Passive Design Toolkit

FOR HOMES

City of Vancouver — Passive Design Toolkit - for Homes

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

Prepared by:

Light House Sustainable Building Centre and Dr. Guido Wimmers.

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Cover Photo: Battersby Howat
Photographer: Michael Boland

Hand Illustrations: Matthew Roddis Urban Design

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1. Introduction

This toolkit outlines passive design practices for low-rise wood framed construction buildings in Vancouver.

How to use this toolkit:

This toolkit has been written to inform City staff and the design and development communities about passive design. While covering best practices, the toolkit addresses the specific needs of Vancouver and outlines a succinct definition of what 'passive' means for Vancouver. This toolkit can be used as a reference for best practices, and considered complementary to design guidelines and policy.

photo: Hotson Bakker Boniface Haden

The principles of passive design are not new and are, in fact, based on simple, proven concepts. Passive design refers to an approach that discourages reliance on mechanical systems for heating, cooling and lighting and instead harnesses naturally occurring phenomenon such as the power of the sun, direction of wind and other climatic effects to maintain consistent indoor temperatures and occupant comfort. By leveraging the natural environment, buildings that incorporate passive design can:

- help to reduce or even eliminate utility bills
- improve the comfort and quality of the interior environment
- reduce GHG emissions associated with heating, cooling, mechanical ventilation and lighting
- reduce the need for mechanical systems, thereby reducing the resources required to manufacture these systems, as well as the costs associated with their purchase or operation
- make alternative energy systems viable

Homes designed using passive strategies do not have to look aesthetically different from those that are designed without consideration for climatic factors, but occupants of a passive home will experience greater thermal comfort while paying lower energy bills. The most rigorous European standard, PassivHaus, regulates input energy to a maximum 15 kWh / m^2/ year for heating/cooling/ventilation – about one tenth of that in a typical new 200 m^2 Canadian house, and a difference equivalent to 300 litres of oil, 300m^3 of natural gas or 3000 kWh of electricity annually.

Homes designed using passive strategies do not have to look aesthetically different

photo: Lang Wilson Practice in Architecture Culture/ Nic Lehoux

A passive design can reduce total energy demand for space heating and cooling to less than 15 kWh / m2 / year.

When approaching the design for a building, the following questions can be considered:

'How important is occupant comfort for this building?'

'How important is occupant health in this building?'

'How important is the environmental footprint of the building?'

'How future proofed is the building design?'

'How will the building make use of natural climatic factors?'

Passiv Haus is a specific design standard developed in Austria and Germany. A building that qualifies for this standard has to meet clearly defined criteria, which include (for a building constructed at Northern European latitude of 40-60˚):

- A total energy demand for space heating and cooling of less than 15 kWh / m^2 / year
- A total primary energy use for all appliances, domestic hot water and space heating and cooling of less than 120 kWh / m^2 / year
- The total primary energy use includes the efficiency of the energy generating system

A Passiv Haus building shares common core features with other passive design buildings, relying on four common strategies:

- A high level of insulation, with minimal thermal bridges
- A high level of utilization of solar and internal gain
- A high level of air tightness (See Chapters 5.3 and 5.4 for a discussion on Thermal Bridges and Air Tightness)
- Good indoor air quality (which may be provided by a whole house mechanical ventilation system with highly efficient heat recovery)

The Passiv Haus approach was used extensively as a reference in developing this toolkit.

For further information on the Passiv Haus system please visit **www.passiv.de**

2. Passive Solar Power

The sun emits energy as electromagnetic radiation 24 hours per day, 365 days per year, at a rate equivalent to the energy of a 5725˚C furnace. In fact, each year the sun can supply nearly 36,000 times the amount of energy currently provided by total world oil consumption.

The sun's energy is radiated to the earth in the form of visible light, along with infrared and ultra-violet radiation which are not visible to the naked eye. When this radiation strikes the earth's surface, it is absorbed and transferred into heat energy at which point passive heating occurs. The rate at which solar energy reaches a unit area at the earth is called the 'solar irradiance' or 'insolation'.

Vancouver has a 'moderate oceanic' climate and is classified as heating dominated. This means that buildings require more days of heating than cooling. Fortunately, Vancouver does not experience extreme heat or cold conditions for long durations, making passive design less challenging. Even though Vancouver receives plenty of sun in the summer, it receives very little sun from November to March and is challenged to benefit greatly from passive winter solar gain (unlike cold and sunny Edmonton winters). Winter also sees early sunsets and late sunrises, while in the height of summer Vancouver experiences long daylight hours (up to 16.5 hours).

Fortunately, Vancouver does not experience extreme heat or cold conditions for long durations, making passive design less challenging in this city.

Table 1: Solar Radiation

Climate: Vancouver
Building: Kitsilano Residence

Interior Temperature: 20 C
Treated Floor Area: 208 m2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Heating Degree Hours - Exterior (kKh)	13.9	11.1	10.8	8.3	6	3.7	2.5	2.6	4.8	8.2	10.9	13.3	96
Heating Degree Hours - Ground (kKh)	6.4	6.2	6.7	5.9	5.2	2.9	2.2	1.8	2.9	3.7	4.4	5.6	54
Losses - Exterior (kWh)	1413	1130	1095	846	615	380	255	263	487	837	1115	1350	9787
Losses - Ground (kWh)	180	173	189	166	145	82	62	51	82	102	125	157	1515
Sum Spec. Losses (kWh/m^3)	7.7	6.3	6.2	4.9	3.7	2.2	1.5	1.5	2.7	4.5	6	7.2	54.3
Solar Gains - North (kWh)	30	53	87	118	171	197	186	140	95	64	38	23	1202
Solar Gains - East (kWh)	1	2	4	5	7	7	8	7	5	3	1	1	52
Solar Gains - South (kWh)	311	438	600	559	652	588	640	692	680	507	300	231	6199
Solar Gains - West (kWh)	2	4	6	8	12	12	13	11	8	5	2	2	86
Solar Gains - Horiz. (kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0
Solar Gains - Opaque (kWh)	21	39	76	105	155	162	167	138	94	52	24	15	1047
Internal Heat Gains (kWh)	367	331	367	355	367	355	367	367	355	367	355	367	4318
Sum Spec. Gains Solar + Internal (kWh/m^3)	3.5	4.2	5.5	5.5	6.6	6.4	6.6	6.5	5.9	4.8	3.5	3.1	62
Utilisation Factor (kWh)	100%	98%	92%	81%	55%	35%	23%	23%	46%	85%	99%	100%	63%
Annual Heat Demand (kWh)	863	453	234	77	6	0	0	0	1	94	526	871	3125

A 150m² passively designed house (2 storey) would need 15 kWh/m²/year or less for heating. This is 150 m² x 15kWh = 2250 kWh in total per year for heating. The roof area of this home would be 75 m². 75 m² x 0.78 (solar radiation) x 31 December days = 1800 kWh. Theoretically the energy from the sun given in December would be almost enough for the whole year!

Due to the low levels of solar exposure, passive design should include a combination of solar heating with passive cooling and shading in the Vancouver climate.

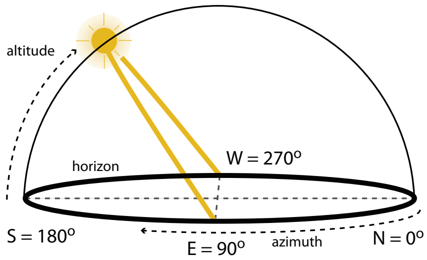
In consideration of Vancouver's climate, this toolkit will focus on maximizing solar gains in winter, and will include some recommendations for avoiding unwanted solar gain in the summer.

2.1 Solar Access

Solar access describes the amount of useful sunshine reaching a building. This value varies depending on climate, and can be impacted by the location of the sun and surfaces which surround a building.

The angle at which the sun strikes a location is represented by the terms *altitude* and *azimuth.* Altitude is the vertical angle in the sky (sometimes referred to as the height); azimuth is the horizontal direction from which it comes (often referred to as the bearing). Altitude angles can vary from 0˚ (horizontal) to 90˚ (vertically overhead). Azimuth is generally measured clockwise from north so that due east is 90˚, south 180˚ and west 270˚.

Altitude and Azimuth



As solar radiation strikes the earth, it is reflected by surrounding surfaces. This is called reflected radiation. Light coloured surfaces reflect more than dark ones.

It is important to understand the pattern of the sun in relation to specific latitudes. A sun chart is the simplest way to determine where the sun is at specific dates and times throughout the year. In order to better determine solar access, there are also computer programs which can manipulate data from charts and formulas.

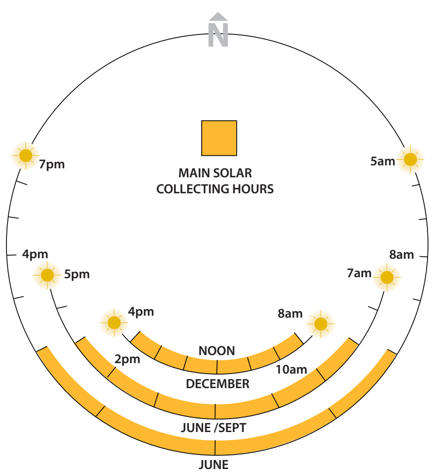
2.2 Energy Efficiency and Thermal Comfort

Though comfort can be highly subjective, The American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) defines thermal comfort as the state of mind that expresses satisfaction with the surrounding environment (ASHRAE Standard 55), and in this application, thermal comfort is achieved within a narrow range of conditions.

Factors such as temperature, ventilation, humidity and radiant energy affect thermal comfort, and for humans the comfort zone is within a very narrow range of conditions. Exterior climate conditions can also alter the acceptable interior conditions.

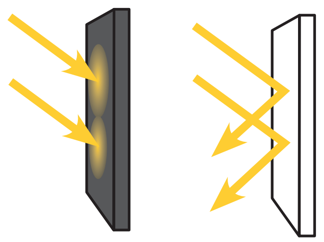
Building occupants are most comfortable when given the opportunity to adapt or have control over their environments (when they can open a window, put on a sweater, pull down the window blinds). Energy efficiency is achieved when occupant comfort is maintained through limited reliance on mechanical space conditioning. Thermal comfort rating software can model the amount of energy required to maintain comfortable temperatures within a building to size mechanical systems appropriately.

Sun Chart



Solar access describes the amount of useful sunshine reaching a building.

Dark and light surfaces



Light coloured surfaces reflect more than dark ones.


photo: Lang Wilson Practice in Architecture Culture/Nic Lehoux

Energy efficiency is achieved when occupant comfort is maintained through limited reliance on mechanical space conditioning.

Passive Solar Power

By planning for passive design, we can reduce the energy requirements of our built environment and improve thermal comfort for occupants. Passive design is not a new concept – ancient and medieval construction practices used abundant natural climatic conditions to passively control indoor temperatures.

Synergies/Barriers:

Designing for passive gains needs to be done keeping in mind best practices in construction – if a building is more air tight and leaks less energy, it must also be properly ventilated. If a building is to gain from south facing windows in the winter, it must also be shaded from the sun in the summer.

3. Orientation

Good building orientation in relation to the earth's axis and a site's geographical features can improve passive gains and thereby reduce the need for mechanical heating or cooling systems. This can also result in lower energy bills, and lower related GHG emissions.

Sites which are aligned along an east-west axis are ideal, as they receive good solar access while neighbouring houses provide protection from the eastern and western sun in the summer.

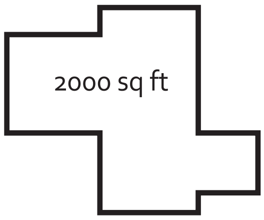
Broadly speaking, homeowners may have little or no control over optimizing site selection and orientation; the former depending on availability of property or land and the latter determined by municipal zoning. For instance, in Vancouver and many North American cities, a grid-oriented system predominates and in Vancouver the majority of homes are oriented north-south on east-west streets.

Still, small shifts in decisions around orientation, based on climatic and regional conditions, can help to optimize passive gains and maximize use of the free energy generated by the local environment.

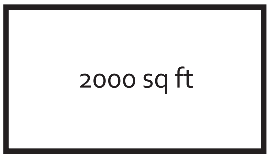
3.1 Building Shape

To maximize the benefits of passive design, a design must first and foremost minimize overall energy consumption requirements. A building design which keeps corners and joints to a minimum reduces the possibility of creating thermal bridges through which heat can dissipate to the outside of a building (see discussion in Chapter 5.4, thermal bridges).

