by Busby Perkins+Will and Hughes Condon Marler : Architects

Dockside Green is a 1.3 million ft² mixed-use development including residential, office, retail and industrial spaces on fifteen acres of former industrial land. The finished development will be greenhouse gas neutral and on site energy generation may exceed on site demand, turning the development into a net energy provider.

Dockside Green Phase R1: Synergy

Provided by Busby Perkins+Will

Completed in March 2008, Dockside Green's Synergy phase represents 95 residential units in 9,344 m², 351 m² of commercial space, and 6,876 m² of underground parking. Among Synergy's many passive features, exterior shading on the west and south facades minimizes solar heat gain in the residential suites.

Dockside Green Phase CI-3: Evolution

Provided by Hughes Condon Marler : Architects

The Evolution phase at Dockside Green is designed to meet the LEED® Platinum rating for Core and Shell under the Canadian Green Building Council (CaGBC). In order to achieve Platinum, the mechanical and electrical systems are designed to optimize passive solar and ventilation principles. Operable windows combine low (desk height) and high (ceiling height) air intakes and exhausts, and elongated floor plates optimize cross-ventilation. Narrow floor plans maximize daylighting potential and view access.

A retractable, vertical venetian blind system shades the south facade, and two-storey vertical fins shade east-facing windows from the late morning sun. Energy modeling shows that Evolution will consume approximately 48% less energy than the reference building. In addition, all hot water and heating energy will come from the Dockside biomass plant.

Butchart Gardens Carousel Building

Victoria, BC

Provided by Hughes Condon Marler : Architects

A traditional 32-figure wooden carousel will be housed within a concrete, wood and glass carousel pavilion at the base of an existing mature forest at The Butchart Gardens. The building consists of two main elements: a 90m long serpentine wall made of board-formed concrete and a glass drum with exposed timber structure. In some locations the wall creates cave-like rooms for children's parties, concession and service spaces, while in other instances it forms the retaining wall at the rear of the main circular carousel room. The circular roof over the carousel will be constructed of exposed glue-laminated ("gluelam") beams with a blue stain pine ceiling infill and a 4m diameter glazed oculus at the centre. The roof hovers over the curving wall on pairs of tilting gluelam columns. The upper domed roof will be covered in a thin layer of native mosses, sedums and Corsica mint. The lower roofs will be a continuation of the forest understorey; snow berry, ferns, salal.

By placing the building to the north of an existing hillside forest, solar overheating is avoided. In addition, by locating the building against the hillside, the planted roofs and thick concrete walls all improve the thermal performance of the interior spaces.

Fresh air is tempered by the earth's relatively constant temperature as it passes through a large earth tube in the hillside. Air is supplied at low levels and exhausted at high levels through operable windows. The operable windows and low velocity supply fan are automatically controlled via the DDC system.

The radiant slab heating/cooling system utilizes the existing main irrigation line running past the site. The irrigation line remains at a relatively constant temperature, and heat is removed using a water to water heat pump.

Hillcrest Community Centre

Vancouver, BC
Provided by Hughes Condon Marler : Architects

The Hillcrest Community Centre is designed to achieve LEED® Gold under the Canadian LEED® standard. This unique facility, which will serve as the curling venue for the Vancouver 2010 Olympic Games, is oriented carefully on its site to optimize solar gains. The strategic location of window and solar shading also contributes to energy savings. The facility features natural ventilation through operable windows, providing fresh air from the adjacent Queen Elizabeth Park and further reducing energy costs.

The preliminary estimated total energy savings is 44.8%, representing cost savings of $170,000/yr. The project will also use significantly less potable water than a similar conventional building by using groundwater and rainwater for toilet flushing and irrigation.

A series of other green building strategies will further reduce the environmental impacts of the building, including Forest Stewardship Council-certified wood for the structural gluelams.