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Habitat Design + Consulting

Pathways to
High-Performance Housing in British Columbia

SP-56 FPINNOVATIONS

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Preface

This guide focuses on design and construction strategies and detailed measures to improve home energy efficiency in British Columbia. The primary purpose of this publication is to provide guidelines for designers and builders who are interested in the design and construction of single-family and small multi-family buildings that are substantially more energy efficient and lower in environmental impact than traditionally built homes. The term used here for this type of housing is high-performance housing. This document will be helpful for builders and designers to meet the requirements of green building programs and labelling systems, and be of particular interest to those who want to produce a high standard of housing but do not want, or are unable, to adhere to a particular green building label. This guide focuses on wood-frame construction because it is the predominant construction method for houses in British Columbia. Chapter 4 also includes some information on cross-laminated timber and structural insulated panel assemblies.

The guide contains seven chapters and 14 appendices.

Chapter 1, Introduction, first provides background information, including the evolution of energy efficiency codes and related programs that have had a large impact on the overall energy consumption of homes. It then defines what high-performance housing is, and what the major features and benefits are. This chapter also introduces the business case for such housing.

Chapter 2, Design and Construction Strategies: Overview, outlines the main strategies as well as performance targets that can be utilized in the design and construction of high-performance housing. Their impacts on whole-house energy consumption are illustrated, and the considerations for cost optimization during the design and construction process are highlighted.

Chapter 3, The Integrated Design Process, covers a step-by-step approach, utilizing building-as-a-system principles, to designing homes with optimized energy performance and long-term durability. It outlines how best practices can be used at the schematic design stage, which is followed by computer simulation and a design charrette process, to develop and optimize solutions.

Chapter 4, Building Envelopes, covers the technical principles of energy-efficient and durable building envelopes including thermal insulation, considerations for air barriers and vapour barriers, and steps towards ensuring long-term durability. It then includes a series of examples of highly energy-efficient and durable building assemblies for foundations, exterior above-grade walls, roofs, and exposed floors. It also covers the characteristics and installation of high-performance windows, doors, and skylights.

Chapter 5, Space Heating, Ventilation, and Water Heating, provides an overview of space heating, mechanical ventilation, and domestic hot water systems that are best for use in high-performance housing.

Chapter 6, Photovoltaic Systems, provides a discussion of design considerations and information related to the use of photovoltaic (PV) systems in high-performance housing. It also describes the basic requirements for making a project PV ready for the future.

Chapter 7 lists relevant references and other resources.

The Appendices at the end of the guide, mostly in the form of tables and figures, provide supporting information ranging from sustainable materials; ways to reduce water consumption; sun-path charts; PV power calculation tables; detailed calculations for home energy consumption; prescriptive paths to achieving high-performance housing in different climates; insulation materials; air-barrier systems and detailing; and effective R-values for a wide range of wall, roof, and foundation assemblies that can be used in high-performance housing.

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Chapter 1 – Introduction

1.1 Energy-Efficiency Requirements Described in Building Codes and Energy-Related Programs

Buildings account for a significant proportion of energy use, greenhouse gas emissions, and water use. Residential space heating and cooling, water heating and the operation of appliances, electronic equipment and lighting account for approximately 17% of secondary energy use in British Columbia (The Sheltair Group 2006), and in 2008 the building sector accounted for almost 35% of the province's total greenhouse gas emissions (British Columbia Ministry of Environment 2012). Over the last few decades, new homes in British Columbia, and in Canada as a whole, have been getting larger but they have also been getting more energy efficient. Thermal insulation and airtightness levels, two important thermal characteristics of building envelopes, have been increasing over the past few decades (Parekh et al. 2007). In the last 20 years, 250,000 detached new homes have been built in British Columbia. The average floor area of these homes has increased by 68% relative to homes constructed in preceding decades, but the total greenhouse gas emissions from the new homes have remained fairly constant (Behidj et al. 2013). Improvements in greenhouse gas emissions in British Columbia homes is in part a result of dropping energy use, i.e., by more than 10% on a per-household basis, and by more than 25% on a floor area basis.

In Canada, construction is governed by the *National Building Code of Canada 2010* or through provincial counterparts, which are themselves based heavily on the *National Building Code of Canada 2010* (National Research Council Canada 2010) and share a common format. Within these documents, single-family and other small residential construction requirements are described in Part 9. In the last few years, a number of Canadian provinces have introduced minimum energy-efficiency requirements for Part 9 buildings that were roughly equivalent to the energy performance targeted by the ENERGY STAR and R-2000 programs at the time. New energy requirements for housing and small buildings covered by Part 9—i.e., Section 9.36–Energy Efficiency—were published and added to the National Building Code in 2013. The majority of the National Building Code additions under 9.36–Energy Efficiency have been adopted by British Columbia and will replace some of the energy requirements in the *British Columbia Building Code 2012* (Building and Safety Standards Branch 2012), effective December 2014.

Not only are building codes increasing the minimum energy-efficiency requirements, more and more designers and builders have been building to above-code levels of energy efficiency through various green building programs and labelling systems, such as ENERGY STAR, R-2000, Built Green, LEED, Net Zero Energy, and Passivhaus (Passive House). Following the changes in building codes for minimum energy-performance levels, green building programs have also been upgraded. As of 2012, minimum energy-efficiency levels in building codes had almost caught up to R-2000, which since the 1980s has been the leading energy-efficiency home program in Canada. Natural Resources Canada, the originators of R-2000, subsequently revamped this program such that it will once again be a leading edge program, aiming to reduce energy requirements by 50% compared to a code-built home. Similarly, Energy Star was upgraded to be 20 to 25% better than code. On the other hand, some programs and labelling systems have fixed performance targets. For example, among the requirements of Passivhaus (Passive House), a labelling program originating in Germany and based on concepts originally developed for R-2000 in Canada in the 1970s, is that the space-heating load must be less than 15 kWh/m^2 and the airtightness must be less than 0.6 air changes per hour at 50 Pa. The Net Zero Energy Building Certification, a program operated by the International Living Future

Institute using the structure of the Living Building Challenge, is performance-based and requires that the building have a net-zero energy consumption for 12 consecutive months.

All housing should be designed and built using building-as-a-system principles. This is particularly true of highly energy-efficient, or high-performance housing. For example, increasing airtightness levels decreases the space-heating requirements of a home, but at the same time this can negatively impact indoor air quality due to the accumulation of moisture and indoor air pollutants unless distributed ventilation systems are incorporated.

In a rapidly evolving industry sector that is utilizing new technologies and building practices, home designers and builders must take the time to evaluate how these changes affect the overall performance of the building. This guide aims to assist designers and builders achieve sustainable, durable, comfortable, and energy-efficient homes—i.e., high-performance housing—by applying sound building-science principles and optimizing design through the use of the integrated design process.

1.2 Definition, Features, and Benefits of High-Performance Housing

Depending on the label and specific targets, a high-performance home can achieve a range of goals. This guide considers high-performance housing to be homes that reduce energy use by 50 to 80% compared with code-compliant homes in British Columbia in 2013, as well as homes that on an annual basis produce as much energy as is consumed by using on-site renewable energy systems. High-performance housing also incorporates features that ensure durability of the building envelope, high indoor air quality, the use of daylight for interior illumination, and the minimization of other environmental impacts. The features and related benefits of high-performance housing include the use of some or all of the following:

- Super insulation, high-performance windows, and airtightness, resulting in:
    - superior thermal comfort in winter by being evenly heated with no temperature stratification, no drafts, and no cold spots;
    - low or no net-energy consumption leading to low or no purchased energy costs, at the highest performance levels;
    - reduced impacts from future energy cost increases by minimizing or eliminating purchased energy consumption;
    - reduced outdoor noise entry, because airtight construction seals pathways for the entry of outdoor noise into a home; and
    - reduced environmental impacts of energy extraction processing and use related to heating and cooling of the home.
- Southward orientation, placement, sizing, and distribution of windows to allow sunlight penetration during the heating season, resulting in:
    - passive solar heating contributing to reduced space-heating requirements.
- High-efficiency household appliances, electrical devices, and lighting, resulting in:
    - a significant reduction in the home’s non-heating/cooling-related, electrical energy consumption.
- High-performance windows, window shading, airflow cooling, high-efficiency household appliances, electrical devices and lighting, and highly insulated roofs and walls, resulting in:

- the home being naturally cooler in summer and having reduced cooling loads where mechanical cooling is required.

- Interior finishes that are chemically inert or are low in chemical off-gassing, and the use of continuously operating, distributed, whole-house ventilation systems, resulting in:
  - a healthier indoor environment, due to the reduction or elimination of indoor air pollutants.
- Windows and skylights sized and placed along with light-coloured ceiling and upper wall finishes to increase daylight penetration, along with electric lighting design and daylighting controls, resulting in:
  - reduced energy consumption for lighting, and
  - enhanced human health and productivity, as indicated by research on the use of daylight for interior illumination.[1]
- All energy-efficiency measures, passive solar heating, natural cooling, and daylighting interior illumination together, resulting in:
  - a more comfortable home during power outages, because high-performance homes are passively heated by the sun and cool off much more slowly than conventional homes in the winter, and require small amounts of energy to heat. They are also largely illuminated by daylight during the day. In the summer, they can be naturally cooled by wind and stack effect.
- Building envelope assemblies that follow sound building-science principles, resulting in:
  - a durable building envelope that effectively resists rainwater penetration, surface condensation, and condensation formation inside building envelope assemblies;
  - lower costs for long-term maintenance of the building envelope; and
  - lower environmental impacts of building maintenance.

1.3 Business Case

Rapid changes in the residential construction industry are providing new profit and diversification opportunities. Those who see and understand these opportunities can position themselves as experts in the field and provide exemplary service to gain an important edge in the marketplace. Knowing where you stand in relation to your competition is paramount. Educating prospective customers and communicating your position to them are just as important.

The benefits of high-performance housing have been demonstrated in many energy-efficiency initiatives across Canada, for example, by the thousands of energy-efficient homes built in the Prairies since the 1970s. Another example is the Building America program in the United

[1] For more information about daylighting, see the Daylight Dividends research program at http://www.lrc.rpi.edu/programs/daylighting/. Daylight Dividends is a joint research program of the U.S. Department of Energy and other organizations to facilitate the implementation of daylighting in buildings.

States[2] that led to the construction of more than 42,200 high-performance homes in its first 15 years. The Building America business case developed for high-performance, energy-efficient construction is straightforward and is based on the following four points (Baechler et al. 2011):

- Consumers prefer energy-efficient homes.
- Builders can use energy-efficiency and other high-performance features to gain a competitive advantage. Addressing consumer preference and having a competitive advantage lead to more and faster sales.
- High-performance homes can meet energy-efficiency goals at no net increased costs to homeowners when added costs are balanced with utility savings.
    - This is referred to as a principle interest taxes and energy (PITE) comparison calculation. What a PITE calculation does is compare a home constructed to code minimum energy requirements to that same home constructed to higher energy standards in terms of the total cost of four factors (including principal, interest, taxes, and energy). If the correct energy upgrades are selected, the energy savings in the upgraded version of the home will offset the larger mortgage payments required to cover the higher capital cost of the home. This can happen in the first year or may happen later. Over time, as energy costs increase, the conventional home will actually cost more to own and operate. This type of calculation makes assumptions about future interest rates and the rate of energy cost increases and relies on computer-based energy analysis to predict energy consumption of both homes. When used correctly it can be a compelling argument for building to high-performance housing levels. The HOT2000 energy analysis software package (Natural Resources Canada 2010a) has a built-in PITE calculator with context-sensitive help that can guide the user through the calculations.
- New building codes are now a driving force in energy-efficient construction.

British Columbians appreciate the value of a green home, with 76% of the province's residents willing to pay more for a house or condo that includes environmentally friendly features, according to the TD Canada Trust Green Home Poll (Angus Reid Public Opinion 2010). Of British Columbians who are willing to pay a premium on environmentally friendly homes, 79% say that cost savings on energy bills is a main motivation. In addition, these people also appreciate the added features of a green home, such as reduced environmental impacts (51%) and health benefits (48%).

The Canada Mortgage and Housing Corporation (CMHC) carried out market research with Canadians who are expecting to buy a home in the next 5 years (Canada Mortgage and Housing Corporation 2007a). The majority of respondents are particularly interested in how to make their residence more energy efficient and a healthier place to live. The majority recognized the need for this type of housing, with about half willing to pay an additional $5,000 to $25,000 (and 15% willing to pay more than an additional $25,000) for an energy-efficient home, with the expectation that the savings from reduced energy costs will offset the extra initial expense over a reasonable time period. The number-one reason builders give for building energy-efficient homes is to differentiate their product from their competitors, however, the old adage of "build it and they will come" does not suffice. Designers and builders need to be

[2] See https://www.energy.gov

proactive in differentiating themselves from their competitors, as recommended by Building America builders:

- Brand and label your product for fast and easy differentiation.
- Train sales staff to or educate real estate agents to help them inform consumers of the features and benefits of energy-efficient housing.
- Market the sometimes hidden energy-efficient features of the home.
- Get your business name and products in front of the public.

Green Building Advisor (www.greenbuildingadvisor.com) is a website that provides various types of information to builders to help them adopt green building practices. Its guide *Stand Out from the Pack: How to Position Yourself as an Expert Eco-Builder* provides the following seven steps:

- **Identify your ideal customer** and direct your marketing at them.
- **Deliver great value -** focus on key specifications that your target market is seeking and effectively communicate how you deliver them.
- **Listen to your customers** – proactively answer frequently asked questions on your website or brochures and make yourself available to answer customer questions.
- **Get organized with a homeowner manual** – implement your customer service and communication approach around a homeowner manual that educates about what activities and services to expect from pre-construction to post-construction.
- **Update your website** – have a professional looking website that addresses what you want potential buyers to do when they first land on your homepage, and tells them what you do, who you are, and how to contact you.
- **Embrace social media** – exhibit your knowledge through social media sites with articles, photos, and videos of your projects.
- **Stay connected with your customers** – quality builders listen to their customers and stay engaged, thus helping foster repeat customers and word-of-mouth referrals.

Local municipalities can facilitate the development of highly energy efficient homes. This may include revisions of local regulations— for example regarding zoning setbacks that restrict thicker exterior walls than conventionally built walls—to encourage the construction of such high-performance housing and to reduce barriers. It may also include preparing the inspectors because specific knowledge may be required during inspections. Given that typical highly energy-efficient homes will deviate considerably from “standard practice”, a project that pursues high-performance housing status or incorporates high-performance housing elements should undertake a pre-permit application meeting with the local jurisdiction to discuss potential issues that could arise. It may also be helpful to connect with the inspectors early on in order to brief them on the project.

Chapter 2 – Design and Construction Strategies: Overview

A range of strategies and techniques, as described below, are used in the design and construction of high-performance housing.

2.1 Passive Heating, Lighting, and Cooling

Where the building site and zoning allow a choice in building orientation and layout, the use of south-facing windows that have high solar heat-gain coefficients will provide passive solar heat gain in late fall, winter, and early spring (Figure 2-1).

Sunlight falling on interior surfaces causes them to heat up, thus raising the indoor air temperature as well as heating up the interior finishes which later release that heat as interior air temperature drops. This causes a temperature swing to occur in south-facing rooms in the range of 2 to 4°C over the day. For typical, light wood-frame, high-performance housing construction, passive solar heating will typically contribute between 18 and 25% of the gross heating energy requirements on an annual basis. A maximum range of 3.5 to 5% of the heated floor area in south-facing windows can be accommodated by the thermal mass provided by typical wood-frame construction.[3] Use of a larger area of south-facing windows will lead to overheating in shoulder seasons and on clear winter days, particularly in October, unless more massive interior finish materials are used or the excess heat is vented. Strategies that allow for higher contributions by passive solar heating are discussed later in this guide.

Sizing and distribution of window, skylight, and tubular daylighting devices, in concert with the use of light-coloured interior surfaces, assist in daylight penetration. Daylight penetration, along with lighting controls, will reduce electric lighting levels and thus permit daylight harvesting.

Natural cooling—typically wind and stack-driven airflow cooling—using operable windows and skylights can be provided if allowed by the local climate. Flushing cooler nighttime air through the home is also very effective where the local climate allows. Additional airflow cooling can be provided by the use of ceiling fans and local “task” fans.

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[3] These percentages are based on calculations that were carried out using an analysis tool called the House Comfort Design Checker for Winter Solar Overheating (Cooper 1997) which was developed by SAR Engineering Ltd. (Burnaby, British Columbia). The Design Checker is based on correlations with hourly simulations (derived using SUNCODE software (Ecotope, Inc.) and ENERPASS software (Enermodal Engineering)) and were verified using monitored data from a series of passive solar homes and a survey provided by their occupants. The House Comfort Design Checker produces results within 2% (of predicted hours of overheating) of the original correlations 81% of the time. This amounts to a difference in recommended south-facing glazed area equal to less than 0.5% of the heated floor area. It is intended for use only in a heating-dominant climate. The guidelines for south-facing glazed area apply to the heating season only (assumed to be October to April). Overheating is considered to occur if the temperature exceeds the set-point temperature by more than 4°C. Overheating is considered excessive if it exceeds 4% of the hours in a given month (based on occupant surveys). In virtually all cases, October was found to be the critical overheating month.

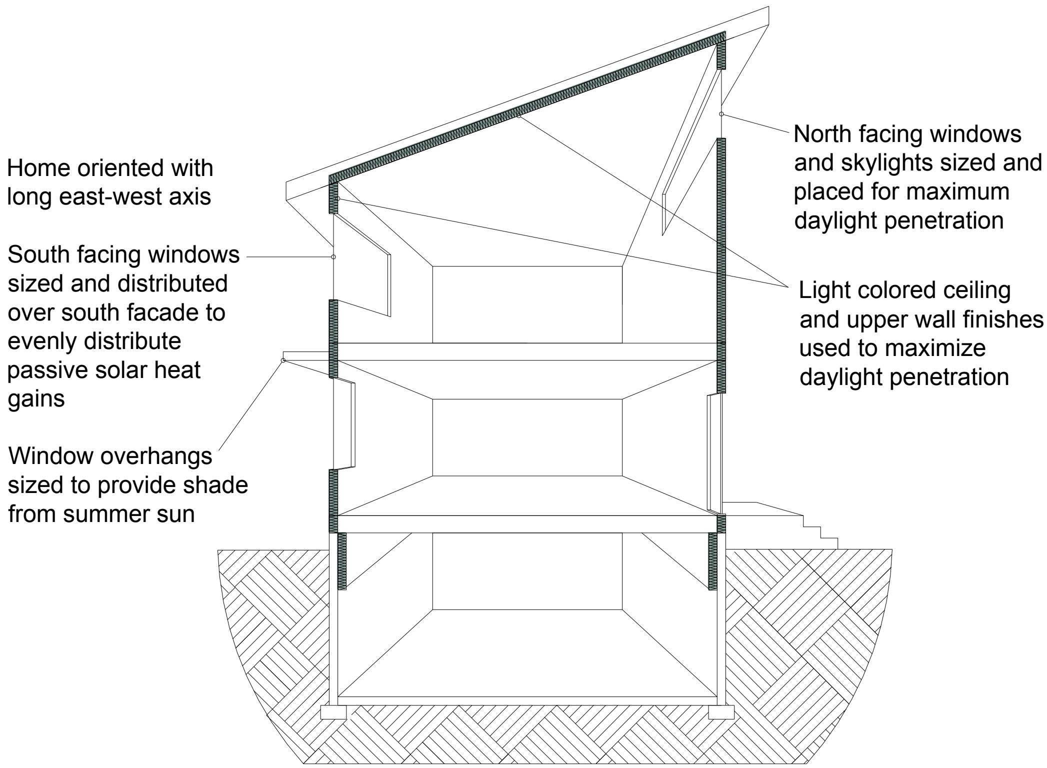


Figure 2-1. Building orientation and window distribution can allow for passive solar heating as well as daylighting, thereby reducing electric lighting requirements. Eighteen to 25% of the annual heating energy requirements can be provided by solar energy for a high-performance home built with light wood-frame techniques. Typically, south-facing windows have an area equal to 3.5 to 5% of the heated floor area. Higher solar-energy contributions using larger window areas can be accommodated through the addition of more massive interior finishes.

2.2 Building Envelopes

The building envelope of a high-performance house typically consists of highly insulated and airtight wall, floor, foundation, and roof assemblies, along with high-performance windows (Figure 2-2). Insulation levels in high-performance housing will range from RSI-5.3 to 10.6 (R-30 to 60) for above-grade walls, from RSI-10.6 to 17.6 (R-60 to 100) for ceilings, from RSI-3.5 to 7 (R-20 to 40) for foundation walls, and from RSI-2.1 to 3.5 (R-12 to 20) for underslabs, depending on climate and other factors. These values are the total effective values for the entire assembly, accounting for thermal bridging through the framing, i.e., they are not just the nominal insulation values alone. Refer to the appendices (Appendices K-N) for a list of building assemblies that meet these effective insulation levels. A wall thermal design calculator is also available from the website of the Canadian Wood Council (2013). Although mechanical ventilation is not part of the building envelope, when a home is made airtight, it must also utilize a balanced heat-recovery or energy-recovery ventilation system to ensure occupant health and safety (section 2.3).

Windows are typically triple-glazed with two low-emissivity coatings, use insulated spacer bars, and contain argon gas fill. The window frames are typically wood, high-quality vinyl (uPVC), or pultruded fibreglass.

The building must incorporate a continuous air barrier for both energy efficiency and building envelope durability (Figure 2-3). Airtightness should target 1.5 air changes per hour at 50 Pa pressure difference, or below, when tested according to the most current version of the CAN/CGSB-149.10-M86 airtightness testing standard (Standards Council of Canada 1986). The testing is carried out during construction so that the air barrier can be repaired if needed.

Cooling loads are reduced by the placement of correctly sized overhangs over south-facing windows. For exposed east- and west-facing windows, the most effective approaches will be solar-control, low-e coatings or vertical exterior shading devices. To allow for access to views, movable vertical exterior shades can be used. Use of high-efficiency appliances and reducing the use of electric lighting through daylighting will reduce internally generated heat that contributes to cooling loads in the summer.

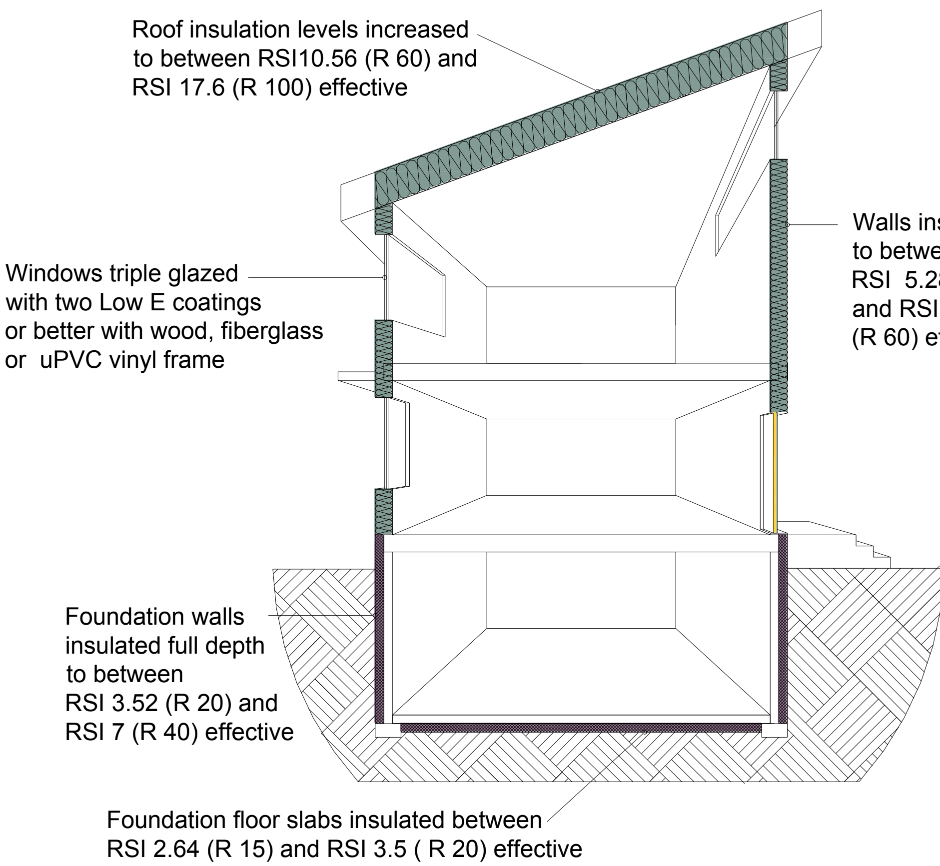


Figure 2-2. Super-insulated building envelope with high-performance windows. Windows typically have effective insulation values in the range of RSI-1.06 (R-6).