Inefficient layout



Efficient layout



Complex layouts lead to more corners and joints which leak energy. It also creates more surface areas which can lose heat

Vancouver's Street Grid

In Vancouver the majority of homes (both house and condominiums) are oriented north-south on east-west streets.

Compactness is a measure of floor space relative to building envelope area. A compact design maximizes living space within a minimum envelope area. The envelope or shell of the building is where heat loss occurs. Restricting the number of exterior walls also ensures that the amount of wall exposed to the elements is kept to a minimum. In an ideal case, a building design will seek to maximize the ratio of usable floor area to the outside wall area (including the roof). The theoretical ideal form would be a sphere, because this is a maximized volume versus a minimum envelope. The next most usable form would be a cube, with every permutation from the ideal a step towards weakening the theoretical performance of the building.

Single family homes are usually not as high as they are wide or long. This varies from the ideal, thus major prominences and offsets should be avoided. These not only increase the envelope surface, but also lead to creation of heat bridges and are harder to maintain. Rowhouses and townhouses are another form of design which achieve maximum floor area and minimize opportunities for heat loss.

- Utilize a compact design in order to minimize exterior wall surface area and associated heat gain/loss potential

- A shape as close to a square as possible is optimum to minimize corners and maximize floor area in relation to outside wall area

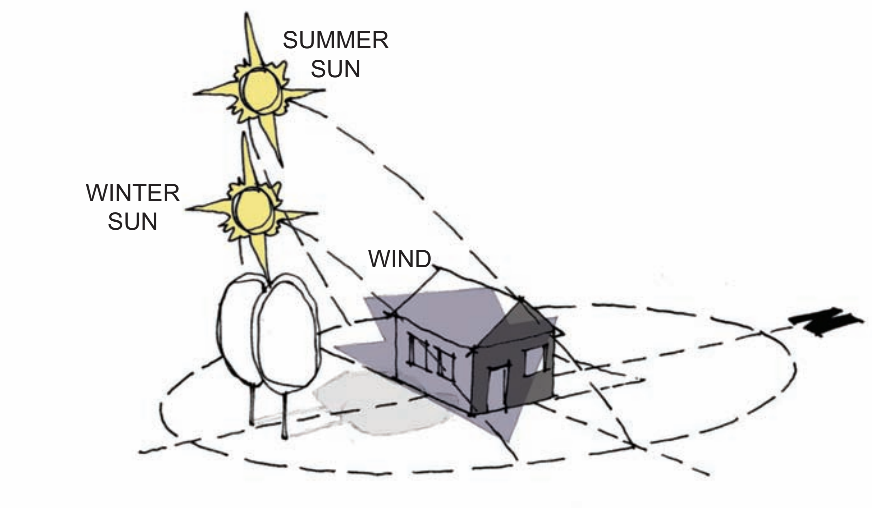
3.2 Ideal Elevations

Orientation can affect the angle at which the sun enters windows, causing overheating in the summer. Attention to overhangs can be useful when a building is poorly oriented. Building homes side by side and to the property line will also affect orientation considerations.

The angle of solar radiation as it enters a window (angle of incidence) will affect the degree of passive solar gain that radiation delivers.

When the sun is low in the sky, the light hits the window perpendicular to the glass. In this case, the heat gain is at a maximum. As the sun is higher in the sky, the angle is increased, reflecting more of the light. In this instance, less heat is transferred to the building. Windows on the south elevation can generally best exploit the sun.

Ideal Orientation



South facing windows allow for winter heat while strategically placed deciduous trees and overhangs will shade the hot summer sun. Neighbouring properties can effect solar access and wind pattern.

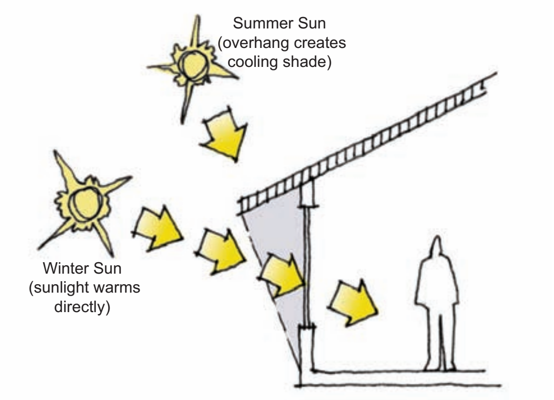
Southern elevation

To maximize the potential for solar gain through the winter months, a building should orient the longest elevation towards the south. (In design terms, south is considered to be anywhere within 30° east or west of true south.)

In addition, to reduce unwanted solar gain in the summer, designing for flexible sunscreens or overhangs for windows on these south facing elevations will ensure that the sun can be shaded during the warmer months.

Fixed overhangs should be designed to have a depth of roughly 50% of the height from the glass to the tip of the overhang. As the sun in summer is higher than in winter along the south elevation, a properly sized overhang can shade a south window for most of a summer day, without blocking out the low angled winter sun.

Overhang



Because the winter sun is at a lower angle, sun can travel directly into the building warming it during the cool months. The high summer sun is blocked by the overhang creating a cooling shade.

- Maximize the window area on the south elevation
- Avoid winter shadows from coniferous trees, other buildings, or other obstacles that will create shadows during the short winter days

Eastern and Western Elevations

To reduce unnecessary solar gain in the summer, a design should minimize window or wall area facing east or west.

Windows on the east elevation are exposed to solar gain throughout the year, while west facing windows will provide too much solar gain in the summer and insignificant gains in the winter.

At the same time, cold winter winds coming primarily from the east should also be taken into consideration.

- East facing windows should be limited in size, or protected by overhangs or trees
- West facing windows should be avoided unless they can be fully shaded during the summer months
- Planting deciduous trees on the east and west sides will shade the home in the summer, and allow winter light in when they drop their leaves
- The majority of residential lots in Vancouver are oriented such that the east and west facades are shaded by

A properly sized overhang can shade a south window for most of a summer day, without blocking out the low angled winter sun

Green roofs serve to moderate internal building temperature as well as to mitigate heat island effect. A study by the City of Toronto found that green roofs provide significant economic benefits in the areas of stormwater management and reduction of heat island (and the energy use associated with them). http://www.toronto.ca/greenroofs/findings.htm

There are several types of green roof systems, and many do not use new technology. Any green roof should be installed and maintained with care, and it is highly critical that a structural analysis of the building be completed prior to installation.

neighbouring houses.

- Landscaping with evergreen trees or tall hedges can help provide a windbreak

Northern Elevation

The north elevation provides the highest quality of daylight – diffused natural light.

- Design wall areas as primarily solid, with windows located where needed for daylighting and ventilation requirements
- Protect and insulate this elevation to prevent unwanted winter heat losses
- Take advantage of adjacent buildings to protect the building from heat losses

3.3 Landscaping

Landscaping can aid passive design strategies

- Plant shade trees in the appropriate locations to block or filter harsh winds
- Vegetation that blocks winter sun should be pruned, deciduous trees should be planted as they shed their leaves in winter, allowing in the sun
- Balconies on the south, if designed incorrectly, can restrict access to the winter sun
- Deciduous vines in combination with overhangs can provide self adjusting shading. Vines on walls can also provide summer insulation but this strategy is complicated as vines can also compromise the building envelope
- Plants can be used instead of paving to mitigate heat island effect in the summer

Key Design Strategies

- Orient the "main" side towards the south ± 30° East or West, and use large south-facing windows
- Keep east, north and west window space small, while also using fewer windows in total (see discussion under windows, chapter 6)
- Minimize unwanted shade to allow passive solar energy use
- Use landscaping consistent with required amounts of shading at different times of the year – deciduous trees will offer shade in summer but access to solar heat in winter
- Use a compact building form to limit heat loss
- Provide operable windows on all building elevations
- Row and multi-story building designs can maximize efficiencies

Orientation:

Cost: $$$$$

Ideal building orientation may be constrained by municipal planning layout requirements. A building can still use passive design strategies through careful consideration of the placement of windows and the design features used for shading and ventilation.

Synergies/Barriers:
As orientation is dictated by municipal planning, design becomes an important consideration – building design should acknowledge site limitations and compensate for them.

Impact on Energy Efficiency:
Even small changes in orientation and attention to details such as overhangs can be very effective.

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

photo: Battersby Howat/Michael Boland

4. Interior Layout

Good interior layout will facilitate many of the passive strategies recommended in this toolkit, in particular thermal mass, lighting and ventilation considerations.

Before deciding on interior layout, consider the following questions:

Which are the most frequently used rooms?

What are the lighting needs for each room?

What is the external shading situation?

4.1 Kitchens

Kitchens should ideally be located within the building in such a way as to avoid over-heating, either the kitchen itself or the rest of the building. One way to ensure this is to avoid placing kitchens on the western elevation. In most instances, this will cause over-heating in the warm summer months. An ideal location for a kitchen is on the eastern side of the building. This catches the morning sun but not the warmer, late afternoon sun. Northern elevations or central spaces within the building are also ideal for kitchens that are heavily used, though kitchens in central spaces need to ensure appropriate ventilation.

- Situate the kitchen on the eastern or northern elevation, or in a central space within the building

4.2 Living Spaces

Rooms that are occupied predominantly in the evening should be located on the western side of the building, in order to take advantage of the evening sun. Frequently used rooms (such as a home office, or the living or dining rooms of a residential building), should be located on the southern side where they can be warmed by sunlight throughout the day.

- Situate evening-use rooms on the west elevation

- Situate frequent-use rooms on the south elevation

4.3 Bedrooms

Bedrooms generally require less heat. Decisions for the location of bedrooms can largely be based on aesthetics and occupant or designer preferences in addition to thermal comfort considerations. Ideally, windows should be kept to a minimum and should allow for passive ventilation (see discussion under Ventilation, Section 8).

- Situate bedrooms as comfort dictates

4.4 Mechanical Systems

Similar mechanical and plumbing equipment should be grouped within close proximity of each other. This minimizes inefficiencies in piping or heat loss due to unnecessarily long lines and also

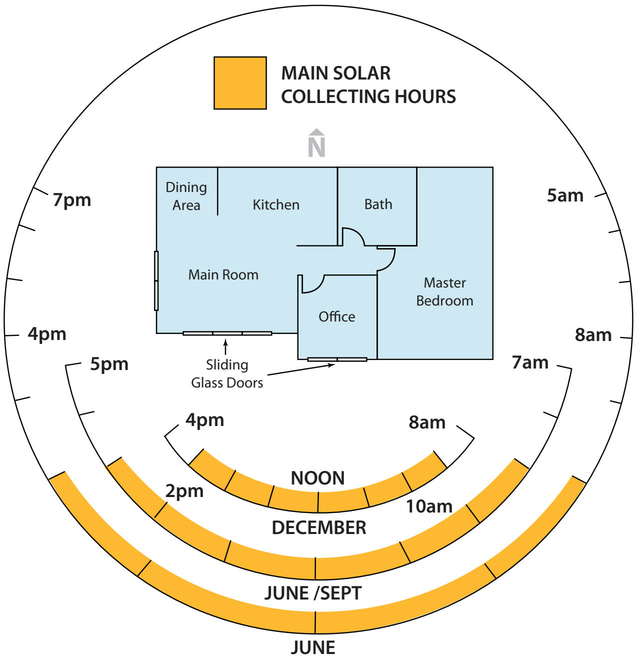
Rooms that are occupied predominantly in the evening should be located on the western side of the building, in order to take advantage of the evening sun.

Temperature sensors should not be situated in the northern part of a building. This area is generally cooler and sensors may detect cold even though the southern part of the building is receiving solar gain. A good passive design strategy would be to attempt to distribute this heat to the cooler parts of the house (see Chapter 9).

economizes on space dedicated to mechanical uses.

- Bathrooms, kitchens and laundry rooms should be placed above or adjacent to each other, so that efficiencies of the plumbing system can be maximized.
- Minimize the building footprint by using short pipe runs (hot/ cold water or sewage) and ventilation ducts
- Place thermostats with due consideration to temperature variances within the building (see sidebar)

Ideal Floor Plan



Interior Layout: **Cost: $$$$$ – $$$$$**

Good interior layout can assist greatly with passive heating and cooling, with particular opportunities for efficient daylighting.

Synergies/Barriers:
Layout decisions should incorporate other building elements and work in harmony with them, such as the windows and mechanical systems.

Impact on Energy Efficiency:
Good interior layout can off-set later energy consumption by reducing need for light and heat.

5. Insulation

In the world of outdoor clothing, breathable fabrics and super insulated linings work with highly detailed seams and closures to keep out wind, water and cold. Sound building envelope design can similarly moderate these conditions.

Minimum insulation requirements are currently embedded in the BC Building Code as well as the City of Vancouver Building By-laws. These can be prescriptive in nature (e.g. 'install R12 insulation'). However, the City of Vancouver and the new provincial building code are moving towards a performance, rather than prescriptive, path. Beyond a certain thickness, there is minimal increase in performance and attention must be paid to the airtightness of the construction. The performance path, which measures the overall energy performance of a construction, is a more accurate way to ensure that a building performs as intended.

For example, the EnerGuide rating system uses a blower door test to measure airtightness. Energy modeling, such as with EE4 software available from Natural Resources Canada, can predict the energy usage of a building. These approaches are more likely to ensure a particular level of performance, rather than specifying insulation values without then confirming that installation of specific insulation is actually delivering better performance.

Appropriate insulation can mitigate heat loss (or gain), while also eliminating the uncomfortable effects of unwanted radiant energy from warm surfaces in summer or cold surfaces in winter. To do this effectively, envelope design should be climate appropriate.

Insulation is arguably the most critical determinant of energy savings and interior thermal comfort, though good insulation should not preclude consideration of air tightness, heat bridges and appropriate windows. An increase in the number of windows or doors decreases a building's performance (see discussion under Chapter 6, Windows).

Among the questions to be asking when making insulation decisions and selecting materials are:

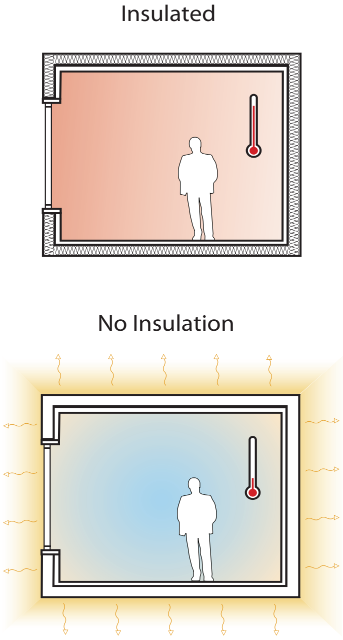
What is climate-appropriate insulation for this building?

What are the environmental considerations of the material selected?

Are there other benefits of the material besides insulation?

How will the design of the building be airtight?

Heat Loss



Heat exits a non-insulated building quickly thus requiring more heating resources to keep a room comfortable.

Thermal Resistance

The thermal resistances of insulation materials will contribute to indoor surface temperatures of a building's exterior walls and thereby the internal thermal comfort. High thermal resistance indicates good insulating qualities. Resistance is in turn influenced by the temperature difference between inside and outside, the conductivity of the insulation used, and the thickness of this material.

Temperature difference is an external factor, while thickness and conductivity are determined by the choice of insulation material. Lower conductivity and greater thickness both reduce heat flow.

R-values are a measure of a material's resistance to heat flow, and are therefore an indicator of a material's insulation properties. On the other hand, U-values are a measure of the amount of heat that escapes a surface. In the case of windows, the glass does not act as an insulation material, and therefore measurement of R-value is not appropriate, and we use U-values instead.

$R=1/U$

The higher the R-value, the better insulation qualities displayed by the material. The lower the U-value, the better performance of a window against allowing heat or cold to pass through it.

Insulation materials can be categorized into organic or inorganic, renewable or non-renewable, or they can be listed by consistency, such as foam or rigid, wool or loose.

5.1 Insulation Materials

Over the lifespan of a building, insulation will always have a positive environmental impact by reducing operating energy. However, the ecological footprint of the material itself should also be taken into consideration. This is complicated to define because there are a lot of different factors to be considered. Insulation can also have a bearing on indoor environmental quality depending on the materials selected, and can have implications for airtightness.

Classification of insulation is not straightforward as there are several systems to differentiate between materials. Materials can be categorized as organic or inorganic; renewable or non-renewable; or they can be listed by consistency, such as foam, rigid, wool or loose.

Examples of insulating materials (all available locally):

Conventional Insulating Materials

Fibreglass

Fibreglass in one of its two forms (loose or batts), remains the industry standard in North America. Most fibreglass insulation now contains some recycled content, and some manufacturers have replaced the traditional-but-toxic phenol formaldehyde binder with other more benign alternatives – or no binder is used at all.

Loose fill, a type of fibreglass insulation which is small and fluffy and blown into place, is associated with black mould and health hazards similar to those associated with asbestos such as lung disease. On the other hand, fibreglass batts are considered to have little or no negative impact on indoor environmental quality.

Spray applied foam

Sprayed foam insulation is used in some higher performance residential buildings. It allows for continuity of insulation as insulation is sprayed when in liquid form, and then expands to fill the cavity – including the smallest cracks. Performance is not as prone to installation errors.

Products range from those with a high content of toxic substances, to those that are water-blown and do not off-gas.

Rigid Polystyrene

This product displays fairly high R-Values (RSI-Values) and is durable as well as relatively affordable.

There are, however, issues with CFC's and other hazardous substances that go into the production of polystyrene panels. Furthermore, this material is a derivative of crude oil, and therefore displays a large carbon footprint.

Some polystyrene products do not off-gas, and of the two main types of rigid polystyrene (extruded or XPS, and expanded or EPS) EPS is the more environmentally benign.

Aerogels

Aerogels are a form of frozen silica smoke with extremely small pores, making this material extremely durable and light with incredible insulation values. Many are also translucent – and can be used to insulate windows and skylights or create translucent walls.

However, this is a very new material and testing is indicating that silica foam has similar detrimental health effects to fibreglass and asbestos; microscopic particles can break off and lodge in skin or lungs. Use of aerogels is not very common.

Mineral Wool

In industrial and commercial construction, mineral wool remains popular for its fire resistance, though extraction and processing of mineral wool (a by product of steel processing) may still be an environmental concern.

Many aerogels are translucent – and can be used to insulate windows and skylights or create translucent walls.

Natural cotton insulation made from recycled or waste denim

Natural Insulating Materials

Cellulose fibre

Among commercially available natural materials, cellulose fibre (usually recycled newsprint), is gaining popularity.

Spray applied cellulose fibre is quite dense and provides a good barrier against air infiltration from the outside. Due to the spray-in nature of the installation, performance is less likely to suffer from installation errors.

Cotton insulation

Cotton insulation made from recycled or waste denim is easy to install and does not off-gas.

Sheep's wool

Wool has been made into warm clothing for centuries but only now is its excellent insulating quality being applied to building structures.

Wood fibre

Waste wood fibre panels, of varying densities, are a popular insulation material for PassivHaus buildings in Europe. With a small ecological footprint this material also provides sound reduction and high thermal mass.

Straw bales, hemp or flax

First used to construct homes by settlers of Nebraska in the late 1800's, straw bale homes offer an insulation value of more than double that of standard frame homes. It's considered a very environmentally friendly building form, as it comes from a quickly renewable source and reduces the need for framing lumber and plastic barriers.

Table 2 – Insulation Comparison Chart

Insulation Material	Common Application	Environmental Impact	IAQ impact	Typical R Value per inch	Other Considerations	Cost Effectiveness ($-$$$$$)
Fibreglass Batt	Typically between floor or ceiling joists or wall studs	Some brands have up to 40% recycled content and have eliminated use of toxic binders, i.e. Formaldehyde-free Made from material with abundant supply	If non-toxic binders used then harmless. Respirator or certified dust mask to protect the lungs and long sleeve garments and gloves to protect the skin should be worn when working with fibreglass	3.6	Low moisture absorption Fire resistant with low flame spread rating (non-faced only) Does not absorb or retain moisture Little or no settling Ease on installation (placement and cutting for irregular spaces) Does not attract insects Insulation value decreases when wet	$
Fibreglass blown or poured	Typically between floor or ceiling joists (horizontally) where there will be no traffic (i.e. attic), can be used in wall studs (vertically) but installation may be restricted due to wall blocking, nails, cables, etc. In horizontal applications it is excellent at leaving no gaps. Will require small holes to be blown into wall cavities	Some brands have up to 25% recycled content and have eliminated use of toxic binders, i.e. Formaldehyde-free	If non-toxic binders used then harmless. Respirator or certified dust mask to protect the lungs and long sleeve garments and gloves to protect the skin should be worn when working with fibreglass	2.9	Low moisture absorption Fire resistant with low flame spread rating Does not absorb or retain moisture Little or no settling Better insulation coverage when dealing with irregular spaces, ceiling protrusions, hard to reach spaces, etc. as it creates a blanket over everything Requires a professional to install Must ensure it does not block attic venting when blown in	$$
Spray Polyurethane Foam	Can be used anywhere insulation is required, vertically or horizontally. Very good for situations where batt or board insulation is hard to attach, i.e. floor rim joists, lintels, etc. Can also be applied just as a base layer and then topped with batt insulation to save costs	Contains a minimum of 5% recycled content Can be up to 33% soy-based HCFC blowing agents replaced with HFCs, carbon dioxide or water and do not harm the ozone layer Can create a fair amount of waste (face shavings in stud cavity) Not recyclable	Once the spray has cured (generally after 24 hours) the components are inert and do not effect IAQ	7	No settling Can be used as an air barrier but not a vapour barrier Can fill and seal tiny cracks Not attractive to insects Mixed and installed on-site by a professional Must be protected from prolonged UV exposure to sunlight Requires covering with a fire resistant material when used indoors	$$$$
XPS (extruded) Polystyrene Board	Confined spaces like basements, foundation slabs, crawl spaces or exterior walls. Must be tight fit to avoid gaps	May contain some recycled content and can be recycled itself. Uses HCFC as blowing agent Made from petrol chemicals Recyclable	Brominated flame retardants present a greater health concern than the nonbrominated flame retardants used in polyisocyanurate, spray polyurethane, and cellulose insulation.	4.7 - 5.0	Moisture resistant and suitable for below grade applications Must be protected from prolonged exposure to UV or solvents If joints are sealed can act as an air barrier With increasing thicknesses can act as a vapour barrier When installed on an interior surface must be covered with a fire resistant material mechanically fastened to the building structure	$$$

Insulation Material	Common Application	Environmental Impact	IAQ impact	Typical R Value per inch	Other Considerations	Cost Effectiveness ($-$$$$$)
EPS (expanded) Polystyrene Board	Confined spaces like basements, crawl spaces or exterior walls. If below grade must be coated with foil or plastic. Must be tight fit to avoid gaps	May contain some recycled content and can be recycled itself. Made from petrol-chemicals	Brominated flame retardants present a greater health concern than the nonbrominated flame retardants used in polyisocyanurate, spray polyurethane, and cellulose insulation.	3.7 - 4.0	Moisture resistant and suitable for below grade applications Must be protected from prolonged exposure to UV or some solvents If joints are sealed can act as an air barrier With increasing thicknesses can act as a vapour barrier When installed on an interior surface must be covered with a firer resistant material mechanically fastened to the building structure	$$$
Aerogel	Not yet ready for commercial use	This technology is still early in the production stage so comprehensive analysis of effects is not yet available. Some research is going into use of discarded corn husks for aerogel manufacture.	Aerogel dust can generate dry skin, eye irritation and respiratory interactions.	> 140	Light weight High compressive strength	$$$$$
Polyurethane and Polyisocyanurate Board	Confined spaces like basements, foundation slabs, crawl spaces or exterior walls. Must be tight fit to avoid gaps Good for locations where a high R-value is required in a small thickness	Some brands use soy-based foams made from renewable vegetable oils and recycled plastics Can have some recycled content. Most brands no longer use formaldehyde or HCFC as the blowing agent Not recyclable Made from petrol chemicals	Boards are cured and the components are inert and do not effect IAQ	5.8 - 7.2	Usually come double faced with foil and sometimes bonded with an interior or exterior finishing material Foil face acts as a radiant heat barrier adding about R 2 to the insulation assembly Must be protected from prolonged exposure to UV or water If joints are sealed can act as an air barrier Can act as a vapour barrier Must be covered with a fire-resistant material	$$$
Mineral Wool (Slag and Rock Wool)	Attics, wood-framed roofs, walls, floors and around chimneys	Made from natural basalt or volcanic rock and slag (a by-product, containing inert materials, produced during the blast furnace smelting process and other steel making operations, therefore post-industrial recycled waste up to 70%) When properly installed can save up to 1000 times the amount of energy used to produce it Product is recyclable Energy intensive to produce but less per R value than fibreglass	Scientific research shows material is safe to manufacture, install and use when following manufacturers instructions. Once installed no significant fibres are released. Can be CFC and HCFC free Mineral wool may contain up to 5 % phenol-formaldehyde by weight—more than most fibreglass insulations.	3.1	Non-combustible and can withstand temperatures up to 1000 ºC Repels moisture Excellent acoustics barrier Ease of installation (placement and cutting for irregular spaces)	$$
Cellulose Fibre (blown or poured)	Typically between floor or ceiling joists (horizontally), can be used in wall studs (vertically) but installation may be restricted due to wall blocking, nails, cables, etc. Not to be used below grade Will require small holes to be blown into wall cavities	Up to 80% recycled paper, 20% fire retardant chemicals Requires up to 30 times less energy to make than fibreglass or mineral wool insulation	Inhalation of dust during installation VOC emissions from printing inks (although an increasing number of newsprint are using vegetable based inks.) Allergenic reactions may occur from inks	3.6	Requires professional installation Voids unlikely with careful installer Absorbs moisture which may led to fungal growth Combustible as fire retardant may not be consistent and may deteriorate over time Can settle up to 20% over time	$$