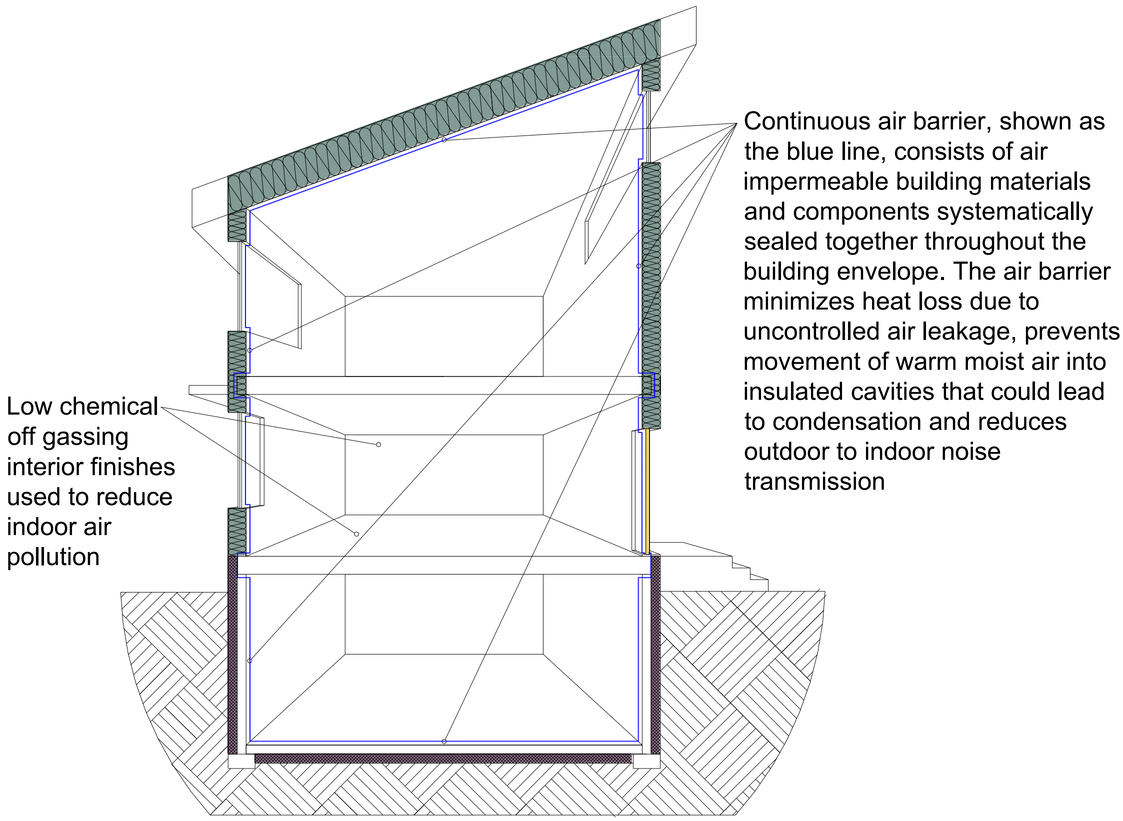


Figure 2-3. A continuous air barrier reduces heat losses and protects insulated cavities from indoor moisture entry. The home should be airtightness tested to be below 1.5 air changes per hour at 50 Pa pressure difference.

2.3 Mechanical Ventilation

When a home is made this airtight, a balanced heat or energy-recovery ventilation system is required to maintain good indoor air quality and minimize ventilation-related heat losses in winter and gains in summer (Figure 2-4). Heat-recovery ventilators (HRVs) continuously exhaust stale moist air from bathrooms, the kitchen, and the laundry room and transfer the heat from that air to outdoor air that is also being supplied continuously to the rest of the home. Energy-recovery ventilators (ERVs) are similar except they also transfer moisture as well as heat. This enables the outdoor supply air to be dehumidified as well as cooled in the summer if the home is air conditioned. In the winter, ERVs recover heat from the exhaust air while also providing humidification of the outdoor supply air. However, in homes that have significant moisture generation from factors, such as high occupancy, multiple pets or plants, or frequent cooking, ERVs may introduce too much moisture due to this same effect. The majority of central balanced ventilators used in British Columbia are HRVs. In the case of a power failure, temporary ventilation can be provided by opening windows and skylights on opposite sides of the home.

Indoor air quality will also be enhanced through careful selection of interior finishes that are inert or low in chemical off-gassing. Some examples of these types of products include:

- low- or no-VOC paints and other coatings
- medium- or low-density fibreboard that uses MDI (methylene diphenyl di-isocyanurate) adhesive
- exterior-grade plywood and OSB
- clay tile
- glass
- slate
- water-based adhesives and sealants

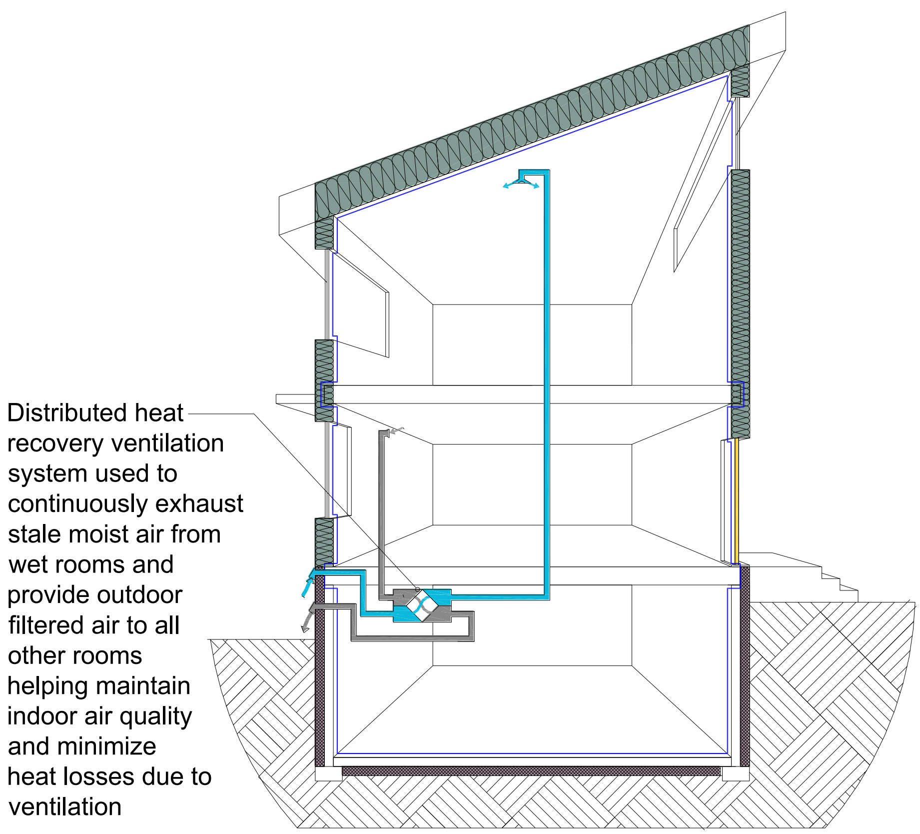


Figure 2-4. Indoor air quality is maintained, and heat losses due to ventilation are minimized, through the use of a heat-recovery or energy-recovery ventilator. The heat-recovery ventilator or energy-recovery ventilator will have heat-recovery efficiencies in the range of 70 to 80%. Stale moist air is exhausted from wet rooms, and preheated or pre-cooled outdoor air is supplied to all other rooms.

2.4 Electrical Energy Loads

When homes are built with a high-performance building envelope, the lighting, appliance, and electrical device loads combined will typically become one of the largest energy loads in the home. If the home is being built to be net-zero energy, this amount of electricity will have to be generated by a relatively expensive renewable energy system, such as a photovoltaic (solar electric) array. Typically these loads will amount to between 15 and 20 kWh/m^2/yr. To minimize these loads the occupants must be energy conscious in the operation of electrical devices and lighting, and the following measures must be taken (Figure 2-5):

- Use high-efficiency household appliances that meet ENERGY STAR standards, at a minimum CEE[4] Tier 2 and 3 where possible.
- Use condensing dryers that have lower energy consumption than conventional clothes dryers, which are large energy users.
- Use high-efficiency lighting with all lamps being tubular or compact fluorescent, or use light-emitting diode (LED) fixtures.
- Use motion-detection light switches in most rooms and corridors, and daylight-sensing controls in daylit areas to reduce the length of time lights are left on.
- Use a central green switch(s) to shut down unnecessary and parasitic (phantom) electrical loads at night and when the occupants are out of the home.

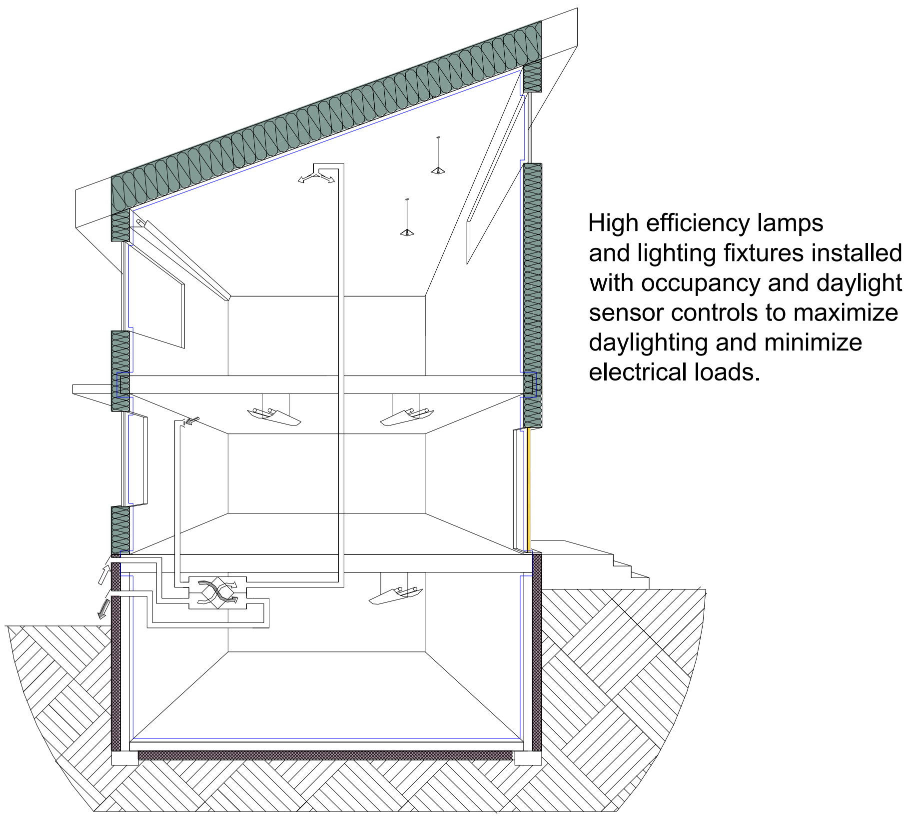


Figure 2-5. Electrical loads are minimized through the use of high-efficiency lighting and lighting controls.

[4] Consortium for Energy Efficiency, http://www.cee1.org/.

2.5 Water-Heating Loads

Energy use for water heating comprises a significant portion of total home energy use and can equal the amount of energy used for space heating in high-performance housing. The following measures can be utilized to reduce water-heating loads (Figure 2-6):

- Use a high-efficiency water heater with an energy factor rating of at least 0.85 for gas or 0.95 for electricity.
- Minimize the length of hot-water piping runs and insulate them.
- If a tank water heater is used, place it on an insulated base.
- Use low-flow shower heads and faucets.
- Use water-efficient, horizontal-axis washing machines and high-efficiency dishwashers, i.e., those that typically meet CEE Tier 2 and 3 requirements.
- Heat can be recovered from waste water by the use of a drain-water heat exchanger. This type of device is most effective when used in combination with showers.

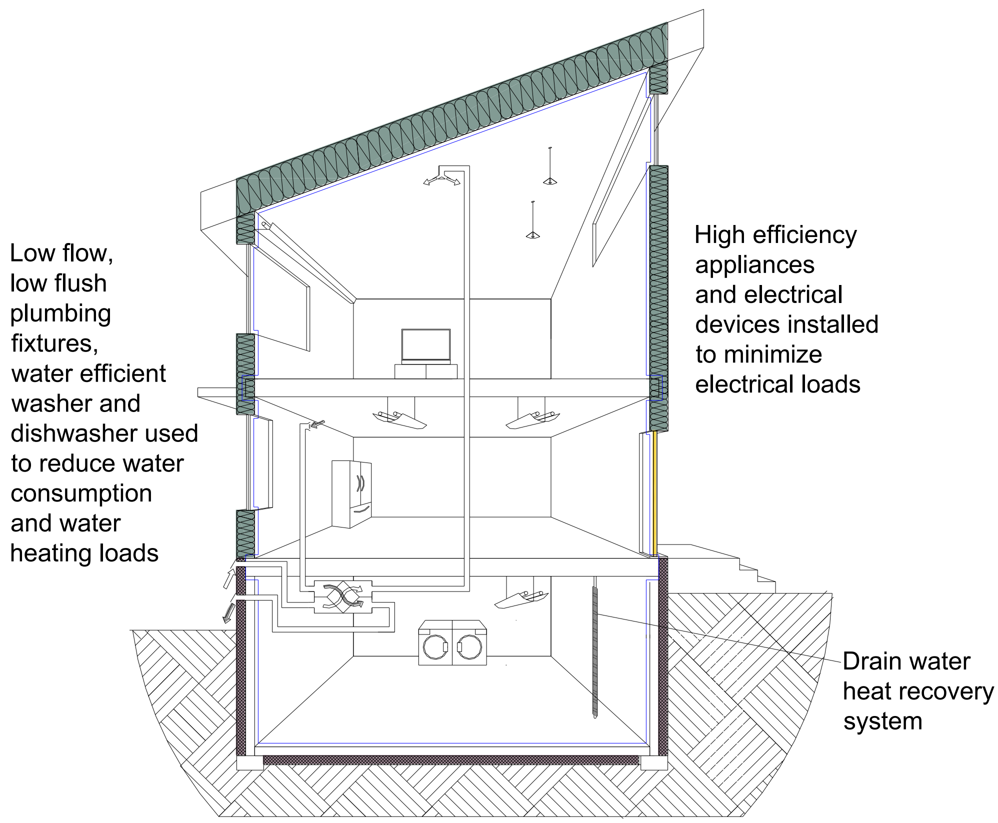


Figure 2-6. Hot-water consumption is minimized through the use of low-flow plumbing fixtures, water-efficient dishwashers and washing machines, and drain-water heat exchangers.

2.6 Heating Systems

A wide range of space-heating systems can be used with high-performance housing, including electric baseboards, gas-fired furnaces and boilers, heat pumps, and others (Figure 2-7). The highly efficient building envelope allows the heating plant and distribution system to be downsized, thus reducing costs and helping to compensate for the increased investment in the building envelope.

For net-zero energy housing, typically the most efficient heating systems are used to reduce the energy required for space heating, thereby reducing the size of the renewable energy systems that must supply the power to offset the operation of the heating system, if it is powered by electricity. In the case of gas-fired equipment, the renewable energy system must generate enough electricity to compensate for the gas consumed. Typical space- and water-heating systems include high-efficiency, cold-climate, air-source heat pumps; ground-source heat pumps; and high-efficiency, condensing, gas-fired boilers, furnaces, and hot-water tanks.

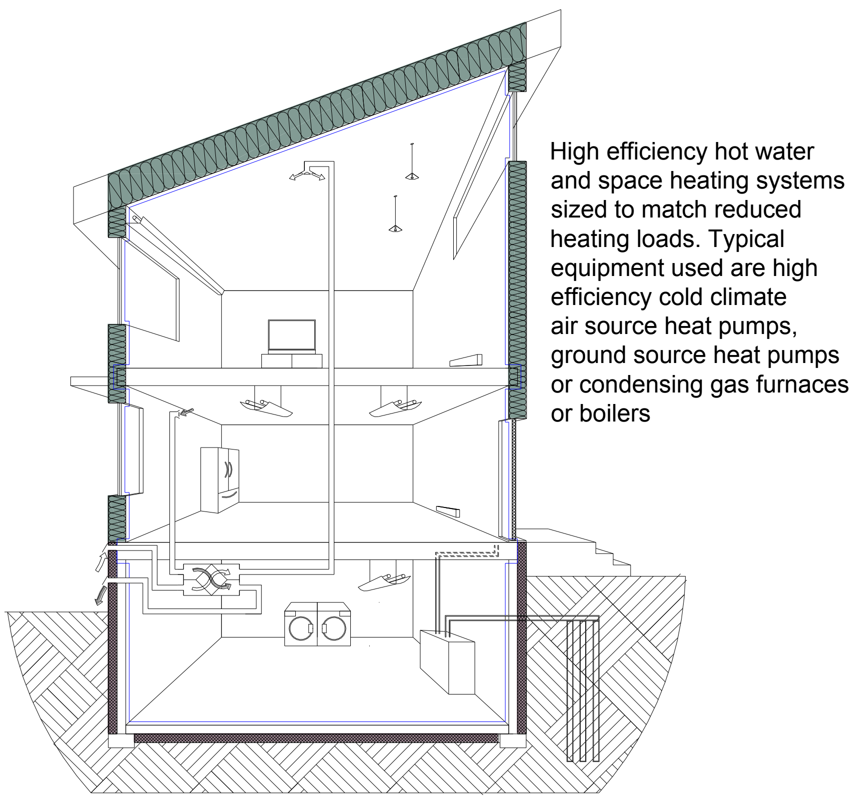


Figure 2-7. High-efficiency heating systems supply auxiliary heating.

2.7 Solar Electric (Photovoltaic) and Solar Thermal Collectors

If the decision has been made to construct a high-performance housing project that is net-zero energy, then the incorporation of renewable energy systems must be considered. The most common systems used include solar electric (photovoltaic (PV)) systems that are connected to the electric grid, and solar water-heating systems (Figure 2-8). Other renewable energy systems, such as solar air-heating systems, small wind-energy systems, and small-scale hydroelectric systems, are occasionally used but are beyond the scope of this publication. This is because these systems require specific site conditions, have complex permitting requirements, and are more complex to construct for the typical general contractor.

PV panels are typically roof-mounted but can also be mounted on adjacent buildings or on independent stands. Solar water-heating systems are typically roof mounted. In many cases the primary south-facing roof supports the PV array, and the slope of that roof is often determined by the optimum slope required for the PV array.

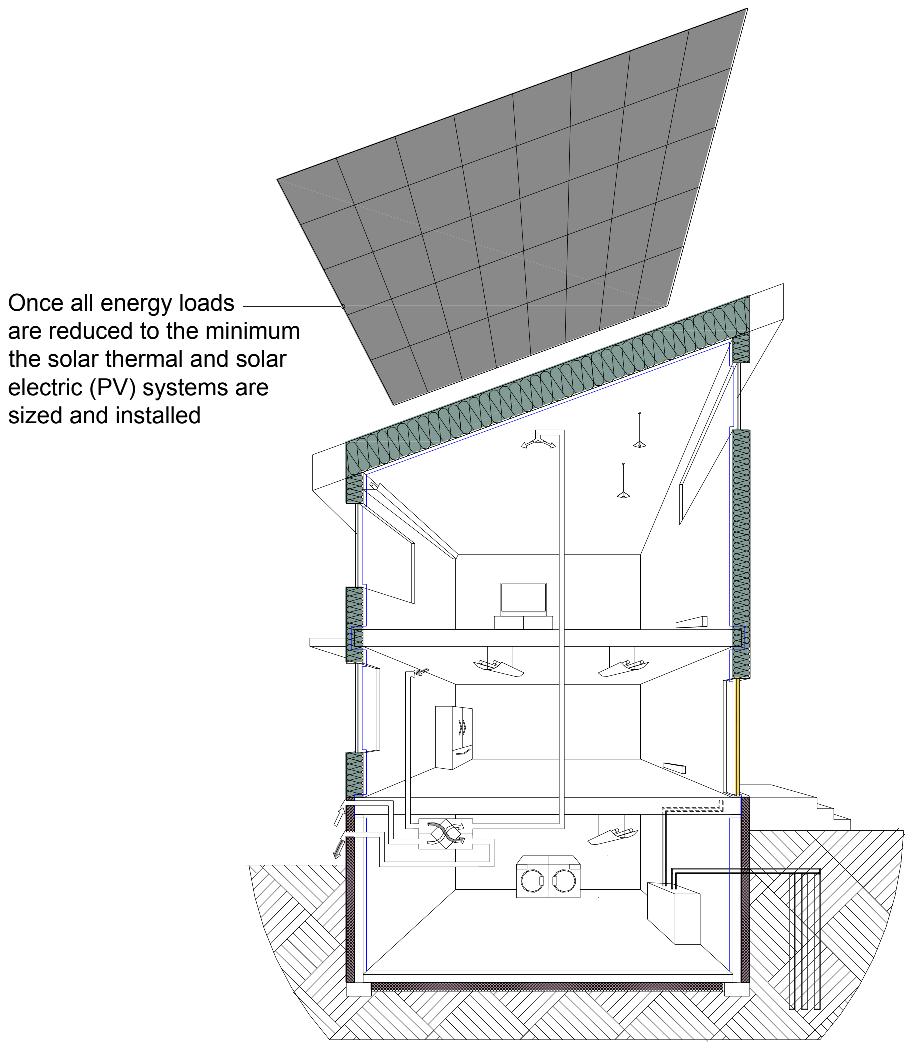


Figure 2-8. Typically, for a high-performance housing project that is net-zero energy, grid-connected, renewable energy systems are sized and installed to meet annual energy demands.

2.8 Whole-House Energy Consumption

For three regions in British Columbia, Table 2-1 and Table 2-2 compare a conventionally built and equipped home (based on the 2013 code) to that same home built as per high-performance strategies, in terms of building envelope, airtightness, and ventilation and heating systems, and the resulting energy consumption.

In these examples, depending on the region (the climate), the high-performance housing versions use between 17 and 25% of the purchased space-heating energy consumed by the conventional home. This is achieved through a combination of super insulation, high-performance windows, airtightness, high-efficiency heating and ventilation equipment, and high-efficiency appliances and lighting. The internal gains component is a measure of the "waste heat" produced by lighting, appliances, and people that offsets the heating in the home. In the high-performance housing version these internal heat gains have been significantly reduced by using daylighting, high-efficiency electric lighting, and high-efficiency appliances. Although the absolute amount of heat supplied by internal gains is reduced in the high-performance housing case, it supplies a larger percentage of the much-reduced heating load. The energy usages shown in Table 2-1 were calculated using the HOT2000 Version 10.51 energy-analysis software (Natural Resources Canada 2010a) which is referenced by the *British Columbia Building Code 2012* (Building and Safety Standards Branch 2012) for performance-path code-compliance calculations.

In the Okanagan Valley mechanical cooling is widely used, therefore the consumption of energy for cooling was also analyzed for that zone (Table 2-3). Many of the energy-efficiency features incorporated in the building envelope and the use of high-efficiency lighting and appliances help reduce cooling loads.

Table 2-1. Estimated energy-related characteristics of a home in three regions in British Columbia: comparison of conventional construction and high-performance housing. Two-story home, 232 m² (2500 ft²), with basement and conditioned crawl space.

Type of construction, by location	Slabs		Basement/ crawl space walls		Above-grade walls		Insulated cathedral ceilings		Windows		Air-tightness (ACH @ 50 Pa)[2]	Type of ventilation system	Type of heating system
	R[1]	RSI	R	RSI	R	RSI	R	RSI	R	RSI			
Southwestern B.C.													
Conventional	1.0	0.2	9.5	1.7	14.7	2.6	24.7	4.4	2.3	0.4	7.00	Central bath fan	Electric baseboard
High performance	10.0	1.8	22.0	3.9	32.4	5.7	38.2	6.7	6.0	1.1	1.5	HRV	Cold-climate air-source heat pump
Okanagan Valley													
Conventional	1.0	0.2	9.5	1.7	14.7	2.6	24.7	4.4	2.3	0.4	4.55	Central bath fan	Electric baseboard
High performance	10.0	1.8	22.0	3.9	32.4	5.7	61.0	10.7	6.0	1.1	1.5	HRV	Cold-climate air-source heat pump
Central Interior													
Conventional	1.0	0.2	9.5	1.7	14.7	2.6	24.7	4.4	2.3	0.4	3.57	Central bath fan	Electric baseboard
High performance	10.0	1.8	22.0	3.9	41.0	7.2	81.0	14.3	6.0	1.1	1.5	HRV	Cold-climate air-source heat pump

[1] All RSI (R) values are effective thermal resistance values accounting for all materials in the assembly and thermal bridging effects.

[2] ACH = air changes per hour.

Table 2-2. Estimated annual energy consumption of a home in three regions in British Columbia: comparison of conventional construction and high-performance housing. Two-story home, 232 m^2 (2500 ft^2), with basement and conditioned crawl space.

Type of construction, by location	Energy purchased for space heating (kWh)	Passive solar heat gains (kWh)	Internal heat gains contribution (kWh)	Appliances and lighting (kWh)	Water heating (kWh)
Southwestern B.C.					
Conventional	23,735	7,207	10,545	8,772	5,128
High performance	3,940	3,171	3,701	3,458	2,122
Okanagan Valley					
Conventional	26,650	7,049	7,864	8,810	5,015
High performance	6,627	3,086	3,540	3,614	2,073
Central Interior					
Conventional	40,203	9,915	8,259	8,771	5,618
High performance	9,944	4,328	3,740	3,460	2,366

Table 2-3. Estimate of purchased energy for mechanical cooling of a home in the Okanagan Valley, British Columbia: comparison of conventional construction and high-performance housing. Two-story home, 232 m^2 (2500 ft^2), with basement and conditioned crawl space.

Type of construction	Type of mechanical cooling	Energy consumption (kWh)
Conventional	Air conditioner SEER 12	4,399
High performance	Air-source heat pump SEER15	1,213

2.9 Sustainable Materials and Products

Whenever it is possible and economical, high-performance housing projects utilize sustainable materials and products to minimize the environmental impacts of construction and long-term maintenance of the building. These products must also be safe for construction crews to handle and must not negatively impact the indoor quality or the water quality in the home. See Appendix A for characteristics of sustainable materials and products.

2.10 Water Conservation

Average water consumption in Canada is about 340 L/day/person (75 imp gal/day/person). Reducing water consumption has numerous benefits:

- Where water is metered, the cost of municipally supplied water is reduced.
- Reducing hot-water consumption in dishwashers, clothes washers, and when taking showers will reduce purchased energy consumption, thus reducing costs and the associated environmental impacts.
- If a solar water heater is used and water conservation is practiced, renewable solar energy will be able to supply a larger portion of the household's total hot-water use.

- Reduced water use lowers the demands on the municipal water-treatment system, lowering infrastructure capital and operating costs, ultimately reducing costs for the rate payers and the environmental impacts associated with water-treatment plants.
- Less waste water is produced, thus reducing demands on sewage infrastructure and treatment and ultimately reducing costs for the rate payers.

See Appendix B for a breakdown of typical household water consumption and an overview of technologies for reducing water consumption on a household scale.

2.11 Storm-Water Management

Storm water is the rainwater runoff from hard, non-absorbing surfaces such as roofs, driveways, paved pathways, patios, lanes, and roads. As it runs over these surfaces, storm water collects dirt, grease, oil, and other pollutants. Storm water is typically collected and treated by municipal sewage-treatment systems. If storm water enters creeks, streams, or rivers, it can pollute those waterways, potentially killing fish and other organisms. In addition to this, the aquifer where rainwater would normally end up does not get recharged as much as when the land was undeveloped. To reduce problems associated with storm-water runoff, conventional hard surfaces are replaced with permeable surfaces that allow rainwater to pass through the soil and into the aquifer. Storm water can also be collected from non-permeable surfaces and then filtered and treated through landscape features called bioswales and rain gardens before entering the aquifer (CMHC 2007, 2011).