Insulation Material	Common Application	Environmental Impact	IAQ impact	Typical R Value per inch	Other Considerations	Cost Effectiveness ($-$$$$$)
Cotton Batt	Typically between floor or ceiling joists or wall studs	Cotton is a natural, renewable resource but the crop is water intensive, and can involve the use of pesticides or fertilizers which contribute to soil erosion. Some sources include scrap denim generated during denim manufacturing giving it a high recycled content (70%+) Low energy consumption in manufacturing process Product can be recycled	No formaldehyde-based binders Safe to handle	3.6	Fire resistant with low flame spread rating Little or no settling Ease on installation (placement and cutting for irregular spaces) Good performance at low temperatures Will absorb moisture	$$
Sheep's Wool	Typically between floor or ceiling joists or wall studs	Wool is a natural renewable resource that is treated with a natural rubber and borax solution for forming into rolls. Borax is a naturally occurring non-volatile salt that is used for it's pest-repellent, fire-retarding, and material preservation qualities. A natural latex rubber is used to allow borax to be applied to each fibre and increases the memory effect of the wool so that it will expand back to it's natural shape after being compressed during installation.	Borax is practically non toxic to birds, fish, aquatic invertebrates, and relatively non toxic to beneficial insects.	3.8	Good sound absorption. Natural buffering effect helps regulate indoor temperatures. Retains thickness reducing insulation efficiency overtime. Wool is also a natural fire retardant, safe to handle, renewable and recyclable.	$$
Wood Fibre Boards	Suitable for internal use as thermal and acoustic insulation on floors, walls and ceilings. They can also be used as external insulation with render protection and can receive lime and earth based clays band renders.	Wood fibre boards are rigid building boards made from sawmill off cuts that are pulped, soaked and formed into boards. The boards are then heated and compressed to their final thickness. Paraffin wax may be used as the binding agent.	Boards do not contain and glue or wood preservers. Non toxic in manufacture, use and waste disposal	3.8	99.5% waste material, off cuts from sawmill mainly. Very good breathability including hygroscopic moisture control to prevent moulds and improve indoor air quality. Uses about 1/10th the energy per tonne of product compared to plastic insulation boards. Wood fibre board insulation provides thermal mass to help regulate interior temperatures.	$$$
Straw Bales	Used as infill in wall assemblies in post and beam construction or as a load bearing wall assembly. Straw bales are typically 18 or 24 inches wide, depending upon stack orientation.	Any type of straw can be used, wheats, oates, barley, etc. The bales are made from the agriculture waste of the harvest, which is annually renewable and in many parts of the world is typically burned in the field.	Straw bales are a non-toxic product that allows a gradual transfer of air through the wall, bringing fresh air into your living environment, especially when combined with a natural plaster. Most straw bale houses do not incorporate vapour, air or moisture barriers as they want the natural breathability of the wall which further reduces the number of man made chemicals impacting the indoor air quality.	2.7	Excellent fire resistance qualities, a plastered straw bale wall will easily pass a two-hour fire test. Straw bales houses have stood the test of time, some being older than 100 years. Excellent sound absorption and ease of building can reduce construction costs. Requires large overhangs for moisture protection in rainy climates	$$

5.2 Selecting Insulation Materials

Insulation can serve as more than just an energy barrier, providing fire resistance, humidity control, and noise reduction among other things. Many fibre-based materials, such as cellulose or wood fibre, are sensitive to water exposure – a common concern in Vancouver's climate. On the other hand, these materials can also act to modify humidity levels, which is particularly relevant for structures which are meant to breathe, such as those which use straw bales.

- Select materials by balancing their relative strengths and weaknesses against environmental impact considerations. Table 2 provides a comparison of common insulation materials and their applications.

Specific Heat Capacity

This term is used to compare the heat storage capacity per unit weight of different materials. Unlike thermal mass, heat capacity is not linearly related to weight; instead it quantifies the heat storage capacity of a building element or structure, rather than its ability to absorb and transmit that heat.

The thermal mass of a material or assembly is a combination of three properties:

- Specific heat
- Density
- Thermal conductivity

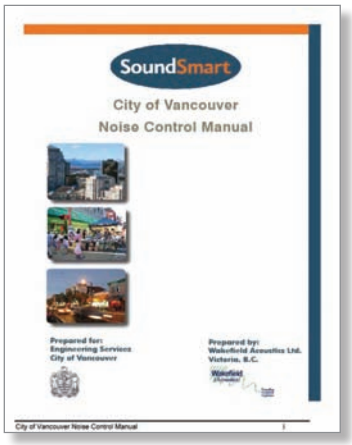
Fire Resistance

The combustibility of insulation materials is also an important consideration, although deaths in fire situations are more commonly caused by the inhalation of smoke generated by combustion of the room contents rather than the building envelope materials. Products like rock wool or even cellulose and wood fibre perform better in fire situations than polyurethane or polystyrene based foams or fiberglass.

Another potential problem is the chimney effect caused by shrinking of insulation materials within the wall cavities. Gaps of 19mm or greater can lead to a convection loop, allowing flames to spread more quickly from storey to storey.

Noise Reduction

Noise reduction can be a valuable indirect benefit of thermal insulation. There are two characteristics materials need to display in order to have a positive influence on noise reduction: high mass and flexibility. Polystyrene or polyurethane, for example, display neither and therefore have nearly no influence on noise. Rock wool, fiberglass and cellulose fibres are soft and have a significant mass, so they can make a contribution to noise reduction. The densest insulating material is wood wool, which is a very efficient sound deadener.



The City of Vancouver Sound Smart Manual can be found at www.city.vancouver.bc.ca/engsvcs/projects/soundsmart/pdfs/NCM1.pdf. **This document contains detailed information on sound control and the use of building materials and orientation to mitigate noise pollution.**

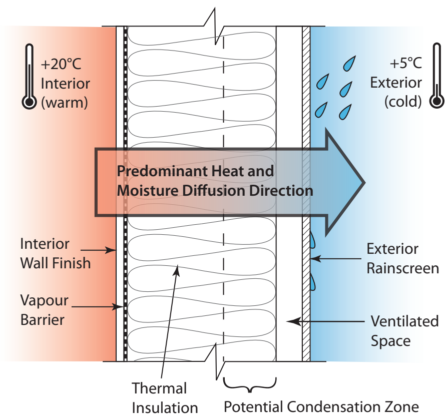
5.3 Airtightness

It is imperative for a structure to have an airtight layer in order for insulation to be effective. There are several strategies for achieving a super tight building envelope.

Air Barriers

Up to 25 percent of the energy loss in a building is attributable to air leakage. This can be addressed quite easily in new construction with careful attention to draught sealing, as well as carefully designed air locks (such as double doors). Poor airtightness can also contribute to mould problems if warm humid air is allowed to seep into the structure. Renovations are more complicated, though an airtight layer has to be added to the existing structure.

Moisture Barrier



An air barrier system should be continuous around all components of the building, with special attention given to walls, roof and the lowest floor. There must be proper continuity at intersections, such as the connection between floors, the joints between walls and windows or doors, and the joint between walls and the roof.

External house wrap, polyethylene and airtight drywall are probably the most common techniques for creating an air barrier. Correct sealants and caulking can help to stop leaks and must be properly installed to ensure durability over time.

Vapour barriers

Vapour pressure is generally higher inside a building due to the moisture generated by the occupants and their activities. This will create an external flow of vapour towards the outside, where the pressure is lower. If the vapour is allowed to move through the assembly it can condense on the surface leading to dampness and ultimately to mould or rot.

A vapour barrier reduces the movement of the vapour through the building assembly so that condensation does not occur. There are several types of vapour retardants including polyethylene, foil or latex paint. Unlike an air barrier the continuity of the vapour barrier is not as crucial as it can still perform well even if gaps are present.

5.4 Thermal Bridges

A thermal bridge occurs where construction materials create a bridge between internal and external environments allowing a heat transfer to occur. Metal is highly conductive and therefore susceptible to thermal bridges but any material can contribute to this effect to some

Up to 25 percent of the energy loss in a building is attributable to air leakage.

Energy modeling software

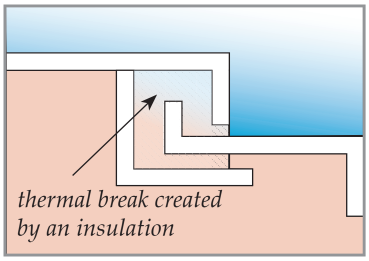
EE4: **Software to assess the energy performance of your design and verify design compliance against the Model National Energy Code for Buildings (MNECB). Available from Natural Resources Canada at http://www.sbc.nrcan.gc.ca/software_and_tools/ee4_soft_e.asp.**

Hot2000: **A low rise residential energy analysis and design software available from Natural Resources Canada at http://www.sbc.nrcan.gc.ca/software_and_tools/hot2000_e.asp.**

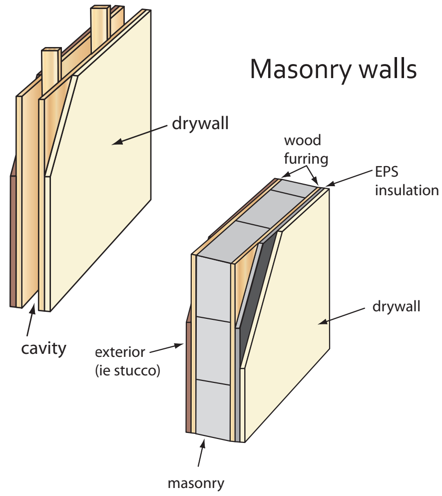
RETScreen**: Evaluates the energy production and savings, costs, emission reductions, financial viability and risk for various Renewable Energy and Energy Efficient Technologies (RETs). Available from Natural Resources Canada at http://www.retscreen.net/ang/home.php.**

degree. Wherever possible, thermal bridges need to be avoided through the use of a thermal break.

Thermal breaks are literally breaks inserted into the component (for instance in the window frame), which separate the exterior and interior materials.



5.5 Assemblies



Insulation: **Cost: $$$$$ – $$$$$**

Insulation is one of the most critical elements in reducing energy consumption requirements by avoiding unnecessary loss of thermal energy. The choice of material can also have non-energy related positive impacts.

Synergies/Barriers:

- When making decisions regarding insulation one should consider the whole building as a system and account for airtightness and vapour protection.
- Energy modeling, for instance using HOT2000 software, can help to determine when increasing insulation in a certain part of the building will improve performance and when it can no longer make a difference.
- It is important to remember that the main source of heat loss is through the windows, so it is essential to install high performance frames and to reduce thermal bridges in these areas.

Impact on Energy Efficiency:

Insulation lowers the need for heating and cooling, reducing overall energy consumption.

6. Windows (Glazing)

One of the most efficient ways to harness the power of the sun is through the use of suitable window technologies. Conventional residential buildings lose upwards of 50 percent of their heat through windows. At the same time, passive solar gain through windows is generally limited to just a few percent. In order to design windows that contribute to passive heating in the cooler winter months without an associated overheating risk in the summer, it is critical to balance location, size and thermal quality.

photo: melis+melis+wimmers

When making window decisions, consider the following:

How does window design address daylighting, views, ventilation?

How much heat loss will be attributable to the windows?

What is the payback for investing in high performance systems?

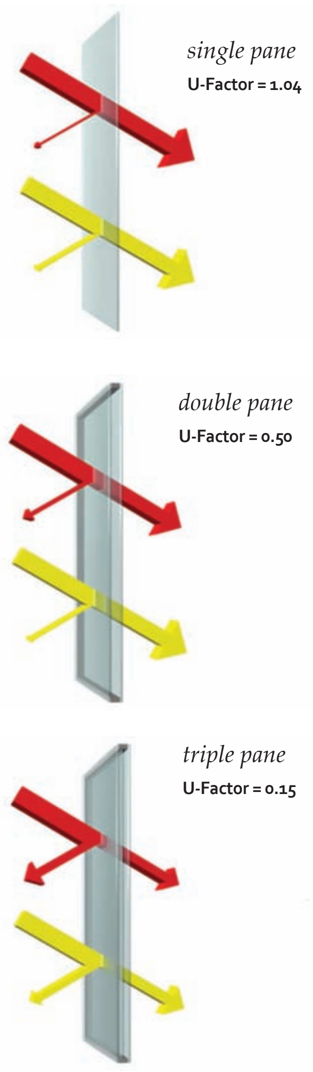
Are there other design considerations? (Overhangs, landscaping etc.)

6.1 Thermal Quality and Style of Window

The overall quality of a window is key to its performance and can be determined by the thermal quality of the glass and the frame. Further considerations are the solar heat gain coefficient of the glass and of the spacer material.

The style of window will also have an effect on its performance. Slider windows may be poorer air barriers as the sealing system is harder to design. Fixed windows are permanently sealed but do not offer the benefits of ventilation. Hinged windows use compression seals that are more sturdy than slider windows but may still wear out. Issues arise when worn out seals are not replaced.

Heat gain / heat loss



What is a U Value?

U-value is measured by U = I/R

U-values for windows can refer to the centre of glass or edge of window 'whole frame' measurements.

The value will change with the size of the window because the ratio of window to frame will increase as the window gets bigger.

Most manufacturers provide the U value of the glass and the frame separately – proper analysis must assess the U value of the **entire system**.

Table 3
Thermal Quality of Glass

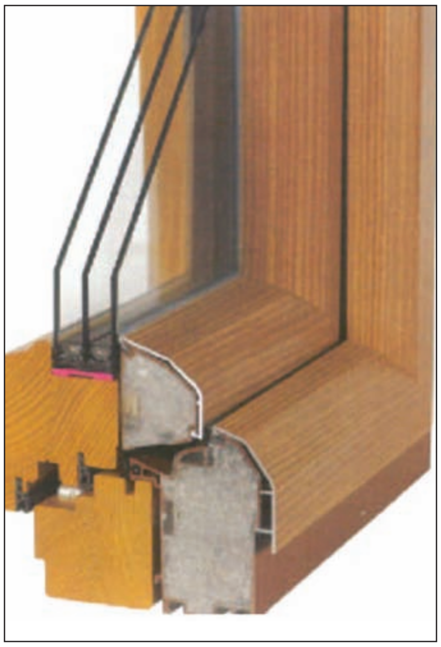
Low-e windows: Double pane glass with a U-value ranging from 1.1-1.5 W/m^2K and a solar heat gain coefficient of approximately 60%.	This type of window is more or less energy neutral when placed on the south side of a building, meaning solar gain is approximately the same as solar loss. If placed in any other location, this type of glass loses more energy than it gains. Therefore, it is recommended to avoid low-e windows when working with passive design especially in Vancouver which gets less than 2.5 hours of sun per day during the winter.
Super high performance windows: Triple pane glass with a U-value ranging from 0.5-0.7 W/m^2K and a solar heat gain coefficient of 50-60%.	When used in cooperation with a super-insulated frame, these windows can facilitate solar heat gain. During cold or overcast days, or overnight, a window using this type of glass will lose less energy than it can capture during sunnier periods. Increasing the proportion of glass of this quality on the south side will encourage more passive solar gain.

A precondition for the glass to deliver the performance as per table 4 is a super-insulated frame. Installing high performance triple pane glass into a common frame would be inefficient. Even using a super-insulated frame, the frame is the weakest link delivering nearly no solar gain while also creating thermal bridges. In other words, windows are always a source of energy loss.

Table 4 – Thermal Quality of Frame

Common wood or vinyl frame	Generally has a U-value between 2.0-2.5 W/m^2K. These are the most commonly used.
Metal or aluminium frames	Though strong, these materials have high heat conductivity – aluminium can decrease the insulating value of a window by 20 to 30 percent. These frames, combined with triple pane windows, would reach a maximum U-value of 1.6-2.0 W/m^2K even if thermal breaks were inserted in the design. See Chapter 5 for discussion on thermal breaks.
Timber frames	Good insulator but requires more maintenance than aluminium. Wood used in their manufacture should be sourced from a sustainable forest (see FSC certification).
Composite frames	Aluminium outer sections with either a timber or uPVC inner section.
Super insulated frames	May consist of wood or a wood/metal composite window frame which is hollowed out and filled in with foam or some other form of insulation. These types of frame may reach U-values of under 0.8 W/m^2K – a good fit for 0.7 or better windows.

- Use a super high performance window and frame to mitigate the amount of energy lost through windows.
- Select window styles with durable seals.
- Keep in mind that this strategy is important, as nearly half of the energy loss of a home is associated with windows.



Super high performance windows used in cooperation with a super-insulated frame can facilitate solar heat gain

6.2 Location and Size of Windows

For a complete discussion of appropriate locations for windows, see the discussion in Section 3.2.

It is also important to remember that, in addition to having the lowest insulation value as a component of the building envelope, windows are also a source for thermal bridges. Therefore, an appropriate number of windows will mitigate unnecessary heat loss or gain. As a general rule of thumb, windows should not exceed 2/3 of the envelope.

In fact, due to the nature of thermal bridges, the number of individual windows should also be kept to a minimum – one slightly larger window is more efficient that two windows even if they equal the same area of window.

- Do not overglaze.
- Minimize the number of windows.

6.3 Shading

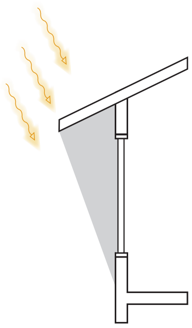
Appropriate use of shading can prevent too much heat from entering a building by shading the glass from direct sunlight. This is particularly important for the south elevation during the warm summer months. Shading strategies can include using overhangs, eaves, louvres and sunshades to regulate solar access.

Louvres are used for shading on this building in Heidelberg, Germany

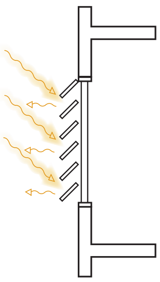
- Properly size and position overhangs to reduce solar gain during the times of the year it is not required

Passive window shading

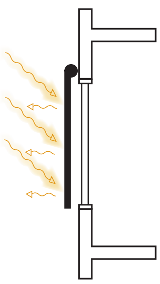
Overhang



Louvres



Sunshades



Passive window shading

Curtains can be used to improve the performance of existing windows but are neither efficient nor effective as the solar heat gain is already inside the building envelope. Heavy curtains may reduce heat loss, but air movement will still encourage the warm air to escape. Blinds can work to reduce glare, but the are also not effective at blocking solar heat gain.

Exterior shading, such as automated blinds, are not truly passive as they consume energy, materials and resources in their manufacture. They also include working parts which are susceptible to failure.

Louvres offer non-mechanical exterior shading

Windows:

Cost: $$$$$

Window strategies are one of the most effective methods to make use of solar gain and limit energy loss. Proper attention to windows and shading can ensure maximizing winter sun, while also preventing summer overheating.

Synergies/Barriers:

- It is important to balance solar considerations of windows with natural daylighting and view considerations.
- High performance windows can be expensive. Aim for the lowest U-value that is affordable and avoid overglazing.

Impact on Energy Efficiency:

Appropriate use of this strategy can greatly increase the energy efficiency of a building.


photo: Hotson Bakker Boniface Haden

7. Lighting

Daylighting and access to natural sunlight are essential for living spaces, as this quality of light promotes occupant comfort. Good daylighting eliminates the need for artificial lighting, reducing energy consumption for this purpose.

7.1 Interior Layout and Windows

When making decisions about lighting it is important to consider that appropriate building layout and orientation can reduce the need for artificial lighting and thus improve occupant comfort. Building layout should respond to the path of the sun, providing a sufficient supply of natural daylight through windows. South facing windows provide lots of daylight, as well as solar gains, while windows facing the northern elevation can deliver diffused lighting with minimal solar gain.

Good passive design should situate windows in multiple directions in order to balance interior lighting requirements. With the appropriate strategy, the amount and quality of light can be varied according to the lighting requirements of each space; direct light for kitchens, offices and workshops, and reflected or diffused light for living rooms or bedrooms.

- Use multiple window orientations for balanced lighting levels
- Choose lighting schemes based on room function

For further discussion of layout and windows, see Sections 4 and 6

When designing a passive lighting strategy, here are some questions to ponder:

What is the primary function of this room and what type of light does it require?

When will the room be occupied (morning, afternoon, evening)?

What is the most appropriate style and placement for windows considering the path of the sun?

7.2 Skylights vs. Solar Tubes

Although skylights can bring in lots of natural daylight, they are also a source of heat loss in the winter and heat gain in the summer.

Solar tubes, on the other hand, are simpler to install and provide daylight without the associated heat gain and a minimal amount of heat loss. Solar tubes are lined with reflective material to reflect and diffuse light to isolated areas.

- Use reflection techniques and solar tubes to funnel daylight into the house

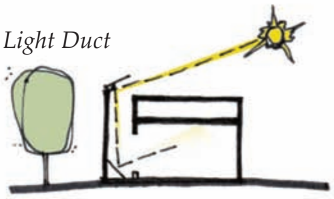
7.3 Clerestory Windows

A clerestory wall is a high wall with a row of overhead windows that

Types of Daylighting

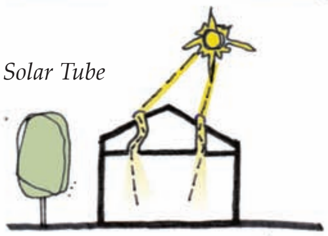
Light Shelf

Light Duct

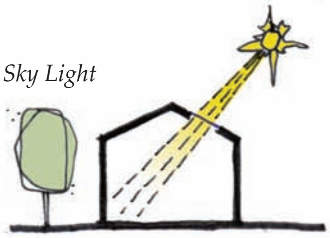


Reflective Blinds

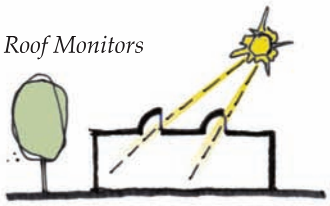
Solar Tube



Sky Light

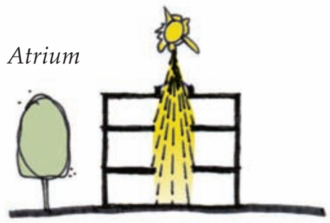


Roof Monitors

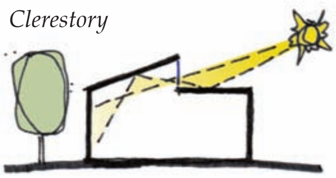


Types of Daylighting continued...

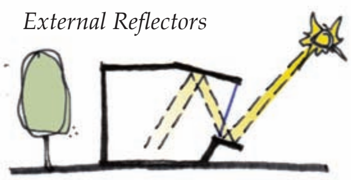
Atrium



Clerestory



External Reflectors



can allow in light. When clerestory windows are opened they can also act to cool the room by creating convection currents which circulate the air.

- Position clerestory windows to face south, with eaves to block the hot summer sun

Heat gain from artificial lighting fixtures

Less than 10% of the energy use of a standard incandescent bulb (e.g. 40W, 60W, 100W tungsten filament bulbs) is converted to visible light, with the rest ending up as heat energy. Using more energy efficient light bulbs will ensure energy is efficiently directed to deliver its assigned purpose, in this case artificial lighting.

Compact Fluorescent Lights (CFLs) are the most significant development in home lighting, lasting up to 13 times as long as incandescent bulbs and using about ¼ the amount of electricity. New and improved colour renditions give a warmer light than older CFL technology.

Tungsten-halogen lamps are a newer generation of incandescent lights that provide a bright, white light close to daylight quality. These are powerful high-voltage lamps best used for general illumination.

More energy-efficient, low-voltage halogen lights are ideal for accent lighting. These lamps can last as long as 2000 hours and save up to 60% of the electricity used with incandescent lights.

Automation techniques and smart technology also help to mitigate high energy use. Dimmer switches and motion detectors can automatically adjust to conditions based on a predetermined schedule.