2.12 Cost-Effectiveness Considerations

The cost-effectiveness of various energy-efficiency measures used in high-performance housing must be evaluated and compared at the design stage. This helps achieve cost optimization and affordability of such housing. The following two indices show the types of consideration and cost analysis that can be conducted to predict the energy savings of an energy-efficiency measure and its relative cost effectiveness. Other factors should also be considered, such as long-term maintenance and repair costs, and other suitable references may be developed for a specific project.

- Value index – One method of determining the cost effectiveness of the insulation, windows, airtightness, and other energy features of a high-performance home is to use a metric—i.e., an energy-efficiency measure—that compares the cost of energy saved to the equivalent performance of other energy-efficiency measures. This index can also be used to compare the economic performance of conservation measures versus renewable energy measures. For example, when the incremental cost of energy saved by an energy-efficiency measure is equal to or greater than the cost of energy produced by the renewable energy system, the upper limit of that energy-efficiency measure has been reached. At that point, further investments in that energy-efficiency measure should be abandoned and additional monies should be invested in other energy-efficiency measures with a lower value index or in the renewable energy system. This metric is referred to as the value index (Proskiw and Parekh 2010).

  The energy-efficiency measure value index is the incremental cost of the energy-efficiency measure divided by the annual energy savings:

  > Energy-efficiency measure value index = (incremental cost of energy-efficiency measure in $) / (annual energy savings in kWh)

- Similarly the renewable energy system value index is the cost of the renewable energy system divided by the amount of energy it produces in a year:

  Renewable energy system value index= (cost of renewable energy system in $) / (annual energy production in kWh)

  As an example: if the cost of an installed PV system that produces 16,000 kWh/yr is $60,000, it has a renewable energy system value index of $3.75/kWh/yr. This means that for the particular home with that PV system on it, the energy-efficiency measures that have a value index of up to $3.75/kWh/yr are justified and should be used; those that are greater should not be used and instead an additional investment in PV systems should be considered. However, other limitations may come into play, such as the available unshaded south-facing roof area for a PV system.

Chapter 3 – The Integrated Design Process

The integrated design process is an approach to design that draws on the expertise of the design and construction teams, computer modelling, and professional judgement to optimize a building's energy and environmental performance while also minimizing construction costs.

At the beginning of the design process the designer, working with the client, will identify the functional, space planning, aesthetic, budgetary, and environmental performance goals of the project. Local input is very important for every aspect of the design and construction of high-performance housing. It is always helpful to have discussions and meetings with the local jurisdiction early on about the project.

As illustrated in Figure 3-1, high-performance housing design can be divided into the following phases:

- program development
- site analysis
- schematic design
- preliminary energy analysis
- design charrette
- design development
- construction document production
- field review and commissioning

Each of these phases has multiple aspects, many of which are beyond the scope of this publication. Here we will approach each of these phases from the points of view of emphasizing energy efficiency, reducing environmental impact, and enhancing human health and comfort.

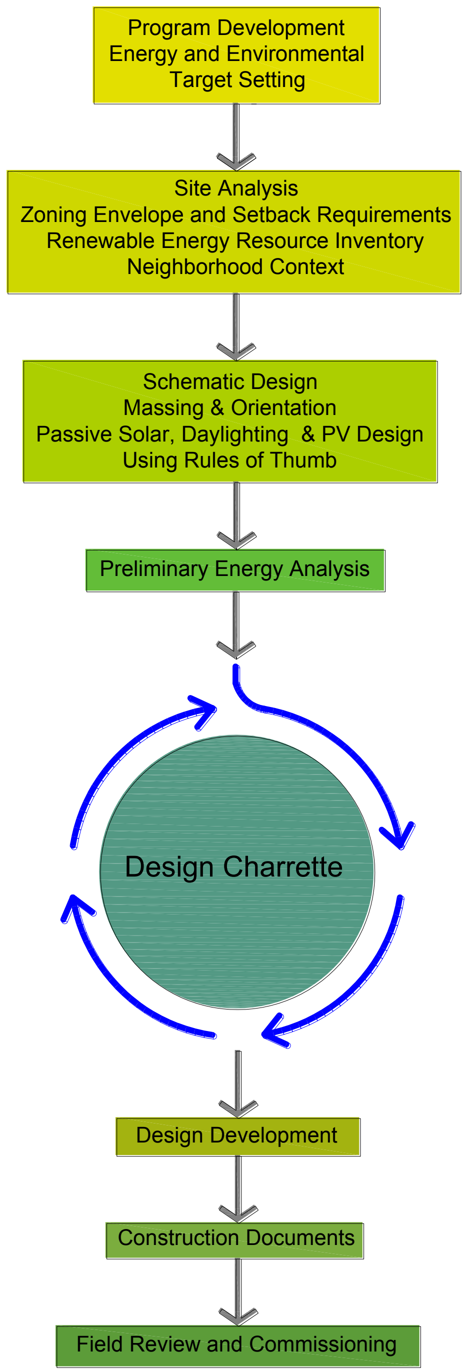


Figure 3-1. The process of designing high-performance housing: flow diagram.

3.1 Program Development

3.1.1 Setting Energy and Environmental Performance Goals

In consultation with the client the designer sets energy and environmental performance goals for the project. One of the primary energy-performance goals of a high-performance housing project is to reduce energy consumption to a minimum. If net-zero energy is the goal, energy consumption must be reduced to the point at which on-site, clean, renewable energy systems can generate as much energy as the home consumes on an annual basis. Reducing energy consumption and environmental impacts while enhancing human health requires addressing the following areas:

- Space heating – Reduce space-heating energy by 50 to 80% compared to code-compliant homes in British Columbia in 2013.
- Water heating – Reduce water-heating energy consumption by 20 to 30%.
- Lighting energy – Minimize electricity required for lighting through the use of high-efficiency light fixtures and lamps. Use controls that minimize the amount of time the lighting is turned on. Also, incorporate features that maximize daylight penetration for interior illumination.
- Appliance energy – Minimize appliance energy requirements through selection of high-efficiency appliances.
- Electrical devices energy – Minimize energy consumption for electrical devices and switch off the power to devices not in use.
- Renewable energy systems – For net-zero energy projects where the goal is to supply all energy needs with on-site renewable energy, the first step is to utilize low-cost/no-cost renewable energy systems such as passive solar heating, airflow cooling, and daylighting. Once these have been fully utilized, solar thermal systems, solar electric systems, and, in certain cases, wind energy and small-scale hydro systems can be incorporated.
- Air quality – Provide high levels of indoor air quality through the use of interior finishes, adhesives, paints, and sealants that are chemically inert or low in chemical off-gassing, and the use of a distributed heat-recovery ventilation system.
- Daylighting – Maximize daylighting for both energy and human health benefits.
- Materials – Use materials that are resource efficient and which have low embodied energy and low embodied pollution.
- Water – Conserve the use of potable water through the use of water-efficient plumbing fixtures, dishwashers, and washing machines; collect rainwater for irrigation and possible use in toilets and for washing.
- Carbon sequestration – Maximize carbon sequestering within the building structure and finishes, largely by using wood and other plant-based products.
- Resource efficiency – Maximize resource efficiency by using engineered wood products and products with high recycled content when possible.
- Rainwater – Where subsoil conditions allow, manage rainwater on site by using permeable pavers and landscaping features that facilitate recharging of the local aquifer.
- Irrigation– Use local, low-water-demand landscaping to minimize irrigation requirements.

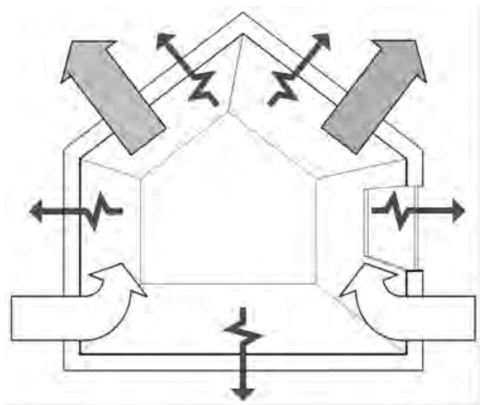
The environmental impacts of building materials and assemblies can be analyzed using life-cycle assessment tools, such as the Athena EcoCalculator (Athena Sustainable Materials Institute 2012). By using life-cycle assessment, it is possible, among other things, to minimize the: embodied energy of building materials by using products that take less energy to manufacture and do not have to be transported large distances, embodied pollution of building materials by using materials that are produced using low-pollution industrial processes, and CO_2

emissions associated with the manufacturing of building materials and the construction of assemblies.

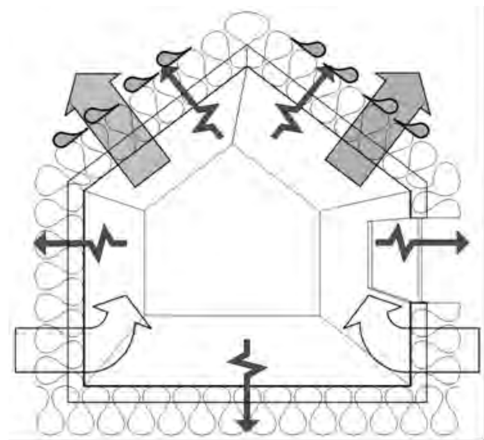
Another useful reference for assessing the environmental impacts of building components is the environmental product declaration. In life-cycle assessment, an environmental product declaration is a standardized way of quantifying the environmental impact of a product or system. Declarations include information on the environmental impacts of raw material acquisition; energy; content of materials and chemical substances; emissions to air, soil, and water; and waste generation. Product and company information are also included.

3.1.2 Building as a System

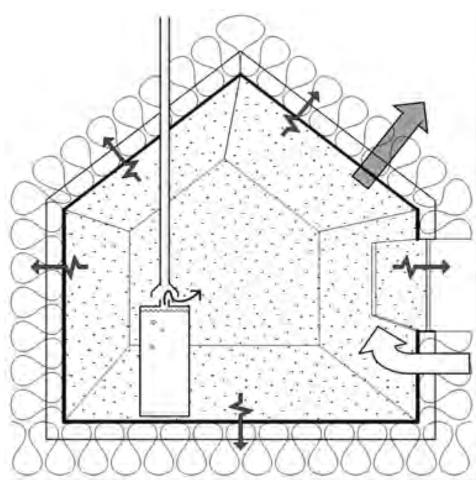
To ensure a home is safe and durable it is necessary that the principles of “building-as-a-system” be followed. The approach is based on the recognition that heat, air, and moisture flows are interrelated and, if steps are taken to change any one of these flows, the others can be affected. Figure 3-2 illustrates an example of the building-as-a-system concept and how increasing the insulation levels in a home to reduce heat flows (heat losses and gains) leads to the need for other measures. Building-as-a-system can also apply to the operation of other equipment and the interaction between occupants, equipment, and the building envelope.



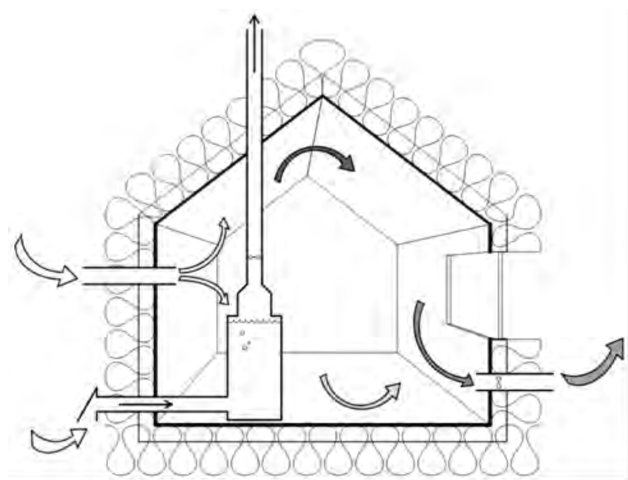
1) Heat is lost from the home due to heat transmission and air leakage.



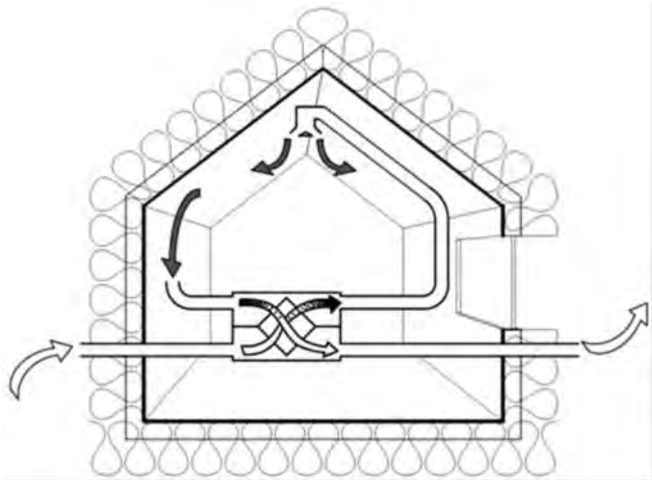
2) Heat losses are reduced by increasing insulation levels, but air leakage through the building envelope leads to heat loss and possible condensation forming in insulated cavities.



3) When a continuous air barrier is incorporated into the building envelope, air leakage is minimized and heat loss is reduced, leading to prevention of condensation formation but also leading to possible back drafting of combustion appliances, elevated humidity, and poor indoor air quality.



4) The use of low-toxicity interior finishes and sealed combustion appliances minimizes release of indoor air pollutants. A ventilation system exhausts stale, moist air and supplies outdoor air but also increases heat loss.



5) Incorporation of a distributed heat-recovery ventilation system minimizes heat loss associated with ventilation while helping to maintain high indoor air quality.

Figure 3-2. One example of how the principles of building-as-a-system are applied to the design of high-performance housing.

3.2 Site Analysis

The site is analyzed to ensure compliance with local zoning requirements and to give consideration to neighbourhood context, and to determine the availability of renewable energy. In most cases the primary form of renewable energy used in a high-performance housing project is sunlight for passive space heating and daylighting. If the home is targeting net-zero energy consumption, sunlight will typically provide electrical power production and contribute to heating domestic hot water. For this reason the solar exposure of the site is analyzed at an early stage. One method for doing this is to plot the buildings, vegetation, and topographic features to the south of the building site that will cause shading on a sun-path chart. A sun-path chart for a particular latitude shows the path that the sun follows across the sky on the 20^{th} or 21^{st} day of each month, plotted according to altitude (height above the horizon) and azimuth (number of degrees east or west of due south). By plotting objects on a sun-path chart the number of hours that the sun is available for a typical day of each month of the year can be determined.

Other proprietary tools are available for solar site analysis using purpose-built hardware, computer software, and smart phone applications. An internet search should be undertaken to review these other options. This method is presented here because it is well proven and easy to visualize, and free tools are available to generate sun-path charts (e.g., Solar Radiation Monitoring Laboratory 2007). Smart phones and tablets can also be used to replace the traditional compass and inclinometers used in completing a sun-path chart for a specific location.

For direct-gain passive solar heating, the availability of sunlight from October through March for at least four hours of the day between 8 a.m. and 4 p.m. is most critical. For PV systems and solar domestic hot-water systems, the availability of sunlight over the entire year is beneficial, but the most useful period is from March to October. Information about the amount of solar exposure on the site can then be used to inform energy-analysis software and renewable-energy-system design software. Depending on the circuit design of a PV system, partial shading of a panel can significantly reduce or stop production of electricity. Ideally, for PV installations, shading should be eliminated or kept to a minimum.

Wind can be used for natural cooling. An estimate of the wind speed and direction experienced at the site can be obtained from nearby weather stations. For a natural cooling system, wind speed and direction from May to October is most critical.

3.3 Schematic Design

3.3.1 Building Orientation and Form

Building form is determined by a range of factors including:

- site shape and topography
- zoning envelope setback and height requirements
- architectural context of the neighbourhood
- the client's spatial and functional requirements
- aesthetics
- views
- access to sunlight within the home
- access to sunlight on roofs
- access to daylight
- existing trees and other vegetation

The task of the designer is to reconcile all of these considerations, some of which may be conflicting. Heat loss from a building envelope can be influenced by the building form. Simple compact shapes have less surface area for their volume than more complicated forms and therefore will lose less heat when insulated to the same levels. Compared to complex forms, simple forms are also generally easier to make more airtight and have fewer corners that can increase thermal bridging due to multiple studs.

In order to utilize passive solar heating and to accommodate solar thermal and solar electric systems, housing forms with an elongated east–west axis are best suited. Houses with elongated forms also typically work better for natural cooling and daylighting (Figure 3-3). For sites that have poor or no solar exposure for passive solar heating, a very compact building form should be considered. While a due-south-facing façade is ideal for passive solar heating, the southward-facing façade of the building can be oriented up to 30 degrees east or west of due south with only a minor penalty in performance (Figure 3-4).

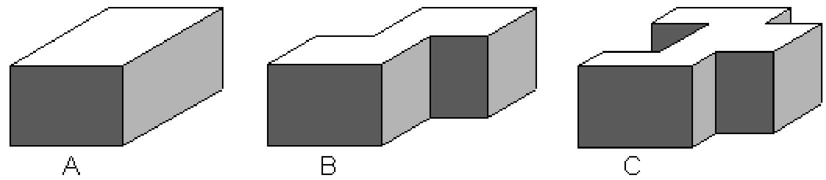


Figure 3-3. Comparison of surface area to volume. All of these forms have the same floor area and volume, but Forms B and C have 10% greater surface area than Form A and therefore will experience greater heat loss when insulated to the same levels.

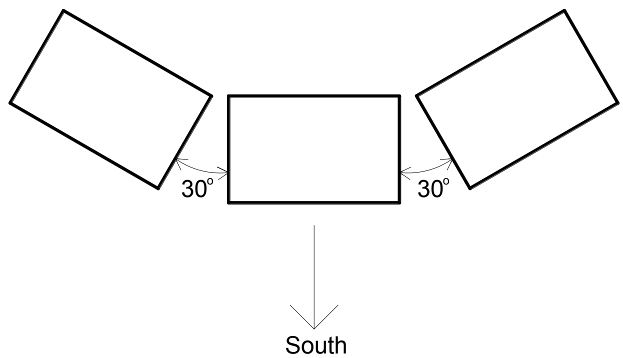


Figure 3-4. While the optimum orientation for solar energy utilization is due south, orientations of up to 30 degrees east or west of due south can be used.

3.3.2 Rules of Thumb for Schematic Design Stage

3.3.2.1 Passive Solar Heating[5]

Use an elongated east–west axis for the building's main axis.

Kitchens can generate a large amount of waste heat (internal heat gain) from the operation of appliances, so they are best placed on the north side and ideally on the northeast corner in order to receive the morning sun.

Place daytime living spaces on the south side of the home.

South-facing windows should be as evenly distributed as possible to allow sunlight to "sweep" across the entire interior, distributing heat and light and most effectively utilizing the inherent heat storage capacity of the building structure and interior finishes (Figure 3-5, Figure 3-6, and Figure 3-7).

For passive solar heating, the light transmission of the windows should be as high as possible, while still maintaining a minimum effective thermal transmittance of Usi 0.94 (Uimp 0.17) or an RSI (R) value in the range of 1.06 (6). This will typically mean using a uPVC vinyl, wood, or pultruded fibreglass frame with triple-glazed, insulated glass units that incorporate two high-light-transmission, low-emissivity coatings, insulated spacer bars, and argon gas fill.

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[5] For more information on passive design, see *Tap the Sun Passive Solar Techniques and Home Designs* (Canada Mortgage and Housing Corporation 2008), *Passive Design Toolkit for Homes* (City of Vancouver 2009), and the *Builders' Manual* (Canadian Home Builders' Association 2013).

For light wood-frame construction with high-performance housing levels of insulation and airtightness, the south-facing window area should be equivalent to 3.5 to 5% of the total heated floor area (including basements) to prevent overheating on clear winter days. This will result in an annual solar contribution to space heating in the range of 18 to 25%. To reduce summer overheating, shading must be provided for south-facing windows, using horizontal overhangs or movable exterior shades. Correctly selected and placed deciduous trees have also been used successfully for shading south-facing windows.

If larger south-facing window areas are desired, movable shading devices and airflow cooling in the form of opening windows and skylights can be used on clear winter days to reduce overheating.

Higher solar contributions in the range of 30 to 40% are possible, if the design incorporates a larger south-facing window area combined with more mass (Figure 3-8). Mass is most effective for heat storage if it is directly illuminated by the sun. The mass usually takes the form of concrete, brick, stone, gypsum board, or clay tile. It should be kept thin, i.e., in the range of 25 to 100 mm (1 to 4 inches), and as widely distributed as possible. Typical thermal mass strategies include a double layer of 16-mm (5/8-inch) Type X drywall; 100-mm-thick (4-inch-thick), fully insulated, slab-on-grade concrete finished floors; 38-mm-thick (1½-inch-thick) concrete top coat over a plywood subfloor and then covered with a clay tile or quarry tile finish; and brick and stone veneers applied to interior walls. This type of construction will accommodate between 7 and 10% of the total heated floor area in south-facing windows. Typical annual passive solar heating contributions will be in the range of 30 to 40%. To prevent overheating, shading must be provided for south-facing windows during the summer, using horizontal overhangs or movable exterior shades. Higher-mass passive solar homes are typically built in geographic locations that get greater levels of sunlight. When larger areas of south-facing windows are used, care must be taken to ensure glare does not cause visual discomfort.

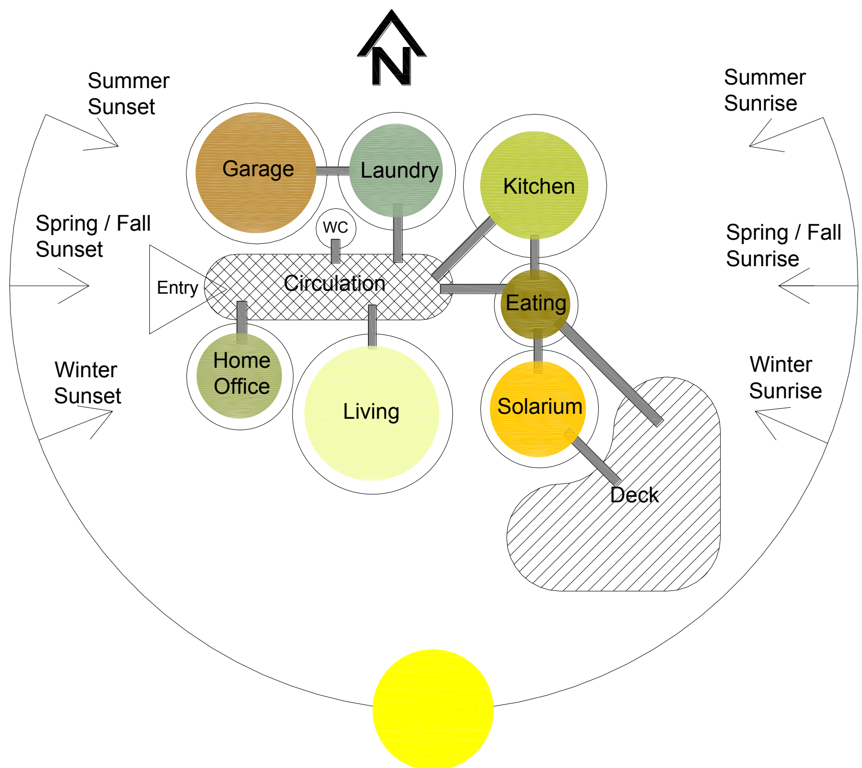

Figure 3-5. Bubble diagram of a room layout aimed at utilizing passive solar heating on the ground floor.

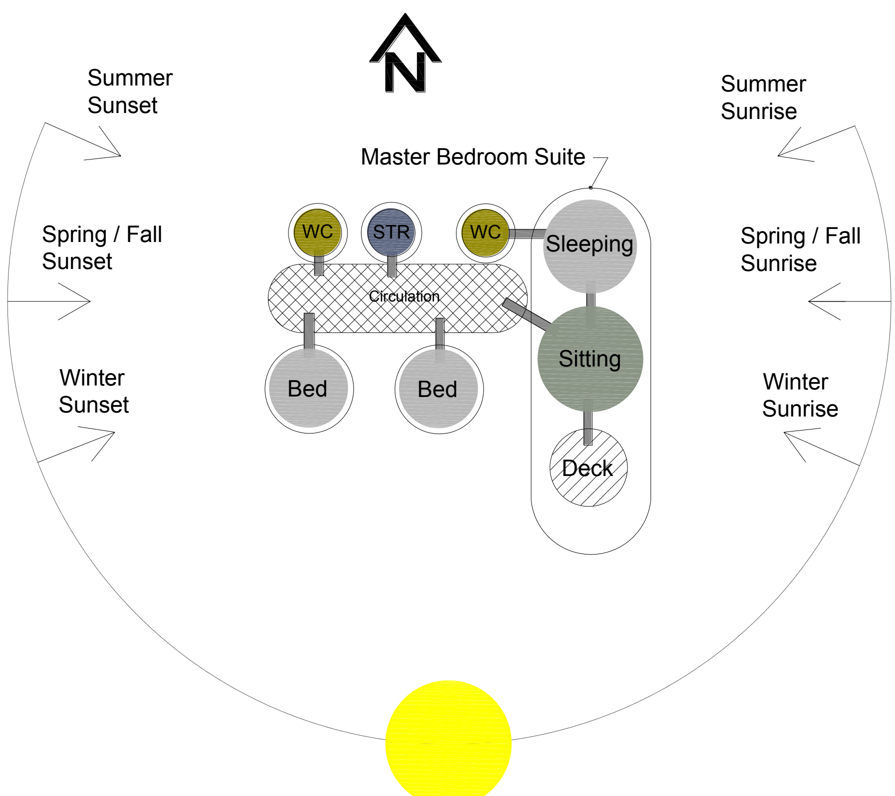

Figure 3-6. Bubble diagram of a room layout aimed at utilizing passive solar heating on the second floor.