- Reduce the reliance on artificial light as much as possible
- Increase illumination effectiveness by using light coloured sources
- Use low wattage bulbs close to where they are needed
- Use energy efficient bulbs instead of regular incandescents
- Eliminate the unnecessary over-use of electricity with the use of dimmers, timers, motion sensors and cupboard contact switches

7.4 Paint as a Passive Lighting Strategy

The albedo of an object refers to its capacity to reflect light. Light coloured paints can make spaces look and feel brighter while also mitigating the heat island effect through reduced heat absorption.

In winter, when solar radiation is not as intense and solar gains are sought after, high albedo surfaces adjacent to the house can reflect solar radiation into the house, to be absorbed by the internal thermal mass. This strategy also provides daylight into the interior, as well as increasing nighttime lighting levels.

- Select appropriate surfaces to paint with light coloured paint or other high albedo material
- Decide where light is required and balance with heat considerations
- White painted windowsills can increase the amount of light into a room by reflecting outside light

Light coloured paints can make spaces look and feel brighter while also mitigating heat island effect.

Heat Island Effect

A heat island is an area, such as a city or industrial site, having consistently higher temperatures than surrounding areas because of a greater retention of heat by buildings, concrete, and asphalt. Causes of the "heat island effect" include dark surfaces that absorb more heat from the sun and lack of vegetation which could provide shade or cool the air.

Lighting:

Cost: $$$$$ – $$$$$

Passive lighting implies maximizing the use of natural daylighting in order to reduce the reliance on artificial lighting fixtures, which can be costly and inefficient.

Synergies/Barriers:

- Lighting strategies need to be balanced against solar heat gains.
- Clerestories and solar tubes can be appropriate where privacy is necessary.
- When choosing window styles for lighting remember to keep in mind other passive design best practices such as quality of windows and ventilation.
- High gloss paint leads to acute brightness – to achieve passive lighting use matte paint to deliver a softer brightness.
- Shade reflective surfaces with overhangs, trees or vegetation to mitigate unwanted heat gain in the summer.

Impact on Energy Efficiency:

Decreasing dependence on artificial lighting can help to curb energy consumption but natural light also contributes to higher occupant comfort. This strategy can be achieved with minimal extra associated costs.

8. Ventilation

When there is a difference between outdoor and indoor temperature, ventilation can be accomplished by natural means. Strategically placed windows make use of prevailing winds to allow ventilation, bringing in fresh air while removing warm or stale air. Ventilation also has an impact on heating and cooling.

When considering ventilation strategies, it is helpful to consider the following questions:

How will the window contribute to occupant comfort?

Where should windows be located to achieve the desired impact?

8.1 Window Placement

The height and opening direction will affect the degree to which a window can take advantage of prevailing winds. Well thought out height and placement will direct air to where it is needed, while choosing windows that either open inward, outward or slide will affect the amount of air that can be captured.

Though ventilation has an impact on heating and cooling it also has stand alone merits to improve occupant comfort through appropriate access to fresh air.

- Know the patterns of prevailing winds
- Identify wind flow patterns around the building
- Account for site elements such as vegetation, hills or neighbouring buildings which will impact breezes
- Orient fenestration and choose a style that catches and directs the wind as required

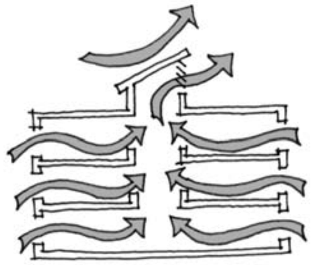
8.2 Stack Effect and Cross Ventilation

The following strategies can effectively encourage passive ventilation in a house.

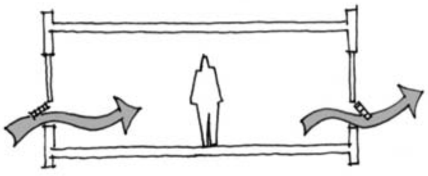
Stack effect is achieved by placing some windows at lower levels (in the basement or at floor level), while others are placed at higher levels (at ceiling height or on the top floor). The lighter, warm air is displaced by the heavier, cool air entering the building, leading to natural ventilation. This warm/light interaction acts as a motor that keeps the air flowing, leading to what is called the 'stack' or 'chimney' effect. The greater the temperature difference, the stronger the air flow generated.

This kind of natural ventilation is appropriate for summer months, as it may also cool the interior space, reducing the need for electric fans or pumps traditionally used for cooling. This in turn can lead to lower energy consumption.

Stack Effect



Cross Ventilation



Cross ventilation occurs between windows on different exterior wall elevations. Patio and screen doors are also effective for cross ventilation. In areas that experience unwanted solar gain, operable clerestory windows or ceiling/roof space vents can aid with ventilation and cooling (see Section 8.3).

- Place windows where it is possible to achieve either stack effect or cross ventilation where required
- Use appropriate window style to achieve desired effect

8.3 Window Style

The style and operability of a window can determine maximum levels of ventilation achievable. Louvres or hinged/pivoting units that open to at least 90 degrees can offer the greatest potential for ventilation. Awning, hopper or casement windows, opened by short winders, provide the least potential.

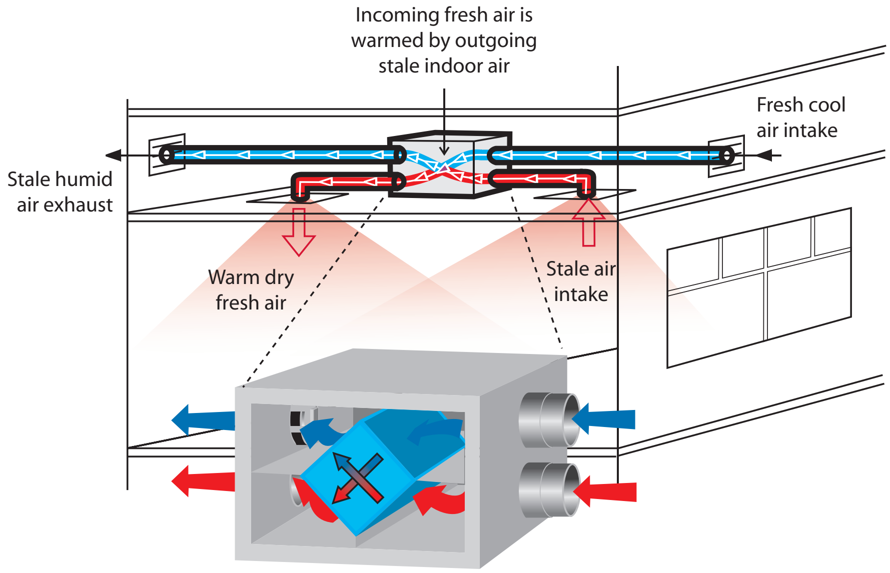
- Maximize window opening and use hinged windows which can redirect breezes

8.4 Heat Recovery Ventilators

Heat recovery ventilators, or HRVs, are not strictly passive technology, but are recommended as part of a comprehensive passive design strategy. Ventilation which makes use of an HRV is more efficient, as the system reclaims waste energy from exhaust airflows. Incoming fresh air is then heated using this energy, recapturing 60 to 80 percent of the heat that would have been lost.

Passive design essentially encourages a very tight building envelope, while an HRV ensures a continuous supply of fresh air to this airtight interior. Filtration of the air through an HRV also stops dirt from entering the building, and can help to prevent development of mould.

Heat Recovery Ventilator



- Aim for a heat recovery rate greater than 75%, an leakage rate of less than 3%, and electricity efficiency of the unit greater than 0.4 Wh/m³ (0.04 Btu/ft³)
- Provide ventilation controls that have user-operated settings for "low", "normal" and "high", and consider additional controls in kitchen and baths/toilets

Ventilation:

Cost: $$$$$ – $$$$$

Natural ventilation eliminates the need for big mechanical systems and can provide occupant control over thermal comfort.

Synergies/Barriers:

- Keep in mind that site conditions affect the ability to capture wind: allow for landscape, building shape and prevailing winds.
- Security and wind driven rain should also be considered when deciding window or door placement.
- HRVs require additional ducting to bring the exhaust air back to the HRV unit.
- Exhaust from nearby cars and other external pollutants should be accounted for.
- Unwanted heat loss can be reduced by preheating incoming air prior to distribution (using an HRV or other system).

Impact on Energy Efficiency:
Using passive strategies for ventilation can leverage natural climatic conditions for little or no extra cost.

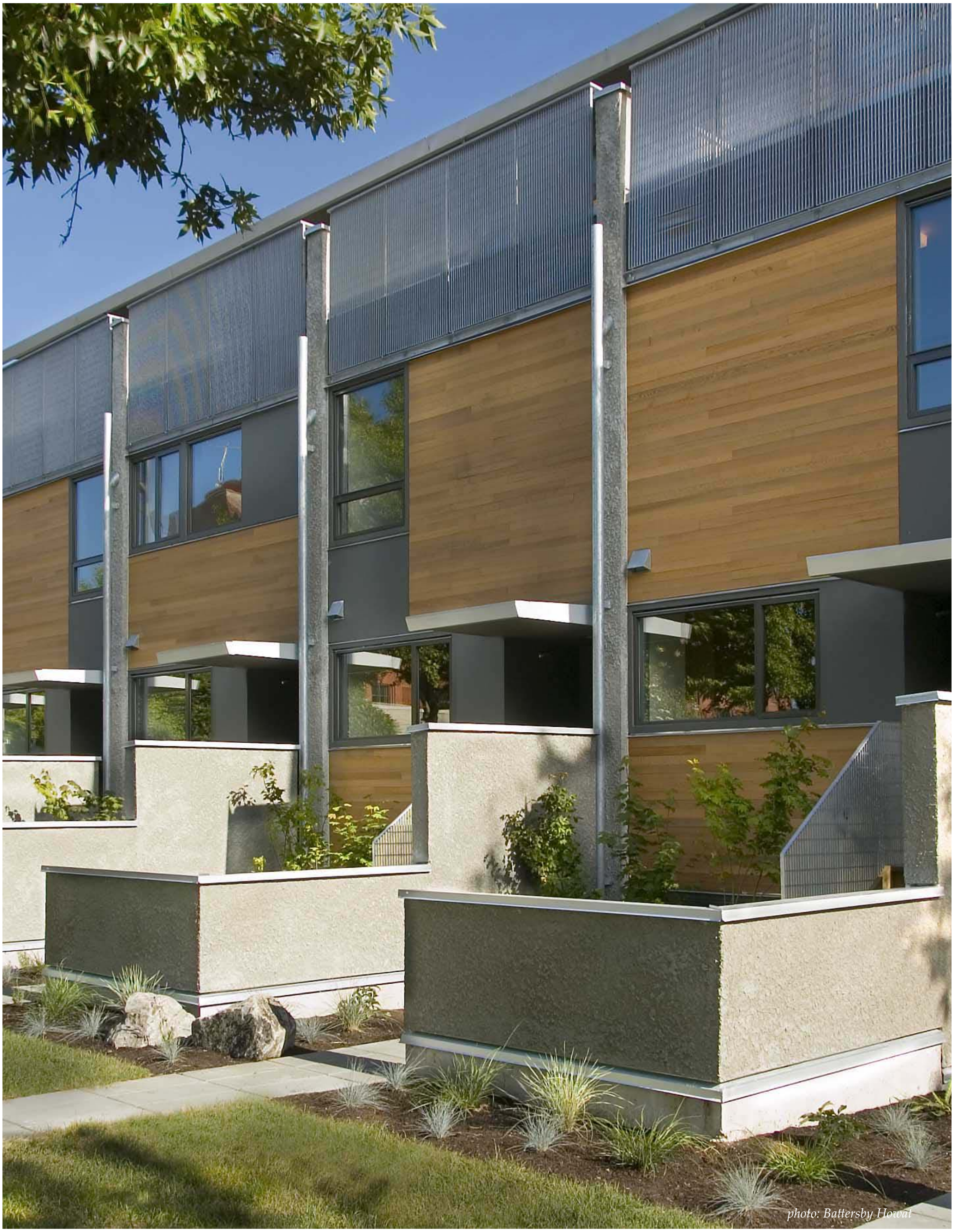


photo: Battersby Howat

9. Thermal Mass

Thermal mass is a measure of a material's capacity to absorb heating or cooling energy. Materials such as concrete or bricks are highly dense and require a lot of energy to be heated or cooled. On the other hand, materials such as timber are less dense and do not need to absorb much energy for smaller changes in temperature. The more energy it takes to affect a temperature change of the material, the higher the thermal mass. The time it takes for the material to store and then release the heat energy is referred to as the *thermal lag*.

The thickness of a material impacts its energy storage capacity. For example, steel studs have a greater thermal mass than wood studs. The density of insulation materials differs and further affects thermal resistance values.

Table 5
Common Density Values

Material	Density
Foams	15-40 kg/m^3
Wood Fibre	160 kg/m^3
Fibreglass	50-60 kg/m^3

The simple application of thermal mass can work to passively heat or cool a building, as internal changes in temperature can be moderated to remove extremes of heat or cold. The reverse is also true; inappropriately located thermal mass can cause external temperatures to disproportionately affect internal thermal comfort.

Before increasing thermal mass to an area of a building, consider:

Will this location be best to exploit solar gain?

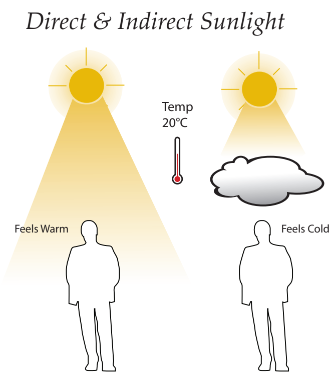
Can this location be shaded to avoid gain when it is not required?

9.1 How to Use Thermal Mass

How can this be applied to low rise wood framed construction ?

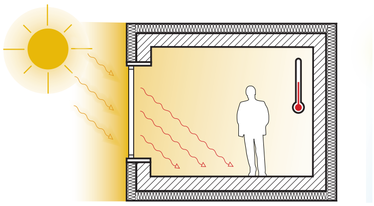
When using thermal mass it is critical to understand that it behaves differently than insulating material. Thermal mass is the ability of a material to store heat energy and then release it gradually. Insulating materials, on the other hand, prevent heat from passing through them. In fact, many high thermal mass materials display poor insulation characteristics.

The embodied energy in some thermal mass materials may also be taken into consideration. Some materials, such as concrete,

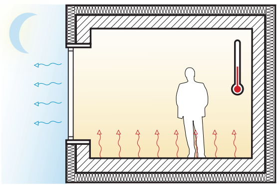


Thermal Mass

Structure with thermal massing:

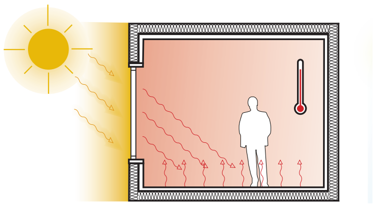


Sun enters room and heat is absorbed into flooring keeping the room temperature comfortable

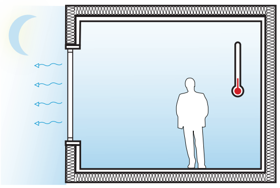


Heat that was absorbed is released during the cool evening to add warmth to the room

Structure with no thermal massing:



In a room without thermal massing, heat from the sun is reflected into the room causing uncomfortable warmer temperatures



In the cool evenings, a room without thermal massing will be uncomfortably cold

require a lot of energy to manufacture and are inappropriate in relation to the actual energy savings they might deliver.

Mass situated on the south side of a building is most efficient for heating in Vancouver. The mass can absorb heat from the sun and then release this energy during the night. To avoid overheating, areas with high thermal mass should be shaded from this sun in the summer, or situated/landscaped to take advantage of cooling winds.

Thermal mass should generally be located on the ground floor, on the inside of a building, exposed to the indoor environment. Exposed concrete floors or concrete block partition walls are very effective at absorbing thermal conditions (heat or cold).

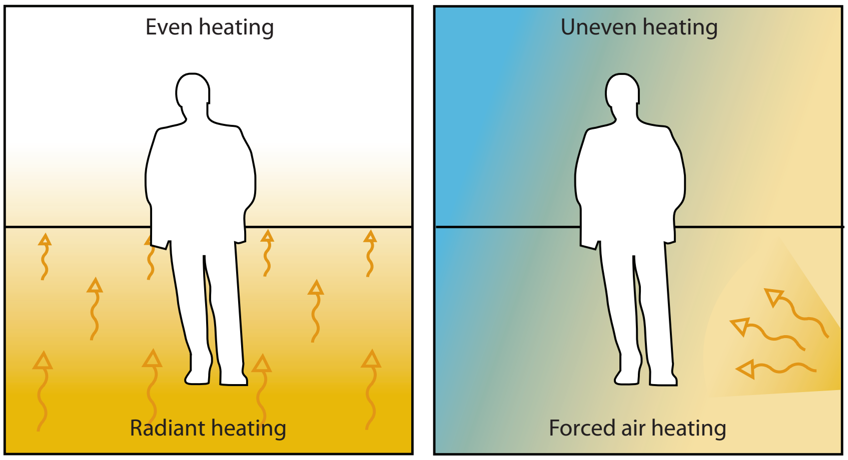
- Use the south side for thermal mass, but apply appropriate shading for summer months
- Apply thermal mass on the ground level

9.2 Slab on grade construction

Slab on grade (SOG) is a very common method to create thermal mass. Generally about 4" thick, SOG should be insulated from the ground below to avoid losing heat in the winter.

Radiant Heating

Radiant heat flooring vs. forced air heating



Radiant energy can be beneficial – this type of energy is emitted from a heat source and is different from tradition convection heating. This type of heating can penetrate all objects in its path and rather than heating the air, directly heats all objects in its path, including people.

This type of heating system can achieve the same level of thermal comfort using less energy, as heat is not lost to the air. Radiant systems include in-floor, ceiling panels or wall heating systems.

Phase Changing Materials

There is growing interest in the use of phase changing materials in construction. These are materials that can either emit or store heat energy as they change from a solid to a liquid or vice versa at certain temperatures. Therefore, these materials can be used, like thermal mass, to manage indoor thermal comfort.

Thermal Mass:

Cost: $$$$$ – $$$$$

Thermal mass can be effectively used to absorb solar heat in winter and radiate it back to the interior at night.

Synergies/Barriers:

- Vancouver has minimal winter sun, so this strategy has limitations to significantly offset winter heating demands though it may be sufficient for shoulder season demands (spring and autumn).
- Naturally occurring thermal mass areas can be used to reduce cooling demands more easily – keep high thermal mass elements shaded or away from solar gains.

Impact on Energy Efficiency:

Allows the house to heat and cool itself based on heat release from materials, lowering the need for additional heating.


81
87
photo: Chesterman Properties

10. Density

In addition to building design, there are other elements that can impact the passive potential of a site. Density, measured in Vancouver as the ratio of building floor space to the site area, impacts energy consumption as well as the capacity of a building to be passively heated or cooled.

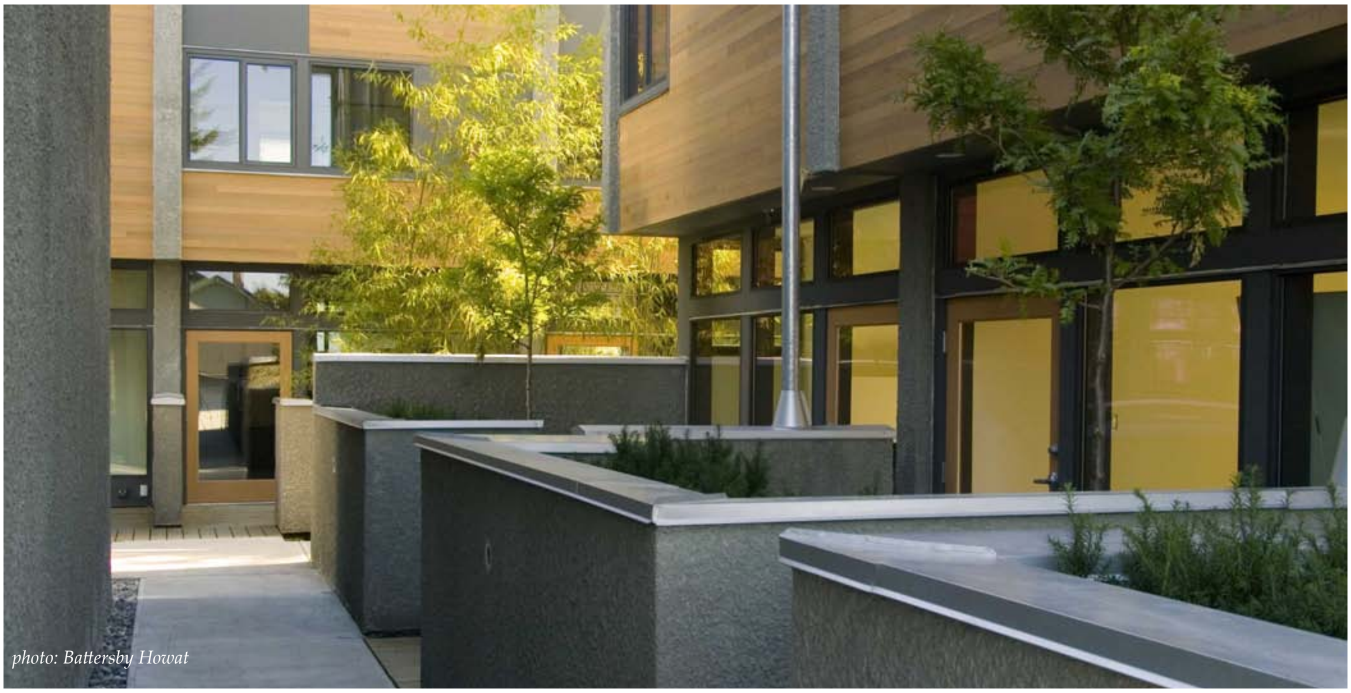


photo: Battersby Howat

Density is regulated in most municipalities, including the City of Vancouver, by zoning by-laws based on development and planning policies. Though there is a process for rezoning applications, density cannot always be increased in every instance. Municipalities often have areas earmarked for greater density based on community plans, and the City of Vancouver has also introduced its EcoDensity policy, which aims to encourage density around transportation and amenity-rich nodes.

In general, large, single-family dwellings have a higher proportion of exterior wall surface and constitute lower density areas. These buildings require more energy for heating or cooling purposes, while 'denser', multi-unit buildings, townhouses or duplexes can take advantage of economies of scale and share or transfer heat between walls or floors thereby reducing overall energy demand. In fact, low-density developments comprising mainly single-family houses use nearly twice as much energy per square foot as multi-unit buildings in Canada.

Multi-unit buildings take advantage of economies of scale and share or transfer heat between floors and walls thereby reducing overall energy demand.

According to a 2006 study, low-density suburban development is more energy and GHG intensive by a factor of 2.0–2.5 than high-density urban core development.

The analysis is based on a per capita calculation. When this functional unit is changed to per square meter of living space, the factor decreases to 1.0–1.5. This suggests that the choice of functional unit is highly relevant to a full understanding of the effects of density, although the results do still indicate in many cases a marginally higher energy usage in low density development.

From:
'Comparing High and Low Residential Density', Jonathan Norman, "Heather L. MacLean, and Christopher A. Kennedy, Journal of Urban Planning and Development, Vol. 132, No. 1, March 2006, pp. 10-21

Single-family dwellings take up half of the land area in Vancouver. In fact, only 11 percent of the city's land area is currently used for multiple-unit dwellings, according to the City of Vancouver's EcoDensity web site.

Density

Density can mitigate pressure on municipal infrastructure including waste, sewer and energy infrastructure. Appropriate use of density can also create efficiencies in the use of this infrastructure, and lead to shared benefits from energy usage and common amenities.

Synergies/Barriers:

- Density is largely determined by wider municipal planning policy so there is little scope for variations on a building-by-building basis.

11. Benefits of Passive Design

The strategies in this toolkit offer suggestions for harnessing the power of the sun and decreasing the energy consumption requirements of a typical home. As in other parts of the world, it seems reasonable to be able to achieve a reduction to just 15kWh/m²/year (heat/cool) if all strategies are used in combination. It is important to keep in mind that reducing consumption is the first step to designing energy efficient homes and approaching carbon neutrality (ie this should come before any discussion of on-site energy generation).

To get an idea of the possible impacts/benefits of passive design on energy consumption, consider the case study presented in the tables on the following page.

In short, a typical Vancouver single family home is 200 m², with a 2x6 fully insulated stud wall and conventional windows with low-e windows. The average annual energy loss associated with a building of these specifications would equal roughly 16,000 kWh, or about 80 kWh / m² / year. The passive solar energy harnessed by this home would be relatively small, at about 1,200 kWh per year, or roughly 7.5% of the amount of energy lost. Annual heating demand would average 64 kWh / m² / year.

photo: Hotson Bakker Boniface Haden

Case Study

Table 6 shows the usual approach and the resulting energy consumption. The energy loss of 18,000 kWh is relatively high and the passive solar impact is with less than 7 percent extremely low.