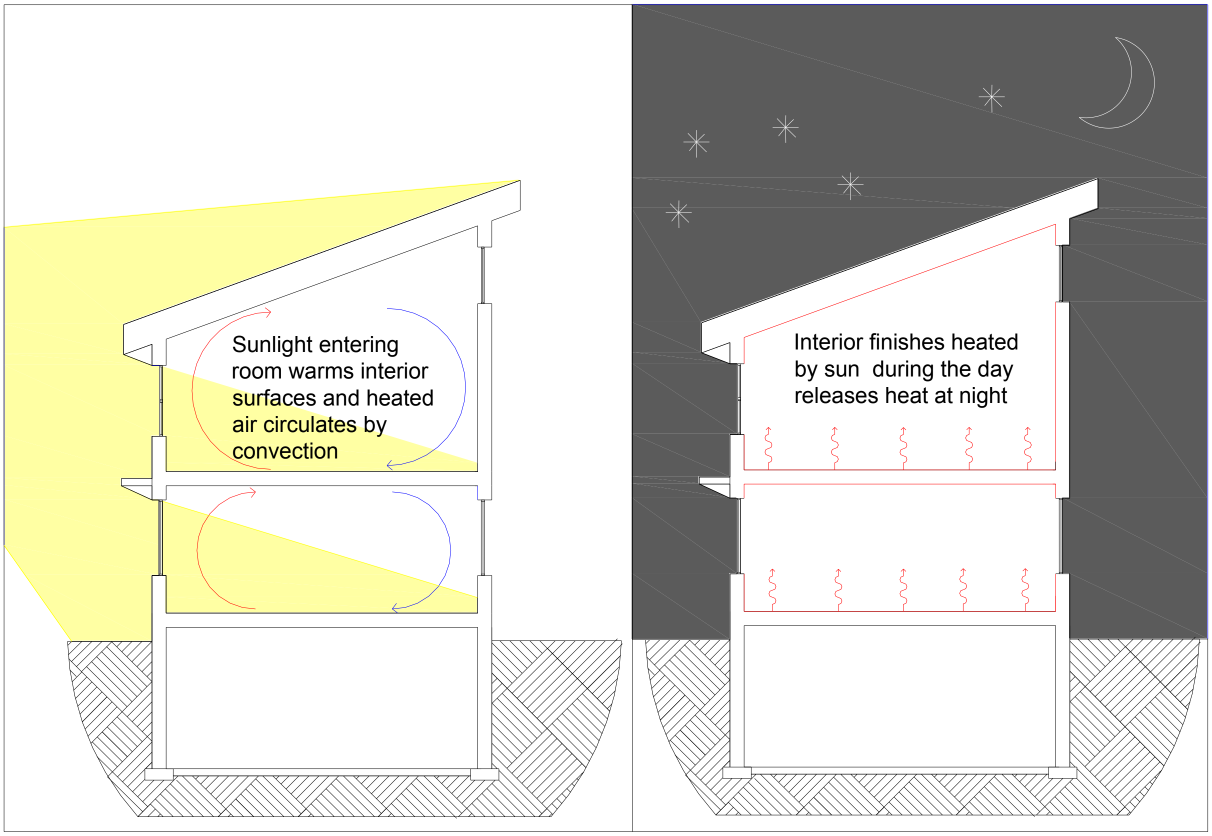

Figure 3-7. During the day, sunlight passing through southward-facing windows falls on interior surfaces, warming them and in turn heating the air in the room. At night, the interior surfaces and structure that were warmed during the day release heat.

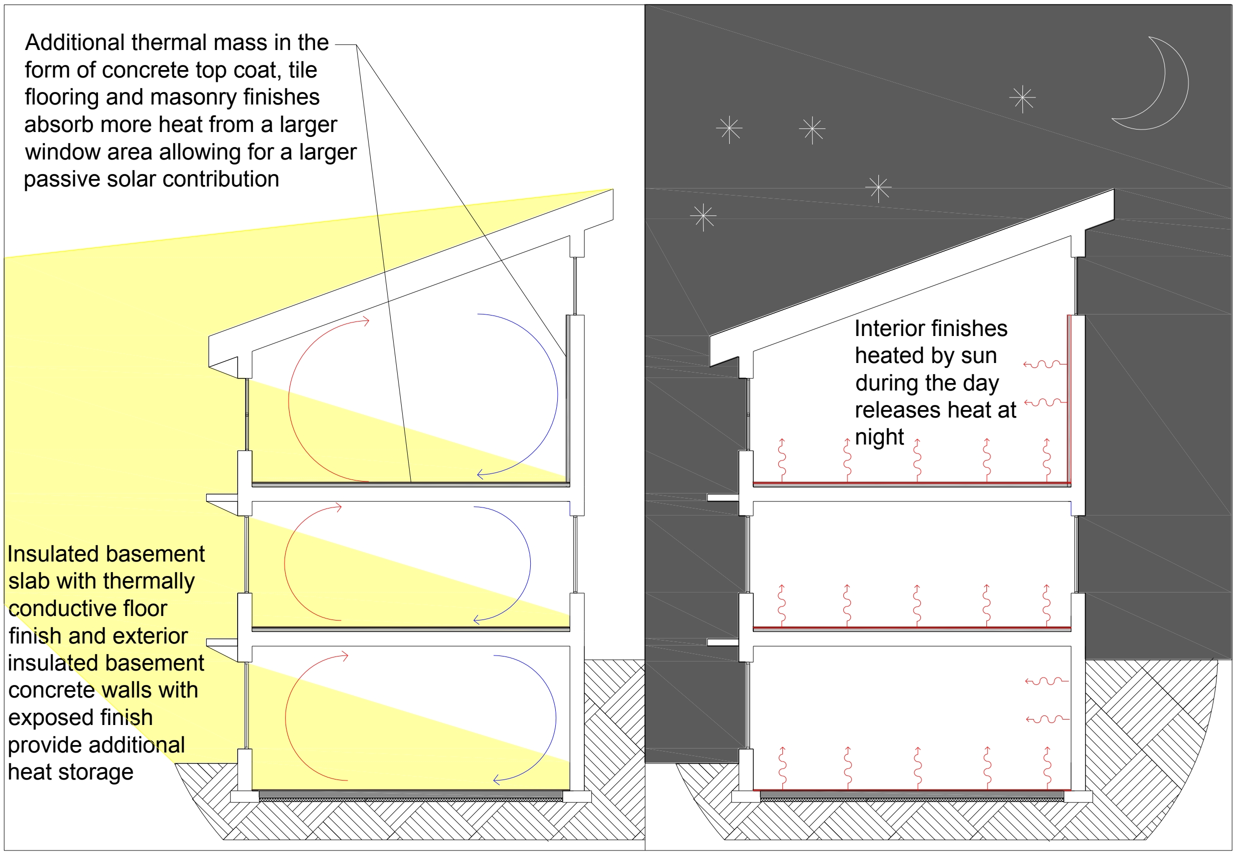

Figure 3-8. Higher annual solar-heating contributions up to 30 to 40% are possible by increasing window areas to be as much as 7 to 10% of the heated floor area, and by adding thermal mass in the form of concrete top coats, insulated concrete floor slabs, ceramic tile flooring, and masonry wall finishes. Heat absorbed during the day is released from the thermal mass at night.

3.3.2.2 Natural Cooling

Summer cooling requirements can be reduced through the use of correctly sized and located window shading, high levels of insulation in the ceiling, daylighting, and high-efficiency lighting and appliances. South-facing windows require overhang depths to be between one-half and one-third of the window height (Figure 3-9). The greatest likelihood of overheating will tend to occur in the late fall when outdoor temperatures are still warm and the sun is lower in the sky. During these times, adjustable interior or exterior shading may need to be used. For east- and west-facing windows, vertical exterior shading devices or the use of cooling, low-emissivity coatings are most effective (Figure 3-10, Figure 3-11, and Figure 3-12).

Skylights must be north facing or covered with exterior shading to minimize solar heat gain in the summer.

Cooling can be provided by air flowing through a room. To be effective, airflow cooling requires air to be moving over the occupants at 1 to 2 m/s, the outdoor air temperature to be 28ºC or less, and the relative humidity to be lower than 80%. These conditions are met during the daytime in many locations in British Columbia.

Air movement through a home can be driven by wind pressure, or stack pressure (warm air rising), both of which can be supplemented by ceiling fans and smaller fans if needed. All of these options use less energy than mechanical air conditioning.

Airflow cooling, whether using fans or the natural forces of wind and stack effect, will be more easily achieved in spatially open designs that have few restrictions to airflow (Figure 3-13).

To utilize wind for natural cooling, use the following rules of thumb (Figure 3-14):

- Operable windows – With opening areas equal to at least 4% of the heated floor area of the home, including basements, operable windows can provide sufficient natural cooling, except on hot, humid, windless days. Automatic window and skylight openers are available to enable airflow cooling when occupants are not home. The use of these devices may also require additional security measures.
- Cross ventilation – This is best obtained by locating operable windows on opposite walls, facing upwind and downwind to the prevailing summer winds.
- Casement windows – These are the best option for ventilation because they provide the largest area of window opening.
- Leeward vs. windward – The leeward (downwind) opening windows should be 50% larger than the windward-facing windows.
- Cross ventilation – To allow cross ventilation to work effectively, the depth of the home should be no more than five times the ceiling height.
- Open plan – Use open-plan designs that have minimum restrictions to air movement.

Nighttime outdoor air temperatures are generally lower than daytime temperatures. This fact can be utilized to provide cooling by flushing outdoor air through the home at night (Figure 3-15). Night flushing can be achieved through the use of the natural forces of wind and stack effect, the use of fans, or by using “free cooling” by drawing large amounts of air into the return-air plenum of a forced-air heating system. In addition to lowering air temperatures at night, the effects of night flushing can provide a cooling benefit the following day (Figure 3-16). This will require that windows and skylights during the day are closed if the following day’s air temperatures are higher.

Airflow cooling can be further enhanced through the use of wind towers (Figure 3-17). One reason for this is that wind speeds increase with increasing height above the ground. Wind flowing across the top of the wind tower will cause a negative pressure that draws air out of the building. The performance of a wind tower can be further enhanced through the use of aerodynamic devices installed at the top of the tower.

In dry hot climates, such as in the Okanagan, evaporative cooling can also be used in which outdoor air is passed through a fine water mist which lowers the air temperature by evaporation.

In climates and situations where cooling and dehumidification are required, high-efficiency air-conditioning equipment that meets ENERGY STAR requirements, or which has Seasonal Energy Efficiency Ratio (SEER) ratings of 15 or higher, should be used. In these cases the HVAC (heating, ventilation, and air conditioning) system will be most efficient if an energy-recovery ventilator is used that will exchange moisture as well as heat, thus both dehumidifying and cooling incoming outdoor air.

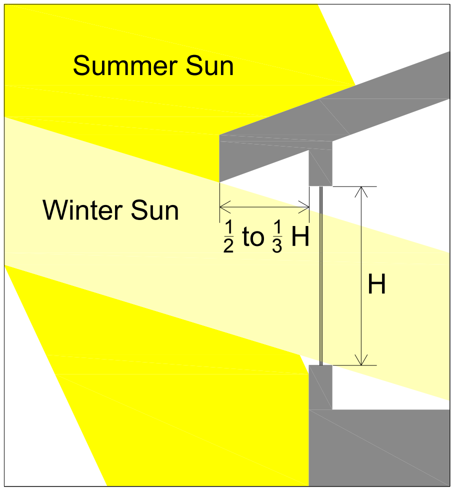

Figure 3-9. Sizing of overhangs for a south-facing window.

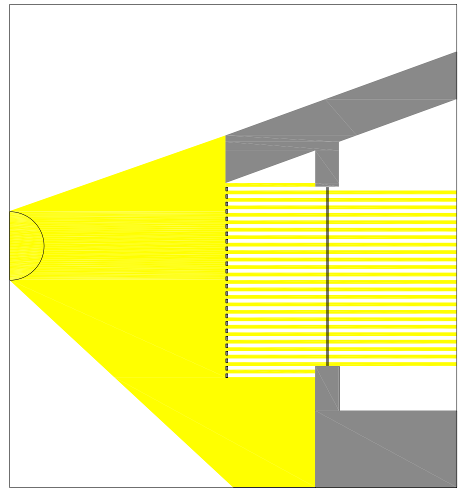

Figure 3-10. Exterior lattice provides partial shading for east- and west-facing windows.

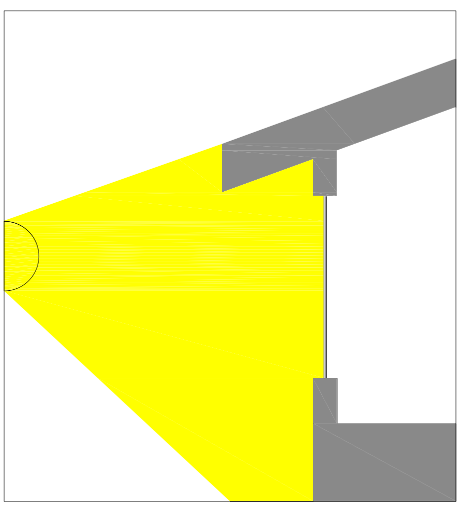

Figure 3-11. A low-solar-gain, low-E coating reduces solar transmission through east- and west-facing windows.

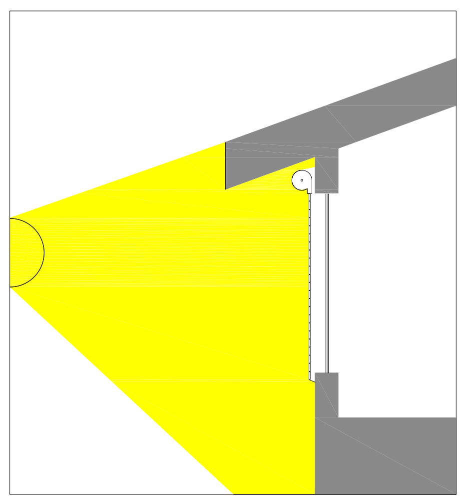

Figure 3-12. An exterior roll shade provides full or partial shading of solar transmission through east- and west-facing windows during mornings and evenings.

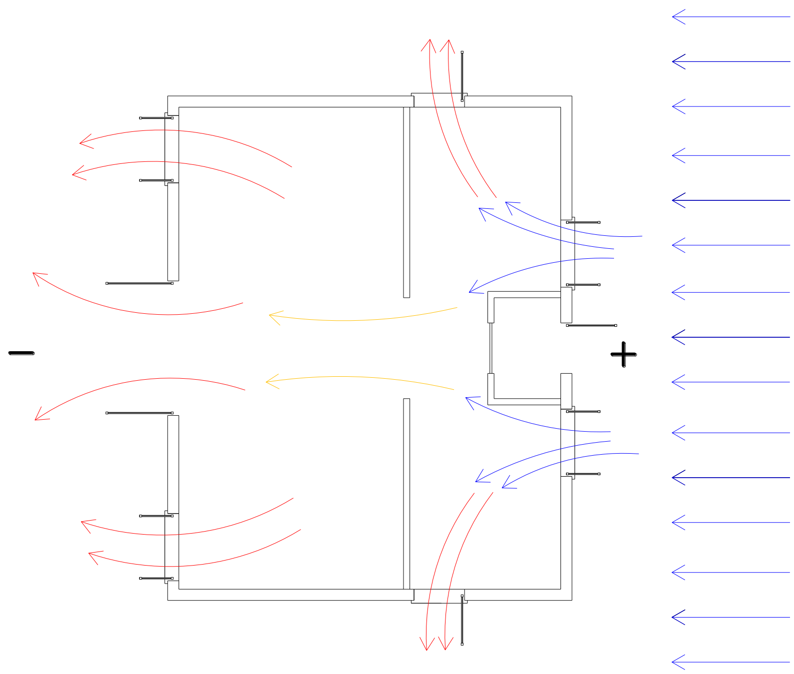

Figure 3-13. Airflow cooling will be most effective with a spatially open floor plan.

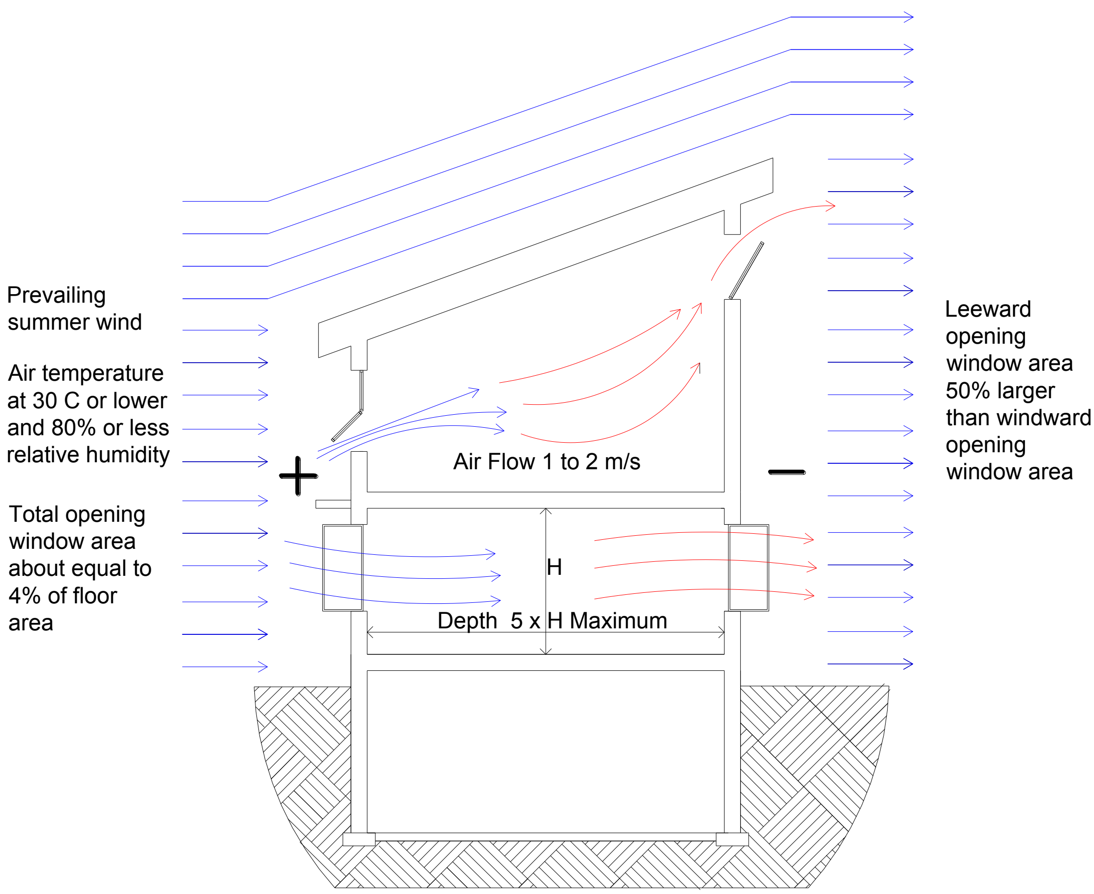

Figure 3-14. Rules of thumb for airflow cooling.

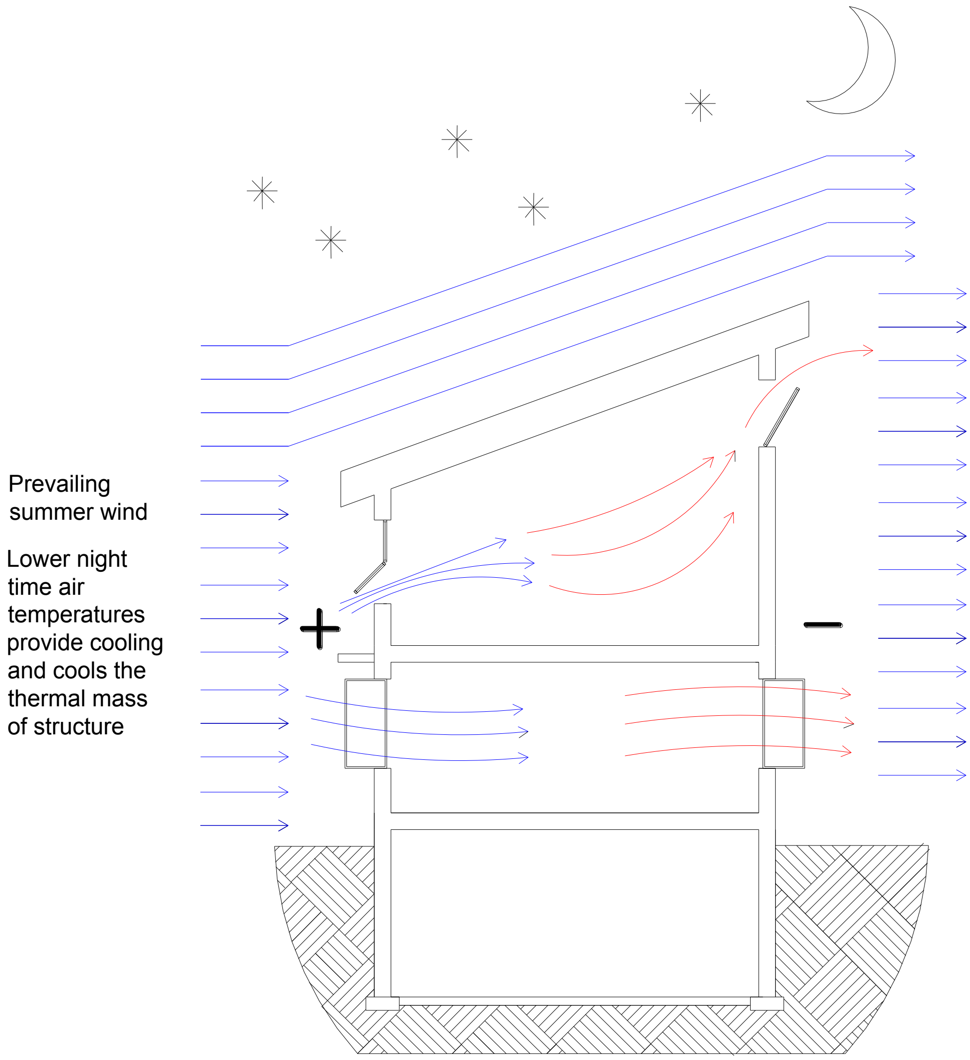

Figure 3-15. With diurnal temperature swings, nighttime flushing of air through the building can provide cooling.

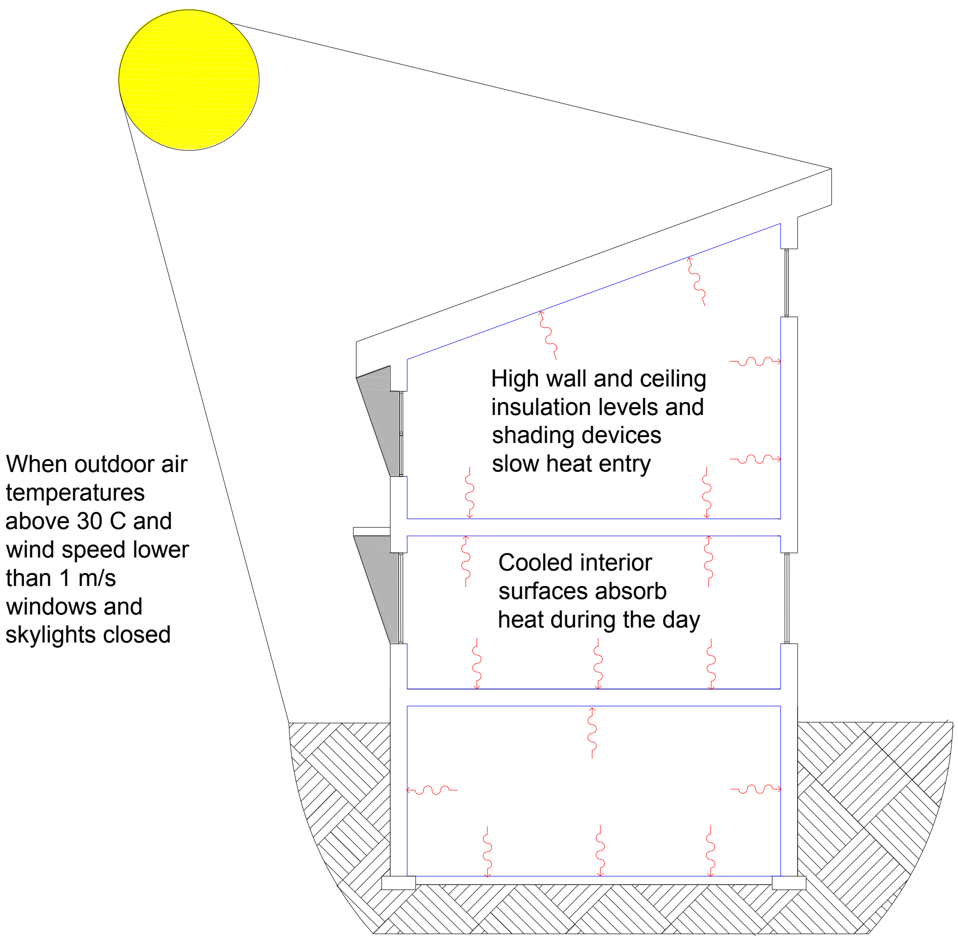

Figure 3-16. During the day, south- , east- , and west-facing windows are completely shaded to reduce solar gain, and the cooled structure absorbs heat.

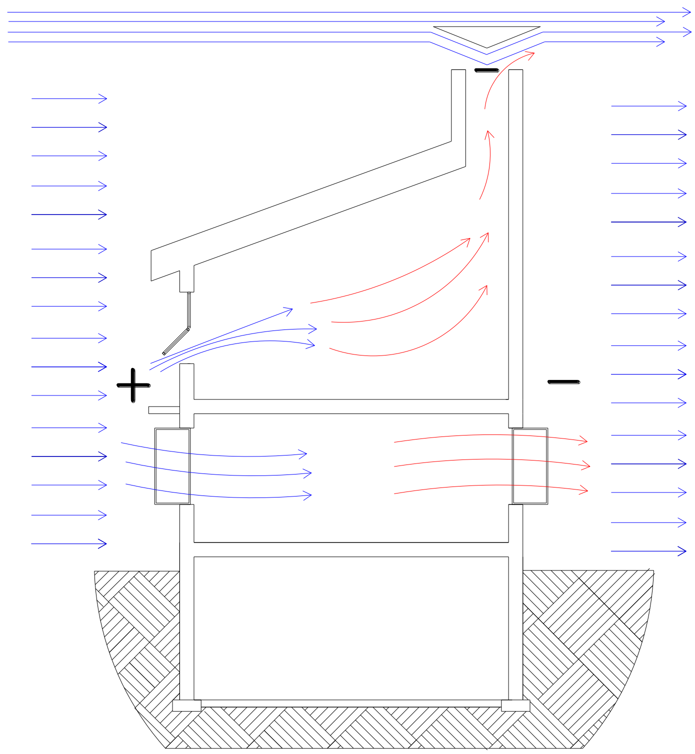

Figure 3-17. Wind tower concept with aero-cap: air flowing past the aero-cap enhances the negative pressure at the top of the wind tower, causing air to be drawn out of the building.

3.3.2.3 Daylighting

Daylight can be used to provide interior illumination and has health, productivity, and energy benefits. A balanced supply of daylight is important for visual comfort and to allow for performance of visual tasks. Typical light levels for reading and performing visual tasks is between 100 and 2000 lux. Light levels within a room should not vary by more than a ratio of 20:1 between windows and the darkest recess, otherwise visual discomfort and glare will result. The following guidelines help achieve balanced light within a space (Figure 3-18):

- Provide light from at least two directions, either through windows on different walls, or by using a combination of windows and skylights.
- Use light-coloured, reflective, low-gloss, interior surfaces to distribute and diffuse light entering the space.
- Use windows with tall head heights to maximize daylight penetration. Use north-facing windows and skylights because these will provide diffuse light with low variation in intensity over the day; and/or use clerestory windows (windows above head height) and roof monitors to enhance daylight distribution and penetration (Figure 3-18).
- In larger daylit spaces, install electric lighting in zones parallel to the main daylight source. When the zones are switched separately, the spaces furthest away from the daylight source are electrically lit when it is necessary to balance illumination levels across the space for visual comfort (Figure 3-19).

- Where possible, use light-coloured exterior surfaces or water features to reflect daylight (Figure 3-20). This is most effective for north- and south-facing windows. Horizontal surfaces can reflect light into south-facing windows, whereas light-coloured vertical fences or wall surfaces can reflect light into north-facing windows. Horizontal reflective surfaces outside of east- and west-facing windows can lead to glare and visual discomfort.
- To gain the energy benefit from daylighting, electric lights should be dimmed or turned off when daylight levels rise. This can be done with daylight-sensing and dimming controls.

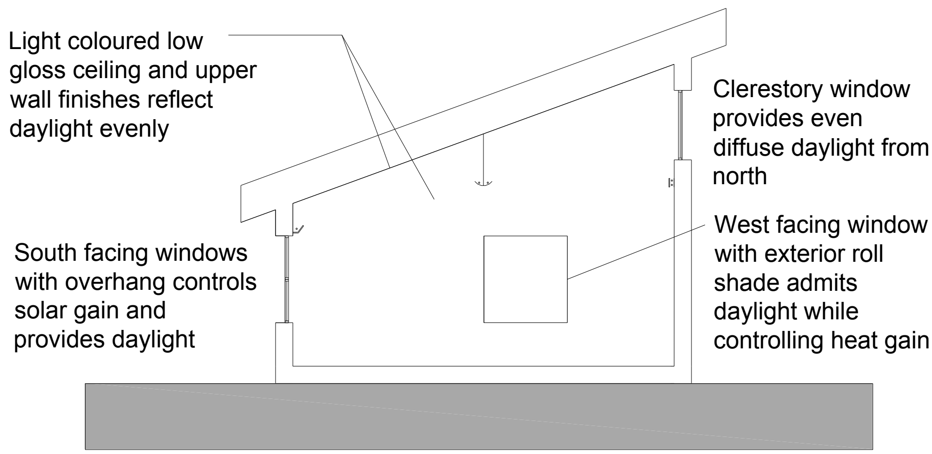

Figure 3-18. Daylighting is most effective when supplied from two or more directions, and when light-coloured ceiling and upper wall surfaces are used.

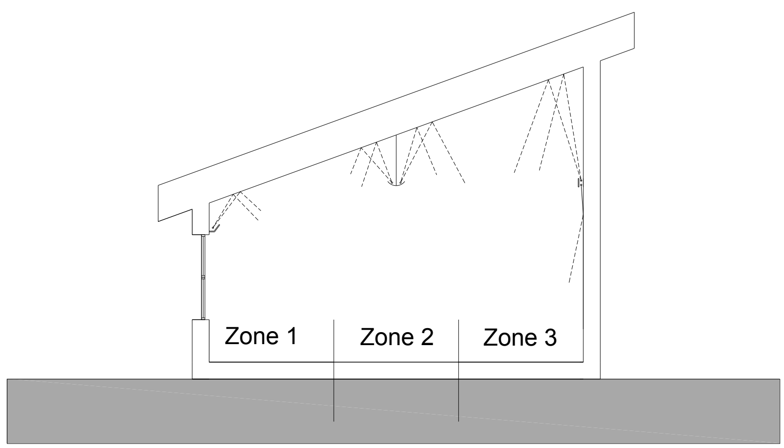

Figure 3-19. Running electric lighting fixtures parallel to the source of daylight and controlling them separately according to zones allows for the balancing of light levels within a space and the reduction of glare.

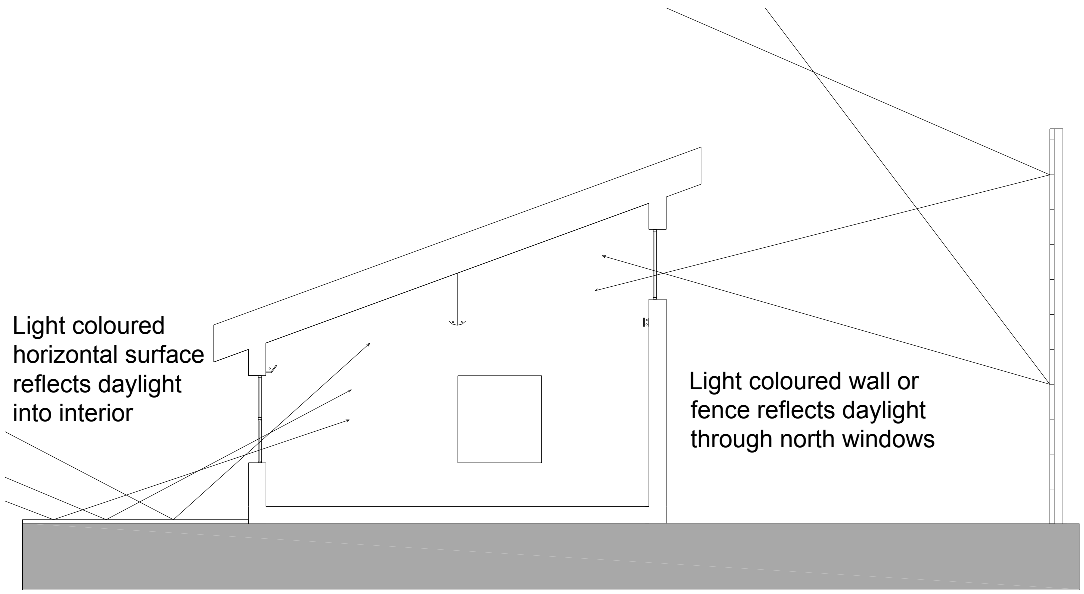

Figure 3-20. Daylighting can be augmented by reflection from outside horizontal and vertical surfaces.

3.3.2.4 Roof Slope, Orientation, and Area

When a high-performance housing project is to be net-zero or net-zero ready, then roof slopes, orientation, and area need to be considered for installation of solar electric and solar thermal systems. The optimum slope and orientation are affected by geographic location, local climate, latitude, topographic features, vegetation, and the particular application. Local knowledge about weather patterns can also help optimize orientation and slope of the solar collector. For example, in southwestern British Columbia, although the theoretical solar radiation available for southwest and southeast orientations with the same slope is the same, in reality, solar radiation levels are typically higher in the afternoon because fog or clouds have burned off. While optimal slopes and orientations for particular types of systems exist, there is, typically, flexibility without large penalties for going away from optimum. The following rules of thumb can be used for general guidance; more detailed information on this topic is presented in Appendix D.

- In southwestern British Columbia, for grid-connected PV systems, the optimum roof slope for a due-south-facing roof is 30 degrees from horizontal (7 in 12). That said, roof slopes can range from 5 degrees (1 in 12) up to 60 degrees (21 in 12) slope with only about 8% reduction in performance.
- In the Okanagan, for grid-connected PV systems, the optimum roof slope for a due-south-facing roof is 40 to 45 degrees from horizontal (10 in 12 to 12 in 12). That said, roof slopes can range from 15 degrees (3.25 in 12) up to 70 degrees (33 in 12) slope with only about a 9% reduction in performance. Although most power generated by a PV array occurs in the spring, summer, and fall, the snow shedding in winter should be taken into consideration when determining the slope of the array.
- In northeastern British Columbia, for grid-connected PV systems, the optimum roof slope for a due-south-facing roof is 50 degrees from horizontal (14 in 12). That said, roof slopes can range from 30 degrees (7 in 12) up to 70 degrees (33 in 12) slope with only about a 10% reduction in performance, assuming the PV array is able to shed snow (snow shedding is quicker at higher slopes).

- In colder climates where additional solar radiation may reach the PV array due to reflection from surrounding snow, a steeper slope for the array will be more beneficial.
- The roof area should be oriented southward; due south is optimum but orientation can vary within a range—from 30 degrees east of due south to 30 degrees west of due south.
    - In southwestern British Columbia, for a PV system at a roof slope of 30 degrees from horizontal (7 in 12), having an orientation of 30 degrees east or west of due south will result in a reduction in performance of only about 2% compared to the optimum south-facing orientation.
    - In the Okanagan, for a PV system at a roof slope of 40 to 45 degrees from horizontal (10 in 12 to 12 in 12), having an orientation of 30 degrees east or west of due south will result a reduction in performance of about 4% compared to the optimum south-facing orientation.
    - In northeastern British Columbia, for a PV system at a roof slope of 50 degrees from horizontal (14 in 12), having an orientation of 30 degrees east or west of due south will result in a reduction in performance of about 4% compared to the optimum south-facing orientation.
- PV array area will vary with home electrical load, site latitude, roof slope, and orientation, as well as PV system efficiencies. These issues are addressed in Appendix D; but, as a starting point for southwestern British Columbia, the total electrical load for a 2700 ft^2, single-family, high-performance housing, net-zero energy home will typically be in the range of 10,000 to 12,000 kWh/yr. With an optimally oriented PV array, the area of the array will be in the range of 750 to 900 ft^2. The large size of the array will limit the use of complicated roof structures in favour of maximizing available south-facing area.
- Solar domestic water-heating systems typically supply 50 to 60% of the water-heating requirements of a household. For a family of four, the solar collectors will have an area in the range of 6 to 12 m^2 (64 to 128 ft^2). The collector slope is typically 25 to 45 degrees from horizontal, but lower slopes can be used.

3.3.2.5 Setbacks and Allowable Envelope Dimensions

Due to the higher insulation levels required in high-performance housing, walls and ceilings are thicker than usual. Wall thicknesses typically range from 254 to 457 mm (10 to 18 inches). The thicknesses of open ceilings typically range from 406 to 610 mm (16 to 24 inches). Where the truss rests on the exterior wall, attic roofs typically utilize raised heel trusses (refer to Section 4.7) that result in increased roof heights. This will have an impact on floor areas and building heights, and must be accounted for in the design stage to ensure compliance with setback and allowable envelope requirements.

3.4 Preliminary Energy Analysis

The schematic design is developed based on the project program, the site characteristics, zoning bylaws, and rules of thumb for insulation levels of the building envelope, window types, passive solar heating, daylighting, etc. A preliminary energy analysis of the project is often undertaken at the conclusion of the schematic design phase to gauge the energy performance of the design and carry out preliminary sizing of any renewable energy systems that may be used. Due to the fact that lighting, appliance, and electrical device loads together can equal the consumption of purchased space-heating energy, conducting an estimation of their energy consumption at this stage is useful. For preliminary purposes, an energy budget of 15 kWh/m^2/yr for lighting, appliance, and electrical device loads can be used. Energy analysis software such as HOT2000 (Natural Resources Canada 2010a) and renewable energy analysis software such as RETScreen (CanmetENERGY 2011) are used for these purposes. In addition to giving a preliminary assessment of the energy performance of the project this sets up the computer models that are later used in the design charrette.

3.5 Design Charrette

One of the most effective tools for refining the design of a high-performance housing project is a design charrette (Figure 3-21). A design charrette is a meeting or series of meetings in which the design of the project is optimized through an iterative process of brainstorming and analysis by a diverse group of individuals who have specialized knowledge of various aspects of high-performance housing design and construction. The design charrette brings together the project participants to get their input and to encourage cross-pollination of ideas. The design charrette also builds understanding and cohesion within the project team because all parties have input and have an understanding of how the design developed. The design charrette not only improves the energy and environmental performance of the project, it in many cases identifies approaches that are more cost effective, i.e., with the potential to reduce costs. For smaller housing projects the design charrette will typically include several professionals:

- facilitator
- designer
- owner
- general contractor
- energy analyst
- cost estimator

Subtrades and suppliers may also be involved, depending on the project, including:

- HVAC contractor
- plumber
- electrician
- PV installer
- truss designer/supplier
- window supplier
- insulation contractor

In some cases one person can act in more than one role. For instance the designer may also be the facilitator, and the general contractor may also provide cost estimating.

For larger housing projects, additional participants would be involved, such as mechanical engineers, electrical engineers, building-code specialists, marketing specialists, building-maintenance services, etc.

This is the general procedure followed in the design charette (Figure 3-21):

1. The project designer makes a presentation about the project program and preliminary design.
2. The energy analyst makes a presentation about the energy performance of the project in its preliminary form.
3. Each of the team members makes a presentation on specific topics, with suggested performance targets.

   The types of topics covered include:

   - insulation levels and airtightness of the building envelope
   - type, placement, and thermal mass of windows for passive solar heating
   - sizing and placement of windows and skylights for daylighting
   - placement of opening windows and skylights for natural cooling
   - electric lighting and controls
   - energy-efficient appliances
   - mechanical heating and cooling systems
   - components, design, and operation of heat-recovery ventilation system
   - domestic water-heating systems
   - water-conservation measures, rainwater harvesting and storm-water management
   - solar hot-water systems
   - solar electric (PV) systems
   - embodied energy and pollution associated with structural and interior finish materials, and the impacts on indoor air quality
   - construction sequencing
4. Brainstorming is carried out on possible solutions related to each topic.
5. Computer simulation, calculation, and/or professional judgment are used to evaluate the impacts of proposed solutions.
6. Each solution is also examined to see how it would interact with other aspects of the building.
7. Preliminary costing is developed for the most-promising solutions.
8. Consensus is then reached on the solutions.
9. Successive presentations and brainstorming sessions are carried out to identify the best possible solutions.

The design charrette concludes with one or more packages of suggested solutions.

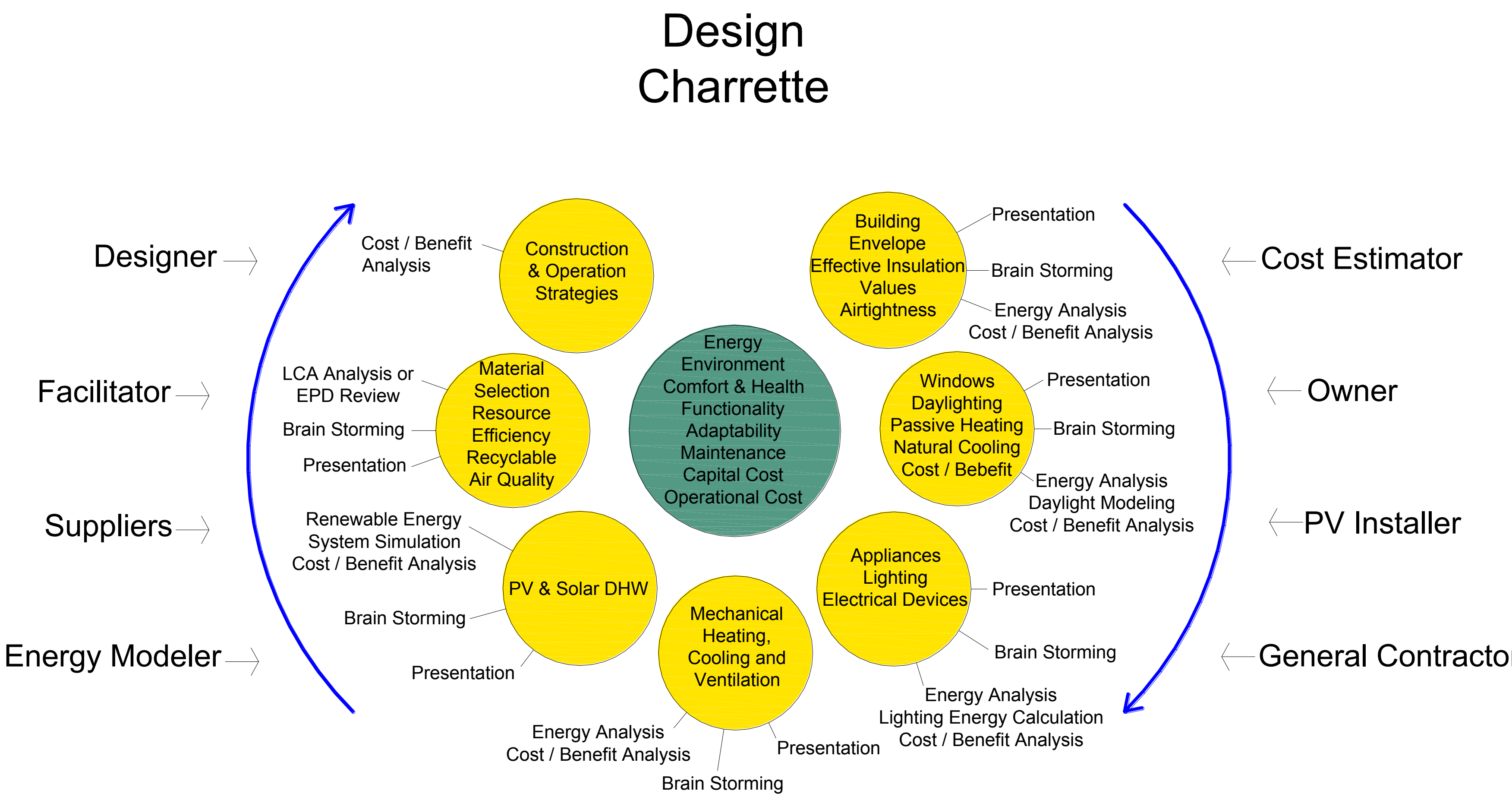

Figure 3-21. The process of optimizing the design of a net-zero high-performance housing project: design charette.

3.6 Design Development

After completion of the design charrette and client approval of the solutions developed there, design development is undertaken, which involves the following activities:

- Finalize building form, layout, room sizes, etc.
- Finalize elevations.
- Finalize window and skylight area and distribution for daylighting, passive solar heating and natural cooling.
- Finalize overhangs for weather protection and south window shading.
- Finalize shading devices for east- and west-facing windows.
- Finalize interior finishes for function, appearance, thermal mass, and chemical off-gassing.
- Decide on an approach for determining final insulation and airtightness levels.
- Finalize construction details of the foundation and exterior wall, floor, and ceiling assemblies.
- Finalize choice of windows.
- Determine ventilation system design and selection of heat-recovery ventilator/energy-recovery ventilator.
- Choose space-heating systems and determine equipment sizing.
- If the project is to be net-zero energy upon completion or in the future, calculate the annual total energy consumption for sizing the renewable energy system (typically a PV array), which will influence roof area and orientation. This involves the following steps:
    1. Develop the lighting plan. Calculate the total annual electrical energy consumption of the lighting by following the procedure in Appendix E – How to Calculate the Total Annual Electrical Energy Consumption.
    2. Select the household appliances. Based on the EnerGuide[6] ratings for the appliances, calculate the total annual electrical energy consumption by following the procedure in Appendix E.
    3. Compile a list of all of the other electrical devices to be used in the home, along with their annual energy use (using published data or the table in Table E-3 in Appendix E). Calculate their total annual electrical energy consumption by following the procedure in Appendix E.
    4. Calculate total annual electrical energy use of space-heating equipment, by following the procedure in Appendix E.

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[6] EnerGuide is Natural Resource Canada's official mark for its energy-performance rating and labeling program for key consumer items—houses, light-duty vehicles, and certain energy-using products. See https://www.nrcan.gc.ca/energy/products/energuide/12523.

5. Calculate total annual electrical energy use of ventilation equipment, by following the procedure in Appendix E.

- If the space-heating and water-heating systems use natural gas, propane, or oil, the annual energy consumption of those fuels is calculated so the equivalent quantity of energy can be generated by the renewable energy system. The area of PV required—based on the make, model, slope, and orientation of the panel, and on its total energy demand—is calculated using software such as RETScreen (CanmetENERGY 2011) or PVWatts (Renewable Resource Data Center 2012).

3.6.1 Determining Insulation and Airtightness Levels

While cost analysis and optimization are being conducted, the selection of the building envelope characteristics can be carried out in several ways. These are some of the selection methods:

- Prescriptive path – By following the prescriptive standards for insulation, airtightness, and windows by climate zones (Appendix F) the need to conduct an energy analysis is avoided. Prescriptive standards by their nature tend to be conservative and will not necessarily reflect the most cost-effective approach to achieving an optimized high-performance housing project. They may also place constraints on design freedom; for example, limiting the maximum window area a home can have. On the other hand, the prescriptive standards are relatively simple to use and faster than other methods. The items shown in the prescriptive tables in Appendix F can serve as a starting point for analyzing a range of options using the other methods listed below.
- Envelope-only score – An "envelope-only" EnerGuide Score of 82 or higher for a particular home design using HOT2000 software (Natural Resources Canada 2010a). The EnerGuide Rating system for new homes[7] assigns an energy-performance score based on an energy analysis of the particular home design. The EnerGuide Rating is influenced by all aspects of the home that affect its energy use, including insulation and airtightness levels of the building envelope, windows, heating and ventilating equipment, and water-heating equipment, etc. In calculating an envelope-only score, all parts of the home that affect energy use other than the building envelope are kept at minimum and default values (Appendix G). This forces the building envelope components to much higher levels in order to meet the EnerGuide Score of 82. An airtightness level of 1.5 air changes per hour at 50 Pa or less should be assumed for reasons of building envelope durability and energy efficiency. The advantage of this approach is that it gives the designer more flexibility in choosing windows and insulation levels for various building envelope components. Designers, who are not familiar with HOT2000 software (Natural Resources Canada 2010a), may wish to engage the services of a local Certified Energy Advisor.

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[7] The EnerGuide Rating is a Natural Resources Canada program which provides a means of standard measure of a home's energy performance. Energy-efficiency level is rated on a scale of 0 to 100. A zero rating represents a home with major air leakage, no insulation, and extremely high energy consumption. A rating of 100 represents a house that is airtight, well insulated, and sufficiently ventilated, requiring no purchased energy on an annual basis. See https://www.nrcan.gc.ca

- Value index – As already discussed in section 2.12, it is possible to compare the cost of achieving the annual energy savings provided by various energy-efficiency measures to the cost of annual power generated by a PV system. When the cost of the energy-efficiency measures meet the cost of PV power generation, the upper limit has been reached.

3.6.2 Calculating Total Annual Electrical Energy Load

Calculating a total electrical energy load is necessary for net-zero energy and net-zero-ready projects in order to size the renewable energy system(s) that will provide the home's electrical energy. The calculation should also be undertaken for all high-performance housing projects because it allows for more accurate inputs to the energy analysis software that predicts annual space-heating and cooling-energy consumption and sizes of the heating and cooling equipment. Also, undertaking the task of calculating total electric energy load is a good practice because it helps to identify where energy is being consumed and may show opportunities for further energy savings.

These are the steps for calculating the total annual energy load, which are covered in detail in Appendix E:

1. Develop a lighting plan and calculate the total annual energy consumed by interior and exterior lighting.
2. Calculate the total annual electrical energy consumed by major household appliances.
3. Compile a list of other household electrical devices and calculate their total annual electrical energy consumption.
4. Calculate the total annual energy consumed by HVAC systems.
5. Calculate the building's grand total annual energy consumption.

3.6.3 Estimating Photovoltaic Array Size

For net-zero energy projects, final sizing and design of the grid-connected photovoltaic (PV) system will be carried out by the PV system supplier and installer. The following shows a simple way that the size of the PV array can be estimated at the design stage. If you wish to look at the system design in more detail in terms of a specific manufacturer's equipment, or in terms of geographic location, slope, and orientation, you can utilize RETScreen's free software and documentation (CanmetENERGY 2011).

Divide the total annual electrical energy demand by the kWhr/m^2 generated by the PV array for the location, slope, and orientation; the number of square metres of PV area will be the result. The actual area of the roof will be larger, to provide for access to the PV array and to account for PV panel dimensions. PV panels are typically installed in pairs. See Appendix D for more details about PV power generation in different locations in British Columbia.

Chapter 4 – Building Envelopes

Heat losses and gains through a building envelope are determined by the effective insulation values[8] of the envelope assemblies; the airtightness of the envelope; and the thermal performance and light transmission characteristics of windows, skylights, and glass doors. When designing building envelope assemblies for high-performance housing, not only is the effective thermal resistance or RSI (R) value considered, but the ability of the assembly to resist water penetration, the ability of the assembly to dry, the airtightness of the assembly, the assembly's thickness, and the assembly's cost are also addressed.

4.1 Thermal Insulation

4.1.1 Materials

The selection and placement of insulation as well as other materials in the building envelope depends on a variety of factors including local regulations, traditional practices, material and labour costs, material availability, thermal performance, and moisture tolerance. There are a range of insulation products available on the market with very different properties, such as thermal conductivity, vapour permeance, and air permeance, and these products require a range of installation methods. The actual properties of the particular insulations used in a project should be drawn from the supplier's literature. Appendix H provides a summary of a range of insulations and provides generic descriptions of their physical properties.