The second example (Table 7) is based on a typical Vancouver single family home with a small rental unit in the basement. With a total floor area of 208 m^2, the house was retrofitted during the last year.

Table 6: Typical Vancouver Single Family Home

Size of Building	208 m^2
Wall assembly	basement 2x6 fully insulated stud wall. Concrete with 2" XPS
Windows	30 m^2 Conventional, low-e U Value=1.6 thereof 7.4 m^2 on south side
Energy loss	18,000 kWh ≈ 80 kWh / m^2/ year
Solar gain	1,200 kWh ≈ 6.6% of energy loss
Heating demand	69 kWh / m^2 / year

This home is lined up against the typical Vancouver house (Table 6) with no recent upgrades. The resulting energy consumption and loss of 18,000 kWh is relatively high, but not an unreasonable assumption. The passive solar harnessed by this building is less than 7 percent of consumption, which is extremely low but again, not an unreasonable assumption with recent construction and design practices.

The main differences between the original house and the improved example in the case study are:

- improved insulation thicknesses
- improved air tightness
- optimizing of heat bridges
- improved thermal quality of windows
- installation of heat recovery unit

With these improvements, total energy loss was reduced significantly despite the fact that it was possible to improve passive solar gain to only 10 percent of energy requirements, which is still very low performance.

Table 7: Better Vancouver Single Family Home

Size of Building	208 m^2
Wall assembly	basement 2x6 fully insulated stud wall plus 2″ exterior insulation. Concrete with 3″ XPS
Windows	Ventilation with heat recovery 37 m^2 Triple pane and insulated frame U Value = 0.78 thereof 7.4 m^2 on south side 82% (air tightness @ 50Pa 0.77/h)
Energy loss	9,500 kWh ≈ 46 kWh / m^2/ year
Solar gain	1,000 kWh ≈ 10.5% of energy loss
Heating demand	29 kWh / m^2 / year

For comparison, the third example (Table 8) offers an estimate of the possible performance associated with a truly passively designed home. In this third instance, improvements would include:

- further increases to insulation
- window placement based on building orientation

Allowing the windows to be distributed according to solar gain potential increases the solar energy the building harnesses to 35 percent. By placing a larger proportion of windows on the southern elevation and less on the northern elevation, the passive design features of this building improve its performance nearly fivefold over the first example.

Table 8: Passive Vancouver Single Family Home

Size of Building	208 m^2
Wall assembly	basement 2x6 fully insulated stud wall plus 3.5″ exterior insulation Concrete with 6″ XPS
Windows	Ventilation with heat recovery 45 m^2 Triple pane and insulated frame U Value = 0.78 thereof 21.5 m^2 on south side 82% (air tightness @ 50Pa 0.6/h)
Energy loss	8,400 kWh ≈ 40 kwh/ m^2/ year
Solar gain	3,200 kWh ≈ 38% of energy loss
Heating demand	15 kWh / m^2 / year (PassivHaus standard)

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i. City of Vancouver Policy Context

The City of Vancouver has a reputation as a leader in sustainable urban development.

Green Homes Program

While developing passive design strategies, it is important to keep in mind the progress the City has already made in promoting green building. For Part 9 Buildings (low-rise wood frame residential), the City has adopted the Green Homes Program.

This program sets out higher standards for all new Part 9 buildings, including:

1. Building Envelope Performance:
   i. Windows must have maximum U-Value of 2

2. Energy Efficiency:
   i. At least 40% of hard-wired lighting should not accept incandescent light bulbs
   ii. Display meters should be installed that can calculate and display consumption data
   iii. Hot water tanks should have insulation with a minimum RSI value of 1.76

This toolkit offers practices to encourage and support the use of passive design in Vancouver.

Part 3 Buildings are defined as structures over 3 storeys or greater than 600 m^2

iv. Hot water tank piping should have 3 metres of insulation with a minimum RSI value of 0.35
v. Gas fireplaces shall have electric ignition

3. Other:
   i. Toilets shall be dual-flush design
   ii. Each suite shall have a Heat Recovery Ventilator
   iii. An EnerGuide Audit is required at Occupancy Permit

Part 3 Buildings

The City is implementing several actions in line with their *Green Building Strategy* (as above) and recently enacted policies directed at energy efficiency and GHG reductions:

1. Improve and streamline enforcement of the energy utilization within the building law

2. Adopt ASHRAE 90.1 2007 as new Energy Utilization By-law

3. Decrease overall building energy use requirements by 12-15% beyond ASHRAE 90.1 2001 to meet Natural Resources Canada (NRCan) Commercial Building Incentive Program (CBIP) requirements

EcoDensity

The City has also implemented the EcoDensity policy, consisting of 16 actions. These actions apply only where there is a rezoning sought for a development.

1. All applicable buildings to be *either* LEED Silver with a minimum 3 optimize energy points, 1 water efficiency point and 1 stormwater management point *or* BuiltGreen BC Gold with an EnerGuide 80 rating

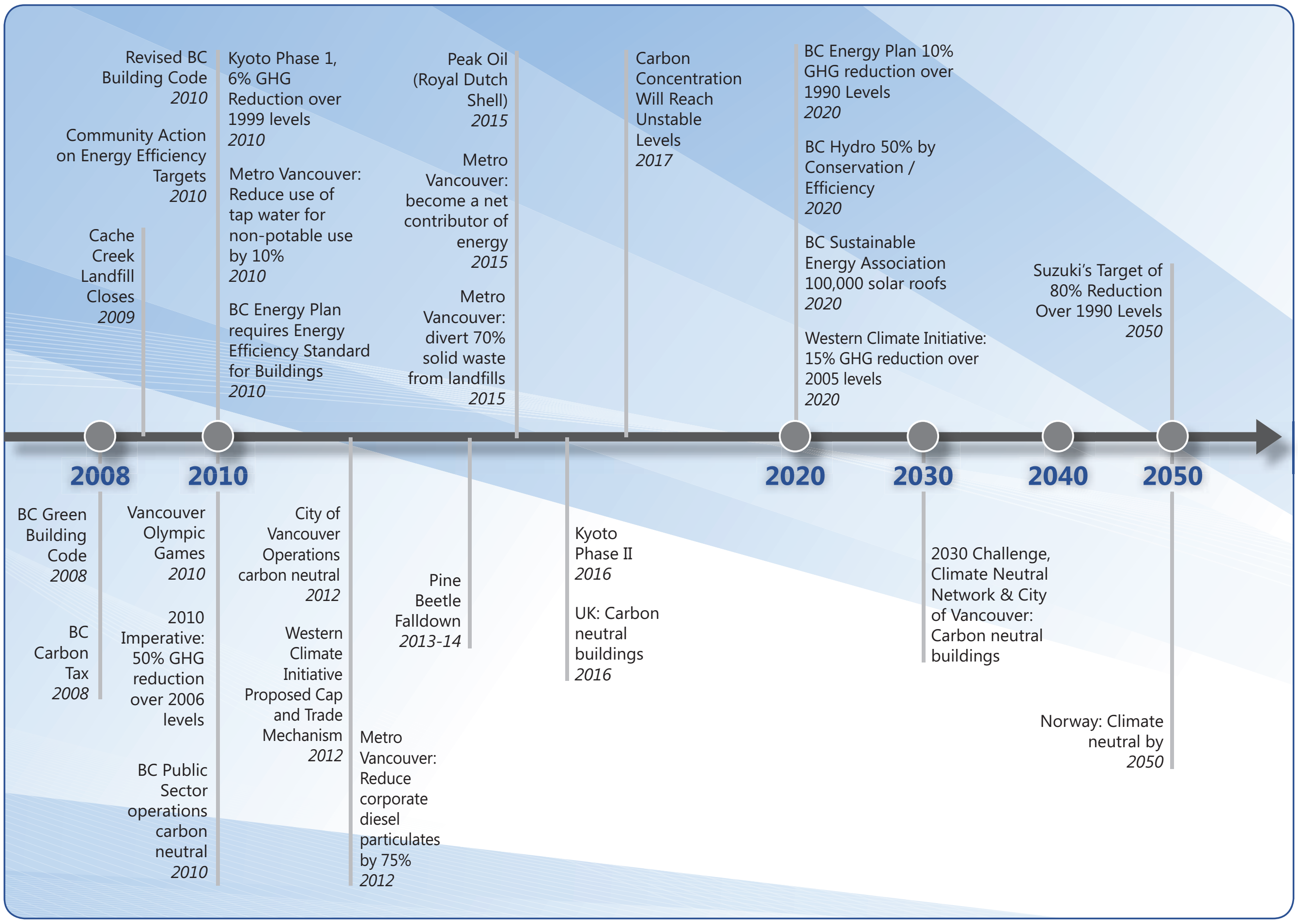
2. In addition, sites over two acres will require:
   a. Business case analysis for viability of district energy systems
   b. Layout and orientation which will reduce energy needs, facilitate passive energy solutions, incorporate urban agriculture and replicate natural systems
   c. A sustainable transportation demand management strategy which includes requisite infrastructure
   d. A sustainable rainwater management plan
   e. A solid waste diversion strategy
   f. A range of housing unit types and tenures to enhance affordability

Climate Neutral Network

The City of Vancouver is a signatory to the UN's *Climate Neutral Network (www.climateneutral.unep.org)* and under this initiative has several climate action targets which include:

1. Making City operations climate neutral by 2012
2. Ensuring all new construction is carbon neutral by 2030
3. Achieving an 80% reduction in all community GHG emissions by 2050

Figure 3: Regional Timeframe Diagram



ii. Acronyms and terms used in this report

Albedo	The ability for an object to diffuse and reflect light from the sun. Light coloured materials and paint have a high-albedo effect.
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers. ASHRAE publishes standards and guidelines relating to HVAC systems (heating, ventilation and air conditioning) and many are referenced in local building codes.
Building Envelope	The roof, walls, windows, floors and internal walls of a building
CFL	Compact Fluorescent Lights
EnerGuide	EnerGuide is the official Government of Canada mark associated with the labeling and rating of the energy consumption or energy efficiency of specific products, including homes. Homes are rated on a scale of 0-100. A rating level of 100 represents a house that is airtight, well insulated and sufficiently ventilated and requires no purchased energy.
Floor space	Floor space as used in this toolkit refers simply to the internal floor area bounded by the building envelope. However the method of measuring floor space precisely varies depending on the context-for example the Vancouver Building Bylaw contains a detailed description of the method of measurement of floor space for the purpose of submission for a Development or Building Permit and should be referred to for this purpose.
GHG Emissions	Green House Gas Emissions
Heat Island Effect	The term heat island refers to urban air and surface temperatures that are higher than in rural areas due to the displacement of trees, increased waste heat from vehicles, and warm air which is trapped between tall buildings.
HRV	Heat Recovery Ventilator
Indoor Air Quality (IAQ)	Indoor Air Quality (IAQ) refers to the composition of interior air, which has an impact on the health and comfort of building occupants. IAQ is affected by microbial contaminants (mould or bacteria), chemicals (such as carbon monoxide or radon), allergens, or any other pollutant that effects occupants.
LEED®	Leadership in Energy and Environmental Design green building rating system
Mechanical Systems	Conventional systems that use fans and pumps to heat, ventilate and condition the air.
PassivHaus	PassivHaus is a rigorous European home design standard developed in Austria and Germany, which regulates input energy to a maximum 15 kWh / m^2 / year – about one tenth of that in a typical new 200 m2 Canadian house.
Solar Gain	(also known as **solar heat gain** or **passive solar gain**) refers to the increase in temperature in a space, object or structure that results from solar radiation. The amount of solar gain increases with the strength of the sun, and with the ability of any intervening material to transmit or resist the radiation. In the context of passive solar building design, the aim of the designer is normally to maximise solar gain within the building in the winter (to reduce space heating demand), and to control it in summer (to minimize cooling requirements).

Thermal Bridges	A thermal bridge is any part of a construction through which heat can travel faster and with less resistance than other parts.
Thermal Comfort	Thermal comfort is defined by ASHRAE as human satisfaction with the surrounding environment, formalized in ASHRAE Standard 55. The sensations of hot and cold are not dependent on temperature alone; radiant temperature, air movement, relative humidity, activity levels and clothing levels all impact thermal comfort.
Thermal Mass	Thermal mass is the ability of a material to store heat. Thermal mass can be incorporated into a building as part of the walls and floor. High thermal mass materials include: brick, solid concrete, stone or earth.