4.1.2 Strategies

Insulation can be placed within the cavities of a wood-frame assembly, or on the outside or inside of the assembly, or in some combination. Insulation placement affects a building envelope assembly's thermal performance and durability, a topic that will be covered later in this chapter. In addition to insulation products, materials, most of them proprietary, such as structural insulated panels (SIPs) and other multi-functional products, can also be used to build energy-efficient assemblies.

4.1.2.1 Cavity Fill

Batt, blown-in, or spray-applied insulation placed in wood-frame assembly cavities (Figure 4-1, and Figure 4-2) has both benefits and drawbacks.

Benefits of cavity insulation:

- The insulation is placed in "free" space provided by the framing.
- Lower-cost insulation can be used.

Drawbacks of cavity insulation:

- The amount of insulation that can be placed in an assembly is limited by the assembly's thickness unless additional framing is constructed to accommodate more insulation.

[8] Effective insulation value accounts for the thermal properties of all of the materials that make up an assembly, including framing, insulation, interior, and exterior sheathings, etc. This will result in a different RSI-value (R-value) than of the insulation alone, which is also known as the nominal RSI-value (R-value).

- Insulation lowers the temperature of the exterior sheathing and framing, thus increasing the potential for condensation and moisture accumulation in those areas and reducing the potential for drying.
- The performance of insulation is reduced by the thermal bridging that occurs through framing members.

4.1.2.2 Exterior

Rigid or semi-rigid insulation is applied to the outside face of the structural sheathing, or over cross-laminated timber (CLT) panels for CLT construction (Figure 4-3).[9] The insulations that can be used in this type of assembly include extruded polystyrene (XPS); expanded polystyrene (EPS); isocyanurate foam board; mineral wool board; fibreglass board; and spray-applied, closed-cell polyurethane foam.

Benefits of exterior insulation:

- The exterior insulation protects the wood-frame assembly from temperature fluctuations and condensation (by raising the average temperature of the wall cavity during winter), thereby enhancing the assembly's long-term durability.
- The impact of thermal bridging through the wood-frame structure is minimized.
- Exterior insulation is continuous across rim joists, which enhances thermal performance and durability in this area.

Drawbacks of exterior insulation:

- Insulation materials are more expensive than those used for cavity insulation.
- Provision has to be made for mounting the insulation and structurally supporting the exterior cladding or roofing.
- Window and door jamb extensions, or drywall returns, must be used.

4.1.2.3 Interior

Insulation is applied to the interior side of the framing assembly. This can consist of a rigid foam board or interior cross strapping which is filled with batt or spray-foam insulation (Figure 4-4). In some cases a 6-mil (150-micrometer) polyethylene air–vapour barrier is placed between the cross strapping and the studs or rafters or joists. If a vapour-impermeable rigid insulation is used, it could also serve as the vapour barrier and the air barrier, if the joints are taped with a durable compatible tape. Interior insulation is always installed in combination with cavity insulation. This is commonly used in retrofit applications where the exterior finish or structure needs to be maintained.

Benefits of interior insulation:

- Insulation application is easier on the interior particularly on upper floors. Interior cross strapping can provide a cavity for wiring and plumbing.

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[9] For more information about CLT see the Canadian and U.S. editions of FPInnovations' *CLT Handbook* (Gagnon and Pirvu 2011, Karacabeyli and Douglas 2013).

Drawbacks of interior insulation:

- The framing located outside of the interior insulation will experience colder conditions than normal, which increases the potential for condensation and reduces the ability to dry.
- It can reduce the interior floor area if the footprint of the building is fixed.
- The interior layer of insulation is not continuous at the rim joist area.

4.1.2.4 Combined Strategies

In order to produce assemblies that meet the requirements for high-performance housing, combinations of insulation strategies are often used. The most common of these are cavity insulation and exterior insulation (Figure 4-5). Another approach to highly insulated assemblies is to use cavity insulation in combination with both interior and exterior insulation (Figure 4-6). When increasing the effective insulation value of a wall assembly the designer must also keep in mind other considerations including:

- Incorporate a continuous air barrier and an effective vapour barrier, thereby preventing the formation of condensation in the assembly due to indoor water vapour entering insulated cavities by air leakage or vapour diffusion and coming into contact with surfaces below the dew point temperature.
- Layer materials within the assembly that will prevent the retention of construction moisture and promote drying.
- Incorporating capillary breaks, ventilated drainage cavities, and flashings that promote drainage and drying of rainwater that penetrates into the assembly.

These issues are covered in detail later in this chapter.

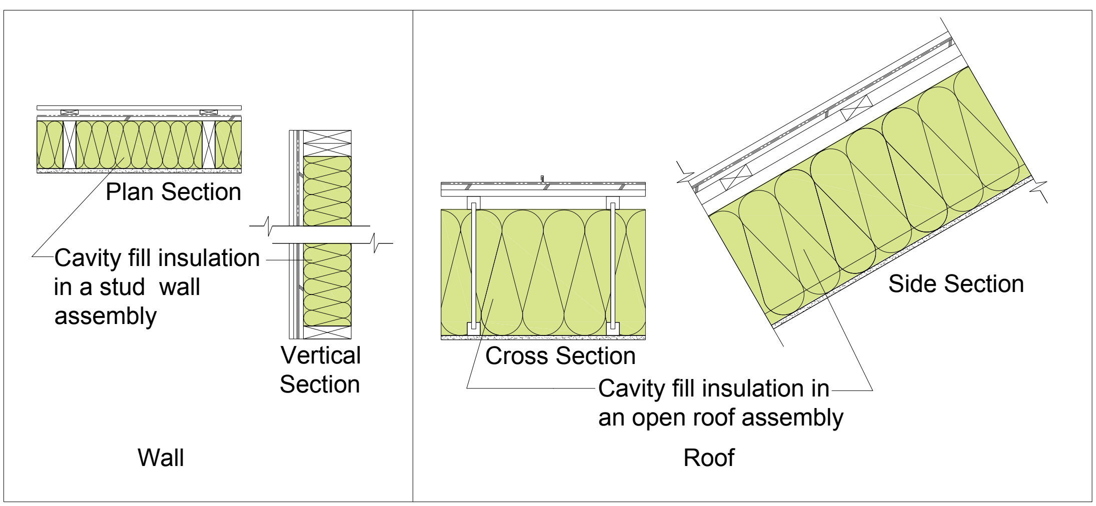

Figure 4-1. Examples of cavity insulation in a wall assembly and an open roof assembly.

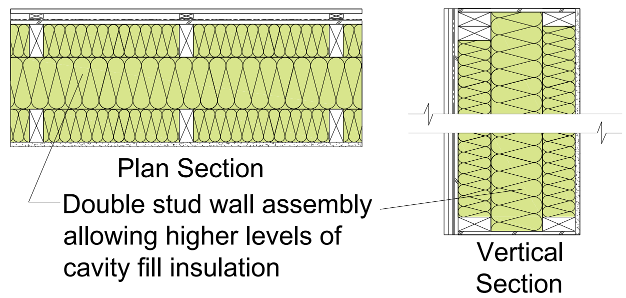

Figure 4-2. Higher levels of cavity insulation can be achieved in walls through the use of larger-dimension studs or double-stud construction. The gap between the double studs varies in order to provide different levels of insulation.

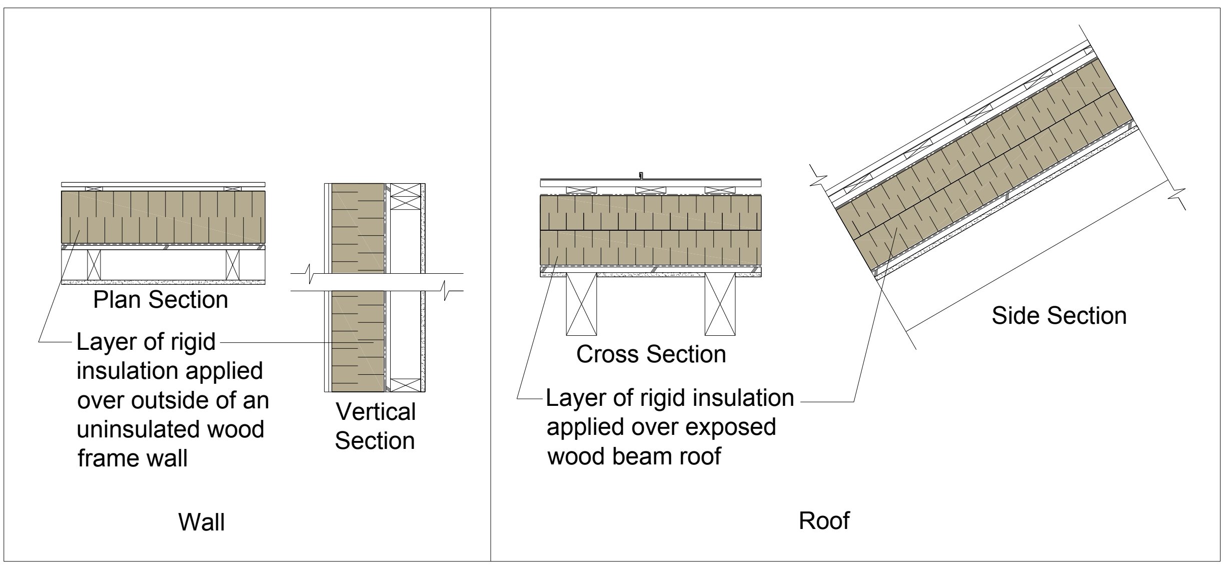

Figure 4-3. Examples of exterior insulation (only) in a wall assembly and a roof assembly.

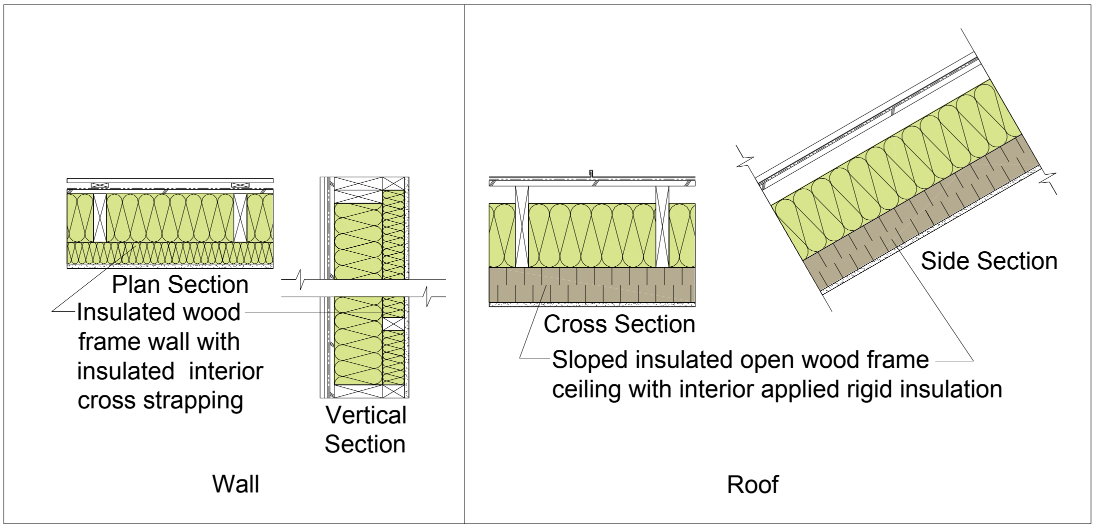

Figure 4-4. Examples of interior insulation in a wall assembly using cross strapping and batt insulation, and in a roof assembly using rigid insulation in combination with cavity insulation.

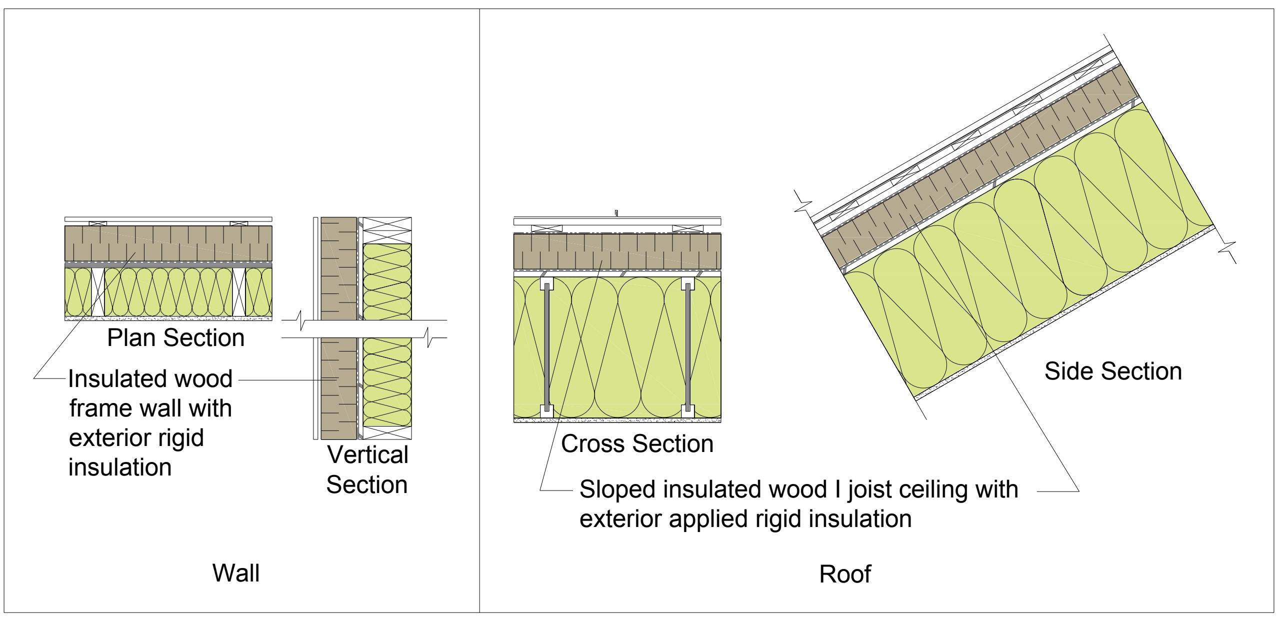

Figure 4-5. Examples of cavity insulation used in combination with exterior insulation for a wall assembly and a ceiling assembly.

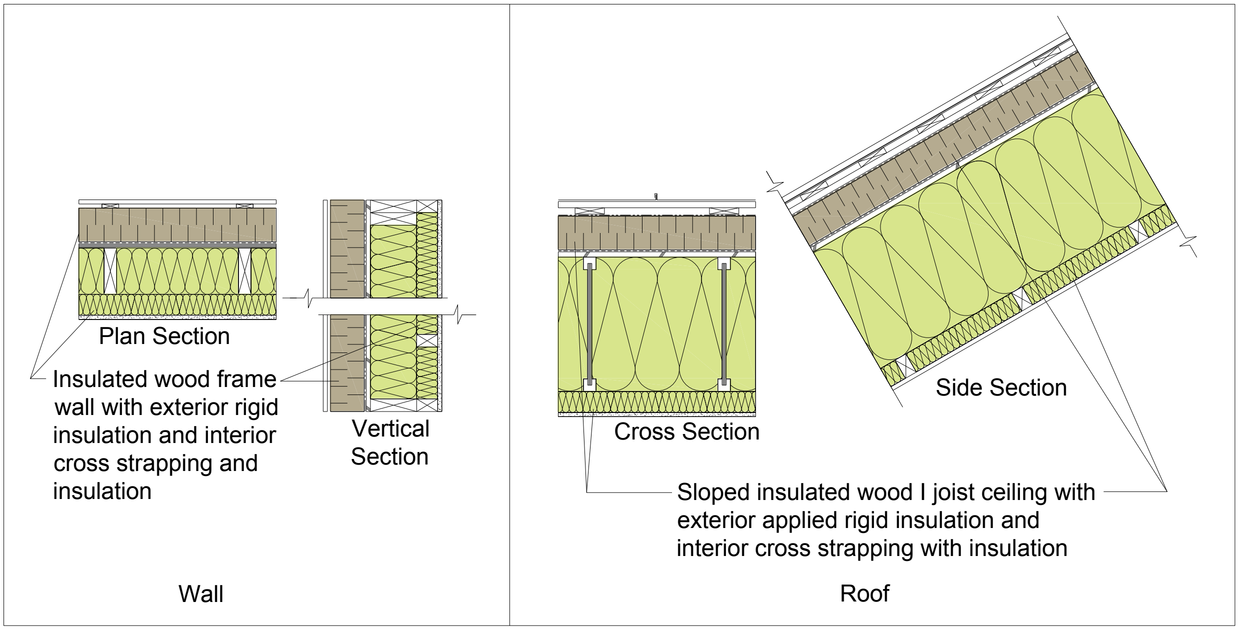

Figure 4-6. The wall assembly combines exterior mineral wool board insulation with interior horizontal 38x64 mm (nominal 2x3 inch) strapping and batt insulation. The roof assembly combines exterior mineral wool board insulation with wood I-joists filled with batt insulation plus interior horizontal 38x64 mm (nominal 2x3 inch) strapping and batt insulation.

4.1.3 The Law of Diminishing Returns

After improving airtightness, increasing insulation levels becomes the most cost effective measure that can be taken to improve a home's energy efficiency. Every time the RSI (R) value of a wall, floor, or ceiling doubles, the heat loss through that element is cut in half. This fact means that the ability of insulating materials to retard heat loss follows the law of diminishing returns. As insulation levels are progressively increased, this approach will reach a point where other methods of saving energy may become more cost effective, such as the use of better-performance windows, and high-efficiency heating equipment and appliances. As shown by the example in Figure 4-7, the initial benefits of increasing insulation levels are significant, but become less beneficial as higher levels are reached. Computer-based energy modelling can be used to predict the energy use and energy savings that can be gained by using increased insulation levels relative to other energy-efficiency measures, which helps to optimize the overall costs of high-performance housing.

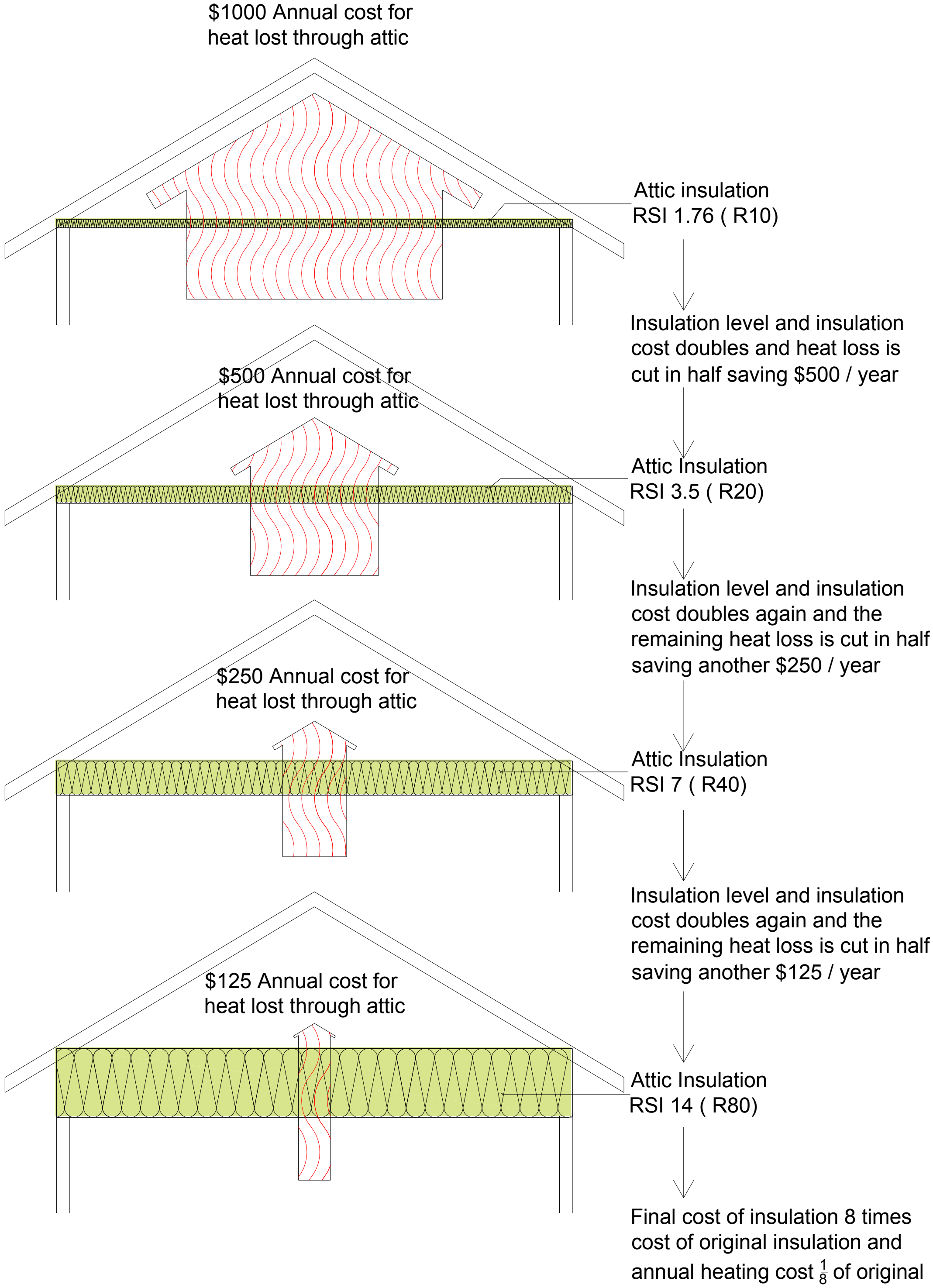

Figure 4-7. A hypothetical example demonstrating the law of diminishing returns as applied to using increasing levels of insulation in a ceiling.

4.2 Air Barriers

4.2.1 Materials

The function of an air barrier is to resist uncontrolled air movement through the building envelope. Resistance minimizes the movement of interior air-borne water vapour into insulated cavities, thus avoiding condensation (Fox 2014), minimizing heat loss, eliminating drafts, and providing thermal comfort. Air barriers can be up to 100 times more effective at controlling the entry of water vapour into insulated building assemblies than vapour barriers and are a critical component of durable, energy-efficient construction. Air barriers consist of low-air-permeance materials in the building envelope, that are systematically sealed together at the edges to form a continuous assembly that resists airflow. An air barrier can be located on the interior, in the centre, or on the exterior of an exterior wall, an exterior floor, or an exterior ceiling assembly. Its location within the assembly can also be moved; for example, an interior (polyethylene) air barrier can be sealed to a strip of building wrap that snakes around the outside face of a rim joist and back into the basement where it connects to an interior (polyethylene) air barrier. If the material forming the air barrier is also a vapour barrier, it must be placed on the warm side (i.e., on the interior side) of the assembly to eliminate the possibility of condensation formation in a heating-dominated climate. Air barriers located on the interior, such as airtight drywall or polyethylene, are protected from outdoor temperature fluctuations and freeze–thaw cycles, which enhances their durability. However, generally speaking, exterior-applied air barriers, such as sealed exterior sheathing or sheathing membrane, have fewer penetrations. When exterior-applied air barriers are used, it is important that the insulation in the cavity behind the air barrier completely fill the cavity and be held firmly against the back of the effective plane of airtightness (see Section 4.6.1). This is to suppress natural convection within the insulated cavity that transports heat and moisture from the interior of the home to the back side of the sheathing. Where plywood or OSB sheathing form part of an air barrier, the gaps between panels that allow for expansion, must be taped; vapour diffusion ports (holes) must not be used. Note, the benefits of vapour diffusion ports are questionable, particularly for plywood (Hazleden and Morris 2003).

The *British Columbia Building Code 2012* (Building and Safety Standards Branch 2012) defines an air-barrier material as one that has an air permeance of 0.02 $L/s \cdot m^2$ @ 75 Pa or less for Part 5 buildings. Part 9 buildings are not required to meet Part 5 requirements but this can be used as a good guideline for high-performance housing. Typical construction materials that meet this requirement include concrete; glass; plywood; OSB; framing lumber; steel; 6-mil (150-micrometer) polyethylene; drywall; building wrap; XPS; foil-faced isocyanurate; at least 2-inch-thick, open-cell, polyurethane spray foam; and closed-cell, polyurethane spray foam.

4.2.2 Performance

Typically high-performance construction requires the airtightness of a home not exceed 1.5 air changes per hour at a 50 Pa pressure difference, when tested according to the most current version of the CAN/CGSB-149.10-M86 airtightness testing standard (Standards Council of Canada 1986). The testing is carried out during construction so that the air barrier can be repaired if needed. A range of sealants, gaskets, and tapes are used to join the various components of the air barrier together. The air barrier must last the life of the building envelope assembly or be easily accessible for repair. This requires that all connections be highly durable and the materials be chemically compatible. See Appendix I for descriptions of a range of air-barrier systems.

Air barriers are an integral part of high-performance housing for the following reasons:

- Air barriers minimize heat losses during winter due to uncontrolled air movement through the building envelope. Uncontrolled air leakage in a conventional home can account for up to 30% of the total heating requirements. Homes in southwestern British Columbia, due to the region's mild climate, are documented to have the poorest air-leakage performance in Canada (Parekh et al. 2007).

- Air barriers minimize heat gain during summer due to the uncontrolled movement of hot air from outside to inside through the building envelope, thus reducing cooling loads.
- Air barriers minimize the formation of condensation inside insulated cavities during winter leakage of warm, moist, indoor air into those cavities.
- Air barriers maximize the efficiency of the heat-recovery ventilation system by ensuring the majority of supply and exhaust air passes through the heat-recovery ventilator.

Additional benefits of air barriers include:

- improved smoke and fire separation
- reduced outside noise penetration
- reduced entry of dust, pollen, and pollutant from outside
- increased thermal comfort due to a reduction in drafts
- minimization of temperature stratification within the home

To ensure long-term air-barrier performance, the system must be able to withstand the following:

- Wind loading – Wind will cause both negative and positive pressure differentials on the air barrier (although not at the same time!). For these reasons air barriers that will withstand wind loads the best are those constructed from rigid materials such as concrete, drywall, OSB, board insulation, and plywood, or those with membranes that are fully supported by rigid materials. In Appendix I, air-barrier systems are classified by their location, and, if it is a membrane system, how well it is supported in the assembly. Unsupported or partially supported air-barrier membranes are best suited for homes of two storeys or less in wind-shaded locations (i.e., surrounded by a forest or other homes). In all other cases the following are preferred: fully supported membrane air barriers; membrane air barriers continuously adhered to structural sheathings; air barriers made from rigid materials such as structural sheathings, drywall, or concrete; and spray-foam air barriers adhered to structural sheathings.
- Structural movement and wood shrinkage.
- Thermal expansion and contraction.
- Physical damage during and after construction.
- Degradation of sealants, gaskets, and adhesives due to aging and chemical attack.

4.2.3 Quality Assurance

When incorporating a continuous air barrier into the construction of a home, the builder must understand the system that is being used and communicate to the subtrades their roles in ensuring that air-barrier continuity is established and maintained. Publications, such as the *Canadian Home Builders' Association Builders' Manual* (2013), the *Building Envelope Guide for Houses* (Homeowner Protection Office 2007) covers the details for a number of air-barrier systems. Section 9.36, which was added to the *British Columbia Building Code 2012* as a mid-stream amendment (Building and Safety Standards Branch 2012), provides prescriptive direction on air-barrier continuity and should prove a useful reference for builders who construct air barriers. Relevant guidelines are also provided in the *Air Leakage Control Manual: Existing Multi-Unit Residential Buildings* (Canada Mortgage and Housing Corporation 2007).

Depending on the system chosen, the subtrades involved in its construction can include the framers, insulators, plumbers, electricians, cable installers, HVAC mechanics, and window and door installers. The continuity of the air barrier can be gauged to some degree by visual inspection but ultimately the only way to ensure that the air barrier is continuous is to physically test it using fan-door depressurization. During this type of testing, leaks in the air barrier can be found and sealed. This testing can also be used as an objective measure of the performance of the air barrier and the workmanship of the subtrades involved. When subtrade performance is measured in this way, experience has shown that very good results can be achieved.

4.2.4 Indoor Air Quality

A continuous air barrier will result in higher indoor humidity levels and the accumulation of indoor air pollutants. For this reason it is necessary to use interior finishes with low chemical off-gassing (Appendix A) and a continuously operating balanced heat-recovery ventilation or energy-recovery ventilation system (see Chapter 5).

4.3 Vapour Barriers

A vapour barrier is utilized to prevent the movement of air-borne water vapour by diffusion through a building assembly to an area in the assembly where condensation could occur. In a heating climate the indoor air is warmer and therefore contains more water vapour than the outdoor air; the resultant vapour drive is across the assembly from inside to outside. A material with a metric perm rating of 60 ng/Pa $\times$ m^{2}s (imperial perm rating of 1 grain/ft^2 $\times$ h (in·Hg)) or less is considered to be a vapour barrier by the *British Columbia Building Code 2012* (Building and Safety Standards Branch 2012).

In British Columbia's climates, vapour barriers are typically located on or just beneath the interior face of the building assembly. A range of common building materials that can function as vapour barriers include: 6-mil (150-micrometer) polyethylene; aluminum foil; glass; sheet metal (aluminum, galvanized steel, stainless steel, copper, etc.); 50-mm (2-inch) or thicker closed-cell, polyurethane spray foam; 9.5-mm (3/8-inch) or thicker exterior grade plywood; and proprietary vapour-barrier paints and primers. Proprietary membranes have been developed that function as a vapour barrier when there is a vapour drive from inside to outside such as in the winter. These same membranes will also allow drying of the wall assembly to the inside when lower vapour pressures occur on the interior; this is usually in the summer when a home is air conditioned.

4.4 Long-Term Durability of Highly Insulated Assemblies

4.4.1 Wetting and Drying Mechanisms

The long-term durability of a building envelope depends on the local climate, the exposure to weather (such as wind-driven rain and drying periods), the choice of construction assembly, construction quality, maintenance of the envelope system (such as reroofing, or replacement or maintenance of exterior cladding), the ability of the assembly to dry, and the management of moisture at the construction stage. Weather exposure is mostly determined by local climatic conditions, such as rainfall and wind; wall orientation; wall height; and the extent to which the wall is protected by overhang(s). Durability of wood-frame walls is tied in large part to the moisture content of the framing lumber and structural sheathing. A moisture content of 19% or less, as required by for wood at the time of installation or before enclosure, provides a good margin of safety. The germination and growth of fungus typically needs a minimum moisture content of 26% and other suitable conditions (Wang et al 2010). Once started, decay can continue until the moisture content drops below 20%.

The wood in buildings can get wet due to one or more of the following mechanisms (Figure 4-8):

- Precipitation landing on the envelope, such as on a roof or the exterior cladding, and penetrating into the envelope by gravity, wind pressure, or capillarity – Managing rainwater through the use of overhangs, flashing, and rainscreens are important strategies for preventing moisture accumulation in the building envelope.
- Snow including wind-blown snow – It also needs to be managed effectively to prevent wetting of the structure when it melts.
- Water vapour transported from the interior or exterior through exterior wall, floor, or ceiling assemblies by air movement or vapour diffusion – This becomes more important for highly insulated assemblies due to the larger temperature differential between interior and exterior and the potentially reduced drying capacity of the assemblies. It also becomes increasingly important with the increasing size of the household and because of cultural factors that lead to increased water vapour generation from cooking, bathing, etc.
- Built-in construction moisture.
- Reverse vapour drive – This can occur when a porous cladding such as unsealed stucco or brick is wetted by rain and then is heated by sunlight. This process results in a very high vapour drive from the cladding into the wall assembly. This can be countered by using lower-permeability, weather-resistant barriers, such as building paper and low-permeance insulated sheathings, and a ventilated rainscreen.
- Groundwater movement into the wall or floor assemblies by capillarity through the foundation.
- Unnoticed leaks in plumbing or hydronic heating systems.

Counteracting wall-wetting mechanisms are wall-drying mechanisms that are related to the properties of the wall materials, the wall design, climate, and wall orientation. Drying mechanisms include (Figure 4-9):

- Evaporation from the surfaces of exterior claddings and interior finishes.
- Drainage of liquid water that enters the wall assembly through the cladding, or drainage of water adjacent to the foundation down to perimeter drain tile.
- Water-vapour movement out of the wall assembly to the exterior or interior by vapour diffusion.
- Air circulation in a rainscreen cavity behind the cladding promotes drying by replacing air that has high vapour content with air that has lower vapour content.

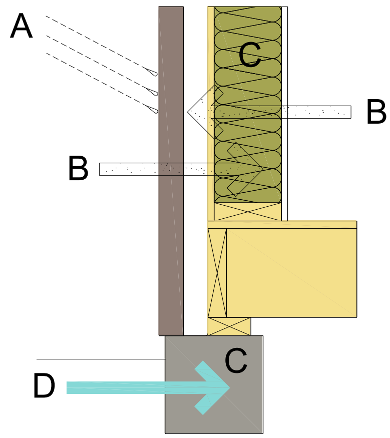

Figure 4-8. Wall-wetting mechanisms (adapted from Straube and Burnett 2005).

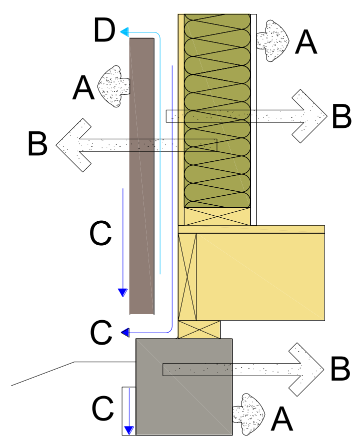

Figure 4-9. Wall-drying mechanisms (adapted from Straube and Burnett 2005).

4.4.2 Measures to Improve Durability

The moisture content of wall-framing lumber and sheathing is determined by the moisture balance that occurs between wetting and drying mechanisms. Highly insulated wall assemblies, depending on the design, construction quality, and building materials used, can either inhibit or promote drying. A considerable amount of field testing conducted in British Columbia as well as across the country in recent years has confirmed that such assemblies can perform well as long as they are designed and built properly. Studies conducted in the Prairies showed that energy-efficient homes built 10 to 30 years ago were performing well in terms of energy efficiency, airtightness, and durability (Proskiw and Parekh 2004, Orr et al. 2012). Appropriate hygrothermal analysis may help to predict local moisture risks. Preservative-treated wood products, such as borate-treated sheathing and framing, may be necessary for high-risk locations, such as north-facing walls and walls that are shaded over the year by adjacent buildings.

Aspects of highly insulated assemblies that could inhibit drying include:

- High insulation levels located inside exterior framing and sheathing – With outer framing and the exterior sheathing being colder due to a slower rate of heat loss through the wall, the drying capacity is reduced. This may prevent drying of construction moisture or moisture that accidentally enters through the cladding, or due to water leakage from window frames and service penetrations. This will be most pronounced in walls that are not exposed to solar radiation, such as those facing north, northwest, or northeast, and those walls that are shaded by adjacent buildings or vegetation.
- Low-permeance exterior insulation – Exterior insulation, such as foil-faced isocyanurate foam board and XPS, are low-vapour-permeance materials that can significantly reduce the rate of drying by vapour diffusion that occurs from the framing and structural sheathing to the exterior. Such impacts on the drying performance of envelope assemblies caused by low-permeance materials have been demonstrated by a few studies, including a roof-drying-performance study recently conducted by FPInnovations (Wang 2014).When using these types of insulated sheathing reference the requirements laid out in Section 9.25 of the *British Columbia Building Code 2012* (Building and Safety Standards Branch 2012).

Effective measures can be taken to prevent wetting and promote drying (see Figure 4-10, overall strategies to improve durability):

- Traditional measures, such as sloped roofs and big overhangs, to divert rain away from the building – The effectiveness of these measures has been proved by long-term experience as well as scientific studies in recent years (Canada Mortgage and Housing Corporation 1996).
- Rainscreen assemblies – These provide a capillary break and a drainage plane, preventing water from being held between the backside of the cladding and the weather-resistant barrier (building paper or building wrap), and promoting drainage and drying to the exterior. In particular, ventilated rainscreen cladding systems that are vented at the top and bottom of the wall are most effective in resisting water penetration and promoting drying. Ventilated rainscreen assemblies have become standard practice in Canada's maritime climates, required by building codes, but are not generally used in dryer climates. Such walls, however, have been commonly used in super-insulated homes built in the Prairies in the past decades and are believed to have helped achieve long-term durability performance.
- Vapour permeable and hydrophobic insulated sheathings – Placement of highly vapour-permeable and hydrophobic-insulated sheathings, such as medium- or high-density mineral wool board, over structural sheathing and framing will raise the temperature of the sheathing and framing and also allow for drying by vapour diffusion, while at the same time resisting water penetration.

- Continuous air barrier – An air barrier, which is required for high-performance housing assemblies, prevents warm, moist, indoor air from passing into the wall assembly by air leakage and leading to condensation on cold framing and sheathing.
- Vapour barriers – Use of vapour barriers, such as vapour-barrier paints and primers with vapour permeance in the range of 60 ng/Pa·m^2·s, will allow drying to the interior for water that may enter a wall assembly, unlike a polyethylene vapour barrier which is vapour impermeable.

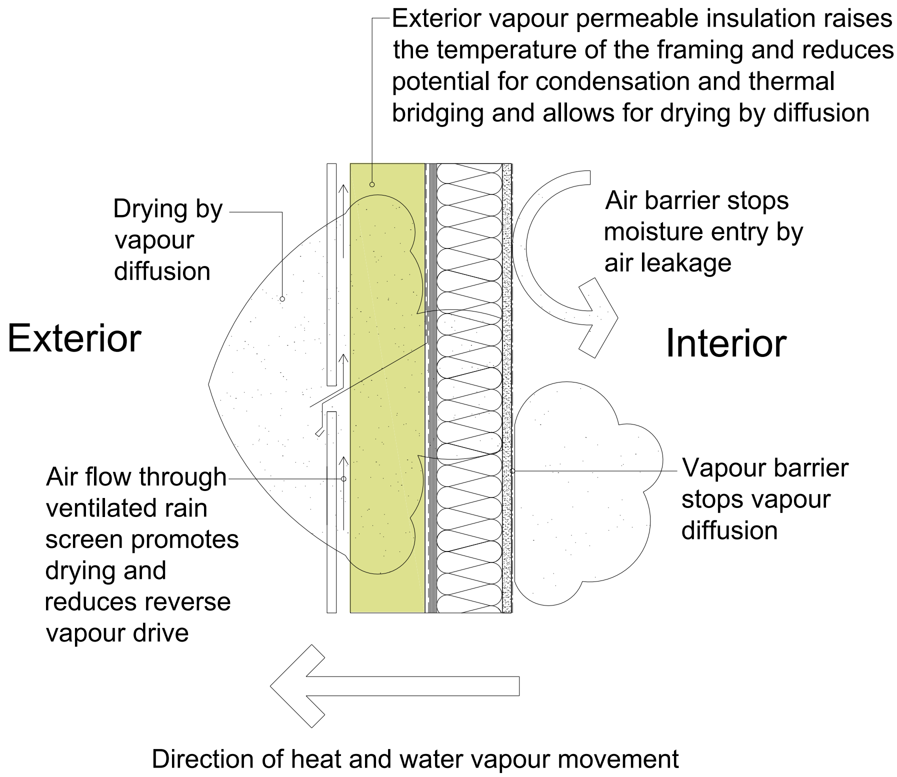

Figure 4-10. Strategies that prevent interstitial condensation and promote drying by air movement and vapour diffusion in a heating climate.

4.4.3 Detailing of Wall Penetration

A critical aspect of building envelope durability, particularly in maritime climates, is water entry that can occur at wall penetrations, such as windows, doors, exhaust and supply hoods, electrical receptacles, and electrical conduits, and at transitions between exterior cladding materials.

For further information on exterior wall detailing to prevent rainwater penetration refer to the *Building Envelope Details Guide—Part 9 Residential Construction* (Homeowner Protection Office 2007) and the *Canadian Home Builders' Association: Builders' Manual* (2013).

Water entry through wall penetrations can be particularly problematic in assemblies that have insulated sheathings with low vapour permeance, because once the wood-frame portions of the wall assembly are wetted, they dry very slowly thus increasing the likelihood of mould growth and general decay. This is discussed further in Section 4.6.4.4 about service penetrations.

4.5 Foundations

4.5.1 Durability Considerations

Heat loss through foundations occurs due to conduction to the surrounding soil in below-grade areas, and to the outdoor air in above-grade areas. The rate of heat loss to soil is influenced by the composition of the soil, its moisture content, and the movement of underground water. For these reasons a foundation will perform better thermally in well-drained soils. To promote drainage and reduce capillary water movement, all foundation slabs and footings should be placed on minimum 100-mm-thick (4-inch-thick), compacted, free-draining gravel pads that are connected to the perimeter drain tile. The gravel pads must be located on undisturbed firm bearing. The services of a geotechnical engineer maybe required to confirm that the underlying material is appropriate for the loads.

Moisture-barrier membranes placed beneath foundation floor slabs and around footings will further reduce the potential for water entry by capillarity; and when lapped and sealed, they will contribute to reducing the entry of soil gas through the slab. At a minimum, a damp-proofing coating must be applied to concrete foundation walls to control capillarity. However, damp proofing will not stop water leaks due to cracks, leaking through snap-tie holes in concrete foundations, or other causes. Depending on local conditions, a drainage layer, such as dimpled plastic drainage matt, with or without a waterproof membrane, may be used over the outside face of the foundation wall to improve drainage against the face of the foundation. In all cases the foundation must be covered with free-draining backfill continuous to the perimeter footing drain. Where there is any likelihood of hydrostatic pressure against the foundation or slab, waterproofing membranes must be installed.

Maintaining a dry foundation interior (i.e., basement or crawl space) is critical for ensuring good indoor air quality throughout the home and for preventing mould growth and decay of framing adjacent to foundation walls. Although every effort should be made to ensure that foundations remain dry over the life of the building, insulation used in foundations must be moisture tolerant. Untreated framing lumber and finished wood used in crawl spaces and basements must never be in direct contact with concrete. Where wood is resting directly on the foundation, or is immediately adjacent to it, a capillary break, such as a closed-cell polyethylene sill gasket, must be used to provide separation, or the wood must be preservative treated to meet the CSA O80-Wood Preservation standard (Canadian Standards Association 2008).

Subterranean termites have been identified in some areas of the province. Where they occur, additional measures will have to be taken to protect the home. For example, the use of foam as exterior insulation will require special measures to prevent termite entry. Termite control measures are beyond the scope of this publication and will have to be obtained from other authoritative sources.

4.5.2 Conditioned Crawl Space

Where crawl spaces are used, they should be insulated, air sealed, heated, and cooled just like basements. This approach manages moisture entry from the ground and provides a conditioned space for heating, ventilation, and plumbing services as well as storage. Conditioned crawl spaces are preferable to unheated or vented crawl spaces because:

- Conditioned crawl spaces protect the floor joists located within the crawl space by bringing them inside the thermal- and moisture-protection envelope of the building.
- Plumbing and mechanical services in the conditioned crawl spaces are protected from high rates of heat loss and freezing.

- HVAC, plumbing, and electrical services are more easily serviced in a conditioned crawl space.
- Conditioned crawl spaces can be used for placement of HVAC and water-heating equipment.
- Floors over heated crawl spaces are typically warmer and therefore more comfortable than those above unheated crawl spaces.
- Conditioned crawl spaces can be used for safe, dry storage.
- Unconditioned crawl spaces change the location of the environmental separation from the slab and foundation walls to the floor assembly, above which air-barrier and insulation detailing can be difficult.
- Conditioned crawl spaces are also more energy efficient than ventilated crawl spaces because the floor of the conditioned crawl space is exposed to soil temperatures that are typically higher in the winter than outdoor air temperatures.

4.5.3 Thermal Insulation and Airtightness

Heat loss from foundations is influenced by insulation levels and insulation placement as well as the foundation geometry and the soil height around the foundation. Heat losses are higher for areas of the foundation above grade and close to the ground surface, and this is the reason that insulation levels are typically higher for the foundation walls than for the foundation slab. Foundation insulation can be applied on the exterior, interior, or to both surfaces (Figure 4-11, Figure 4-12, Figure 4-13, Figure 4-14, and Figure 4-15). Exterior insulation has the benefits of protecting the foundation from temperature fluctuations and freeze–thaw cycles, and allows the thermal mass of the foundation to be utilized for storing solar and internally generated heat gains. Interior wall insulation can be applied after completion of the foundation. When underslab insulation is made continuous past the edges of the floor slab and is connected to the interior wall insulation, heat losses will be lower than if an equivalent level of insulation is applied to the exterior of the foundation. Insulated concrete forms insulate both on the interior and exterior while also providing a stay-in-place concrete form. Insulated concrete forms offer many of the thermal and durability benefits of both interior and exterior insulation approaches.

In high-performance housing projects, the levels of insulation in foundation walls typically range from RSI-3.5 to 7.0 (R-20 to 40) depending on geographic location and how much of the foundation is located above grade. Insulation of the floor slab typically ranges from RSI-2.1 to 3.5 (R-12 to 20), and should be installed continuously underneath the slab and at the slab edges. See Appendix K for a list of effective RSI-values (R-values) for foundation assemblies.

To enhance durability, construction moisture should be removed as much as possible before foundation walls are closed in. To minimize the amount of water coming out of cast concrete foundations, water should not be added on-site to improve workability because this decreases strength and increases the required drying time. Cast concrete foundations should, if possible, be left exposed on either the interior or exterior as long as possible before being covered with vapour impermeable membranes, such as damp proofing, polyethylene, or impermeable insulations.

Foundation airtightness is important. In winter, colder, denser, outdoor air will, by gravity, exert a pressure on the above-grade portions of the foundation. The air will enter if the rim joist and upper foundations walls are not airtight, leading to greater energy use, thermal discomfort, and temperature stratification. To resist this requires that the air barrier on the foundation be continuous, the sill plate be air sealed to the top of the concrete wall, and the rim joist be sealed with a membrane wrap, i.e., air-sealed foam blocking or spray foam. All penetrations of the rim joist will also require air sealing.

Another key area for air sealing is the foundation slab, to prevent the entry of soil gases such as methane, and, in some locations, the entry of radon, a radioactive gas. All joints, penetrations and cracks in slab and between the slab and the foundation walls must be continuously air sealed with a durable sealant. Refer to the *British Columbia Building Code 2012* (Building and Safety Standards Branch 2012) for specific radon-mitigation requirements.

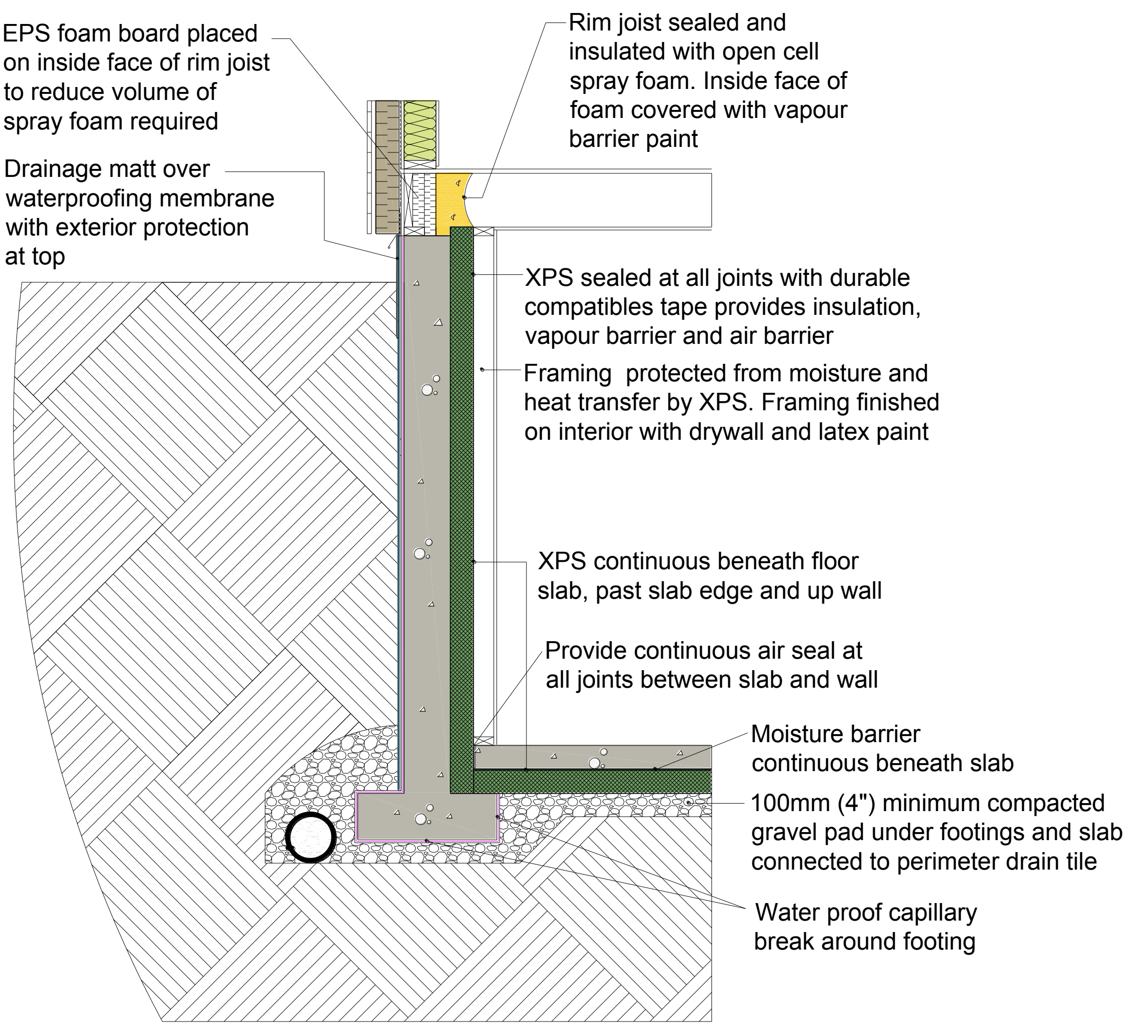

Figure 4-11. Interior-insulated foundation.

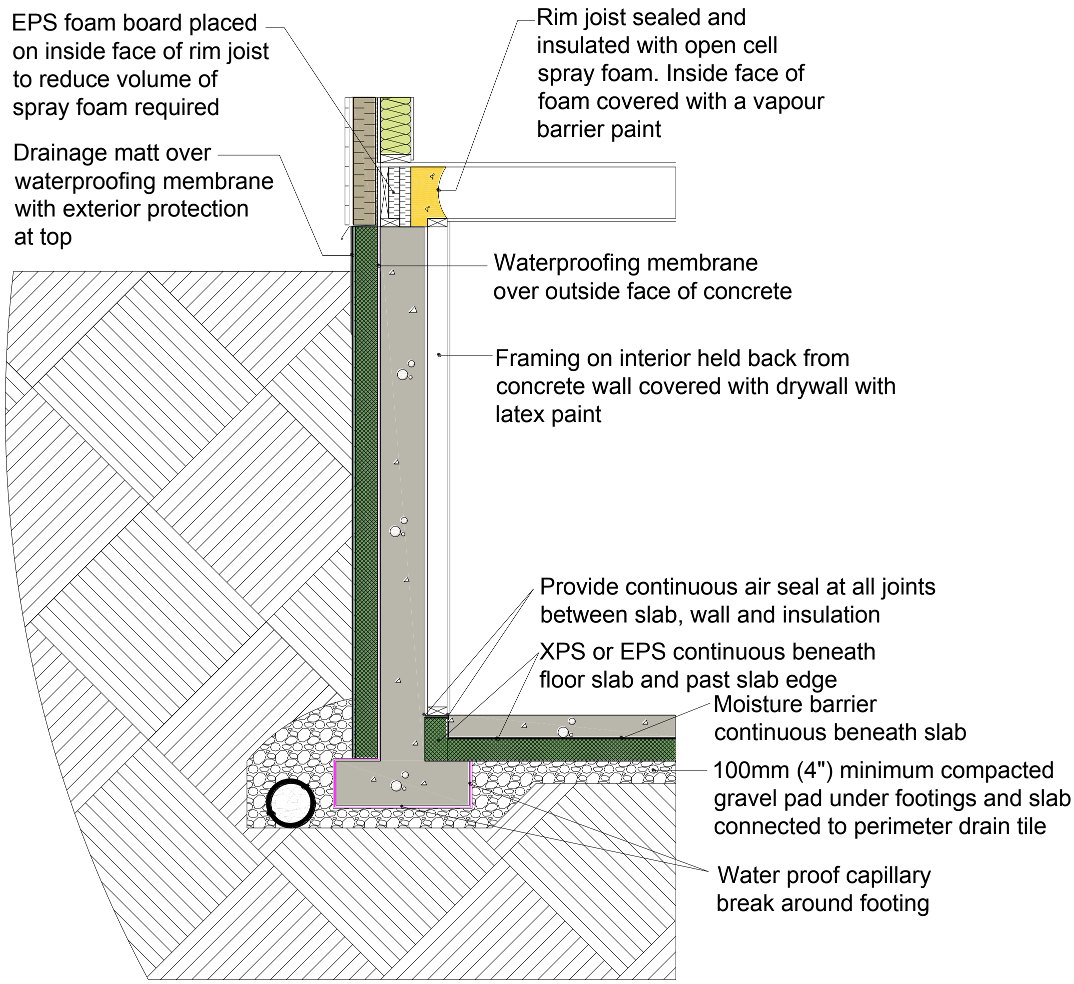

Figure 4-12. Exterior-insulated foundation. Exterior insulations used for foundation walls include XPS, high-density EPS, and high-density mineral wool board. Underslab insulations include XPS and EPS.

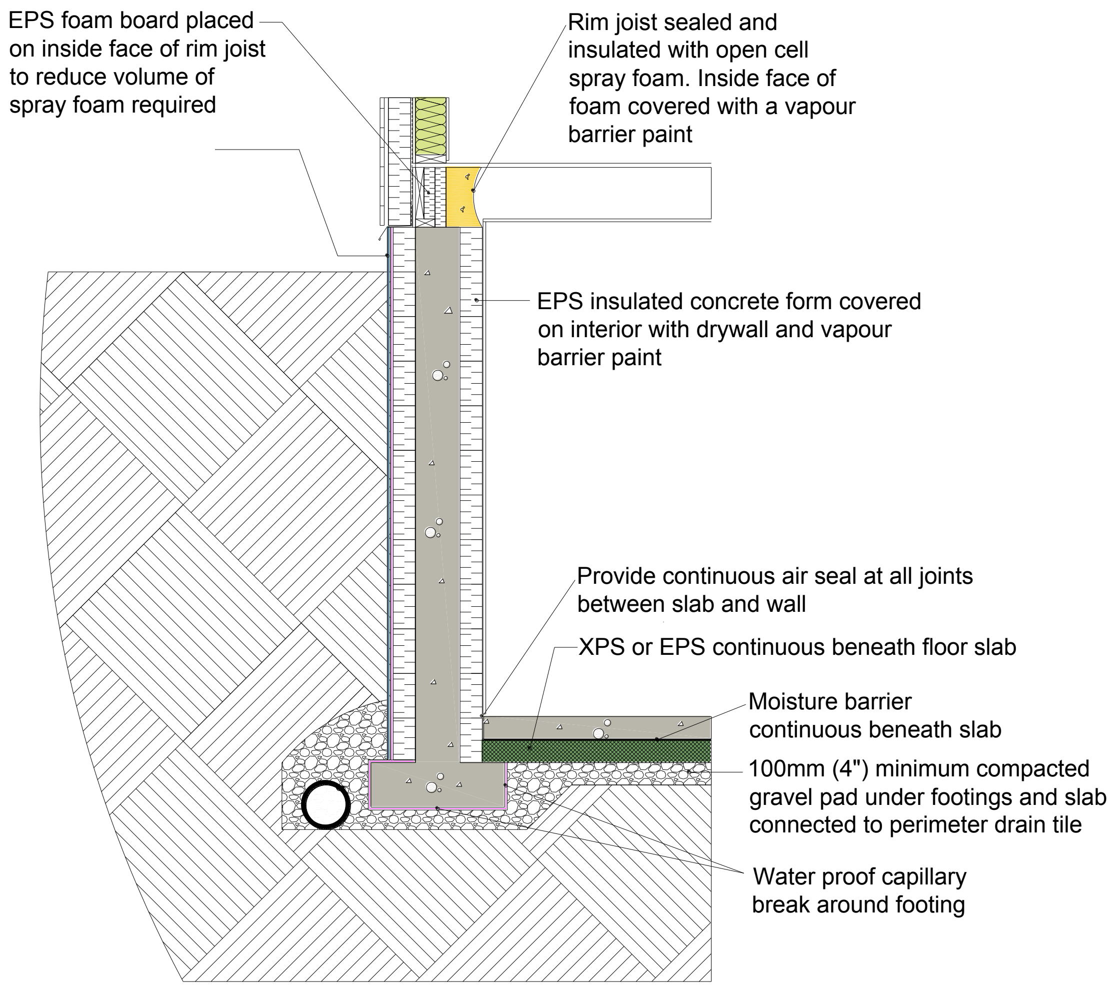

Figure 4-13. Insulated concrete-form foundation.

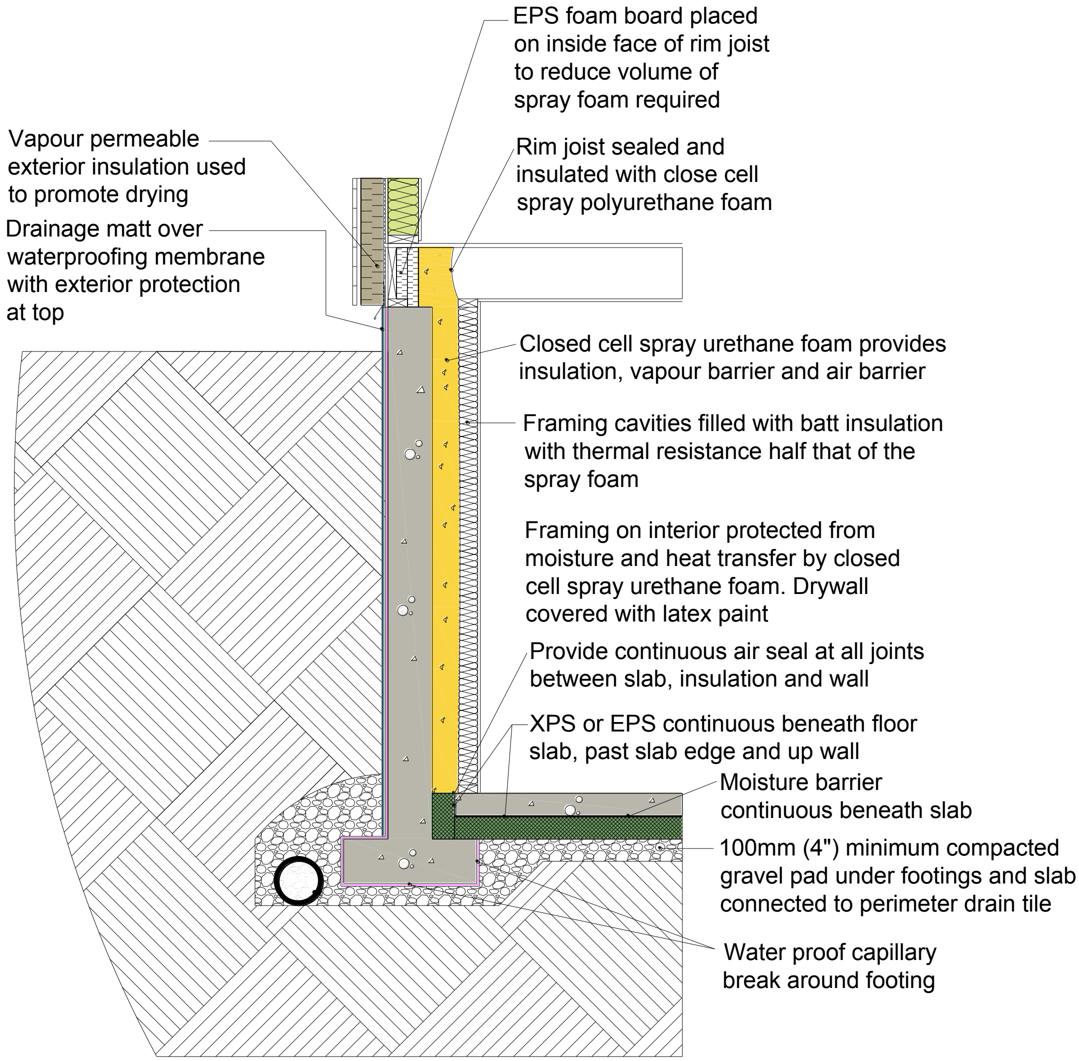

Figure 4-14. Interior-insulated foundation using 2 pcf, closed-cell, polyurethane, spray-foam insulation and batts.

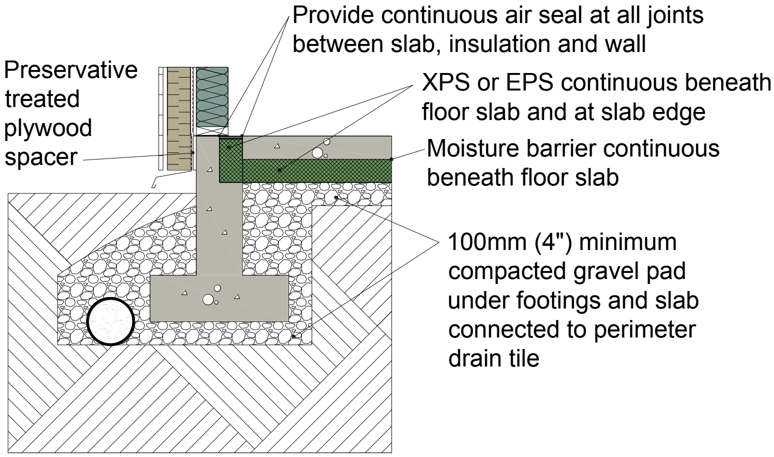

Figure 4-15. Slab-on-grade foundation.

4.6 Exterior Above-Grade Walls

Appendix L lists a range of above-grade wall assemblies that are suitable for high-performance housing, including their effective insulation values.

4.6.1 Cavity Insulation

As discussed in Section 4.1.2, placement of insulation in wall-framing cavities has the advantage of using “free” space provided by the structure. Higher insulation can be achieved by increasing the wall thickness using various approaches:

- Deeper studs – Such as 38x184 mm (nominal 2x8 inches) or 38x235 mm (nominal 2x10 inches), spaced at 610 mm (24 inches) o.c.
- Double-stud construction – In which two 38x89-mm (nominal 2x4-inch) walls are constructed and in some cases are held apart, with OSB or plywood top and bottom plates, to produce wall cavities 300 to 405 mm (12 to 16 inches) deep. See an example of double-stud walls in *Riverdale NetZero Deep Wall System* (Canada Mortgage and Housing Corporation 2010).
- Stand-off trusses – Constructed of plywood gussets and 38x38-mm (nominal 2x2-inch) cords that are attached to the studs of a conventionally framed wood-frame wall.
- Products such as wood I-joists and I-section studs – These products could provide wall-cavity thicknesses ranging from 235 to 508 mm (9¼ to 20 inches). However, they need to be certified by the manufacturer for structural performance in this type of application.

Where cavity insulation is used, it is critical that it completely fill the wall cavity; it must prevent air circulation within the cavity by natural convection that would transfer both heat and moisture (Figure 4-16). This can be achieved by careful cutting and placement of batt insulation, use of closed-cell or open-cell spray foam, or complete filling with blown-in insulation, such as a dense-packed cellulose fibre, or chopped fibreglass.

The drawbacks of cavity insulation are that up to 23% (Section A-9.36 of the *National Building Code of Canada 2010* (National Research Council Canada 2010)) or more of an assembly could consist of framing that results in thermal bridging through the assembly, which in turn would reduce the effective RSI-value (R-value) of the wall assembly. Thermal bridging caused by wood elements in a building enclosure is much less than that which occurs through other construction materials; this is because wood has a much higher thermal resistance than steel and concrete (Morrison Hershfield 2014). Cavity insulation can be made more effective by reducing the amount of framing in the wall assembly by using advanced framing. Advanced framing involves a range of techniques, including spacing studs at 610 mm (24 inches) o.c. two stud corners and single top plates (ensuring continuity of load path from studs above to studs below), and eliminating headers for small window openings occurring between studs and let-in headers. Advanced framing can reduce framing lumber to about 16% of the wall area (Section A-9.36 of the National Building Code of *Canada 2010* (National Research Council Canada 2010)), thereby reducing heat losses up to about 10% (Figure 4-17). Refer to Appendix J for more details on advanced framing. However, additional engineering may be required to ensure structural performance.

Another type of wall in which insulation is placed between the interior and exterior finish is a structural insulated panel, or a SIP. These products in general fall into the category of proprietary products. The two skins of a SIP usually consist of OSB, although sometimes various types of plywood are used. The core consists of foam, typically EPS, although in some cases urethane foam is used. The insulation core is adhered to the skins, forming a rigid panel. Typically the panels are tied together using a continuous top and bottom plate. Studs or columns maybe incorporated in the panel, particularly for concentrated loads. SIPs come in a range of thicknesses and configurations. As with all other wall assemblies, SIP walls must be made as airtight as possible to prevent heat loss and condensation damage due to air leakage. This requires air sealing of joints that are between panels on the inside face, between panels and floors, and of panels and ceilings, as well as between panels and windows, doors, and service penetrations. In all cases the air sealing is done on the interior. As with all high-performance housing projects, a home constructed with SIPs must be airtightness tested in order to locate and repair locations of air leakage and to ensure that the building meets the airtightness of 1.5 air changes per hour at 50 Pa or less.

Figure 4-18 shows a generic SIP wall. Wiring can be passed through predrilled wiring chases in the SIPs panel or be surface-mounted using metal conduits to protect the wiring. Another approach is to use an interior service wall built with small dimensional lumber or strapping. This interior wall can accommodate electrical and plumbing services and further improve airtightness performance of the air barrier.[10]

4.6.2 Exterior Insulation

Placing insulation on the exterior of the framing has the advantages of increasing the thermal resistance of the assembly, providing a thermal break, thereby reducing thermal bridging and raising the temperature of the framing and sheathing in the winter, which in turn reduces the potential for condensation formation (Figure 4-19, Figure 4-20, Figure 4-21, Figure 4-22, Figure 4-23, Figure 4-24, and Figure 4-25). CLT walls are insulated using exterior-applied mineral wool board or foam board insulation with a rainscreen cladding assembly (Figure 4-24).

[10] For general information on SIPs, refer to www.sips.org. For specific information on a particular SIPs panel, consult the manufacturer.

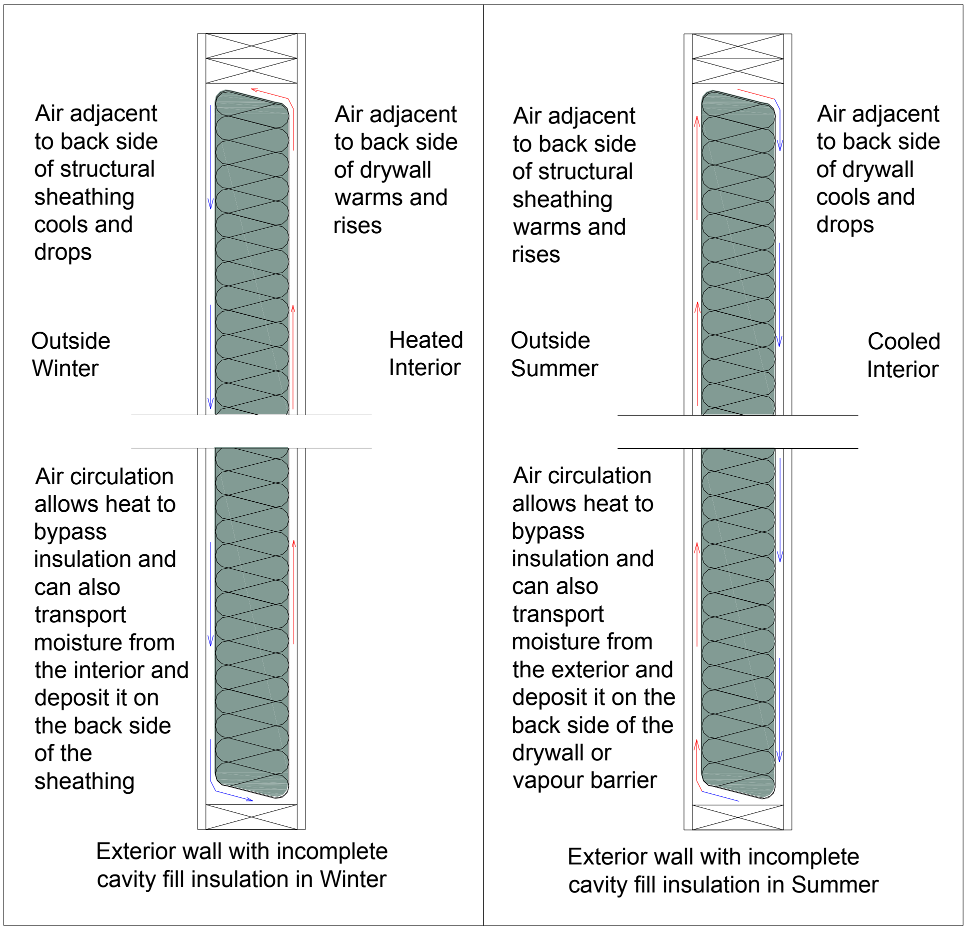

Figure 4-16. The incomplete filling of wall cavities with insulation can lead to air circulation that transfers heat and moisture.

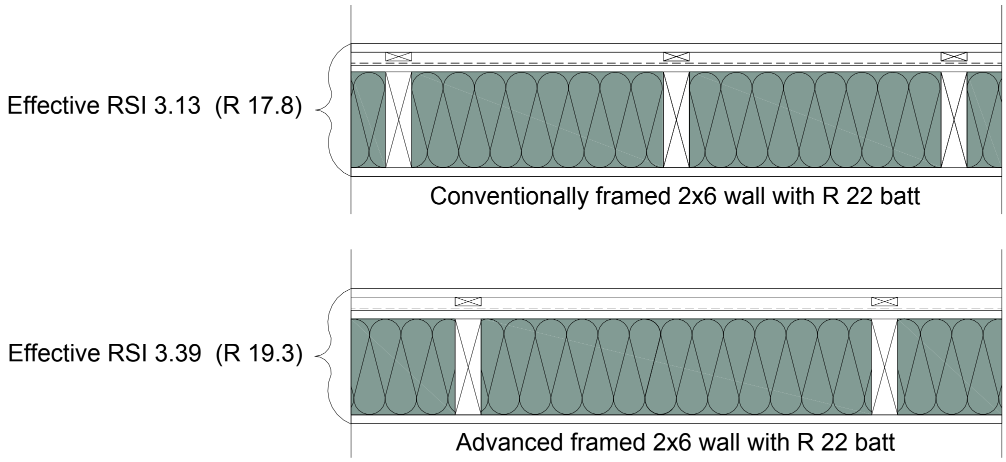

Figure 4-17. Effective insulation values of 38x140-mm (nominal 2x6-inch) walls: comparison of conventional and advanced framing having the same density of batt insulation.

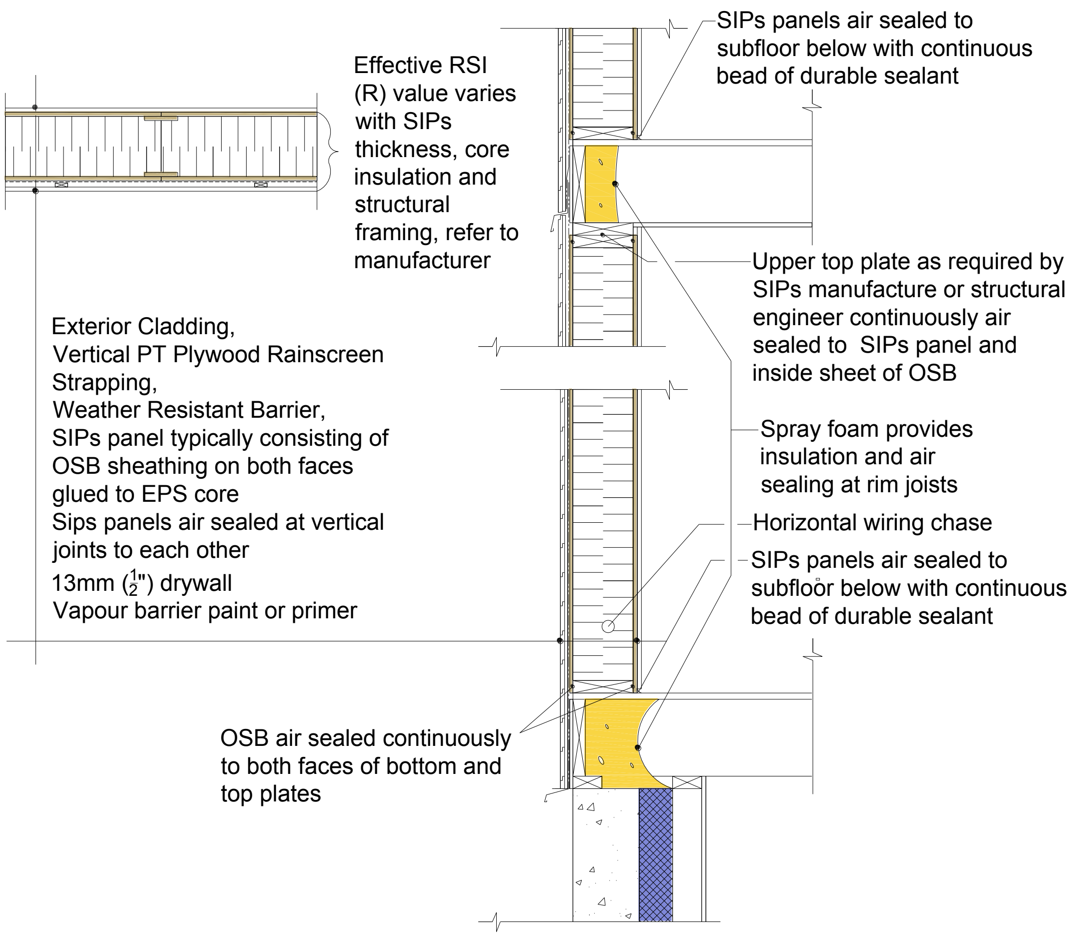

Figure 4-18. A generic SIP wall showing first-floor and second-floor walls. Details vary between manufacturers, so always refer to the manufacturer's literature when designing a specific assembly.

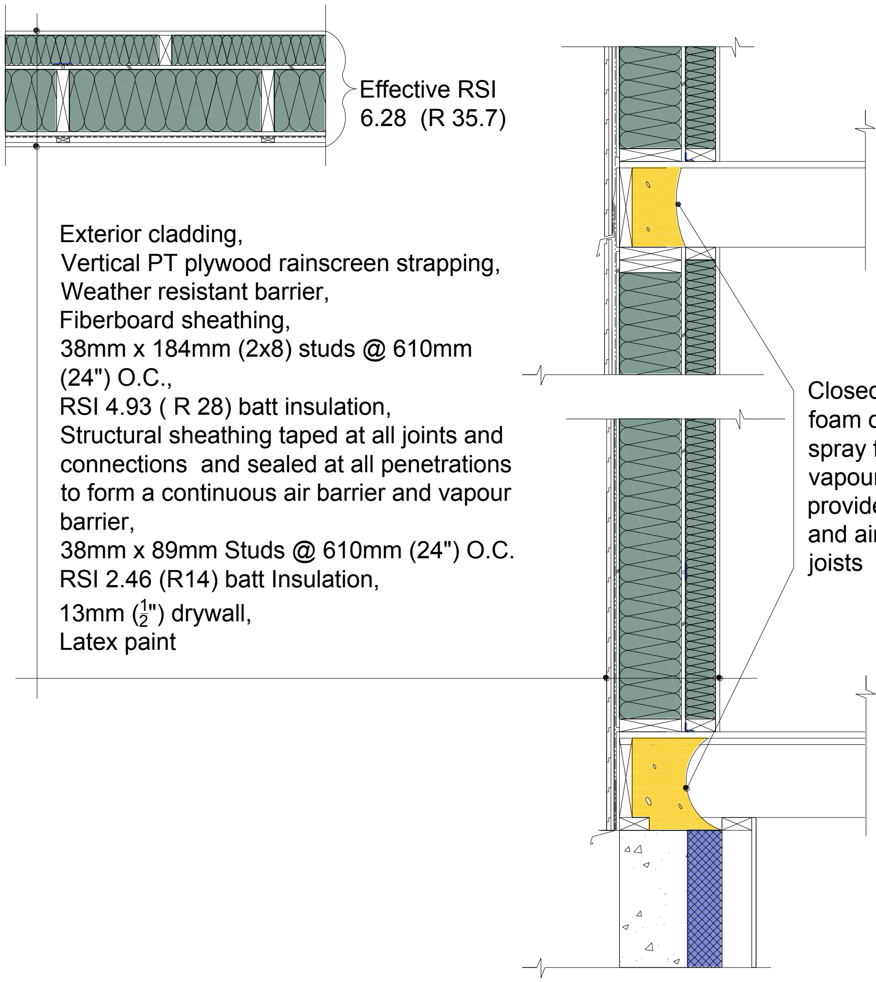

Figure 4-19. In this wall assembly, larger dimension studs (38x184 or 38x235 mm (2x8 or 2x10 inches)) are spaced at 610 mm (24 inches), and the structural sheathing is placed on the interior, taped at all joints with a highly durable tape, and sealed at all penetrations, thus forming the air barrier and the vapour barrier. A highly vapour-permeable fibreboard sheathing is used on the outside to promote drying. An offset 38x89-mm (2x4-inch) wall is placed inside the structural sheathing to provide a cavity for electrical, plumbing, ductwork, and insulation. Such assemblies have been used in Passive House construction.

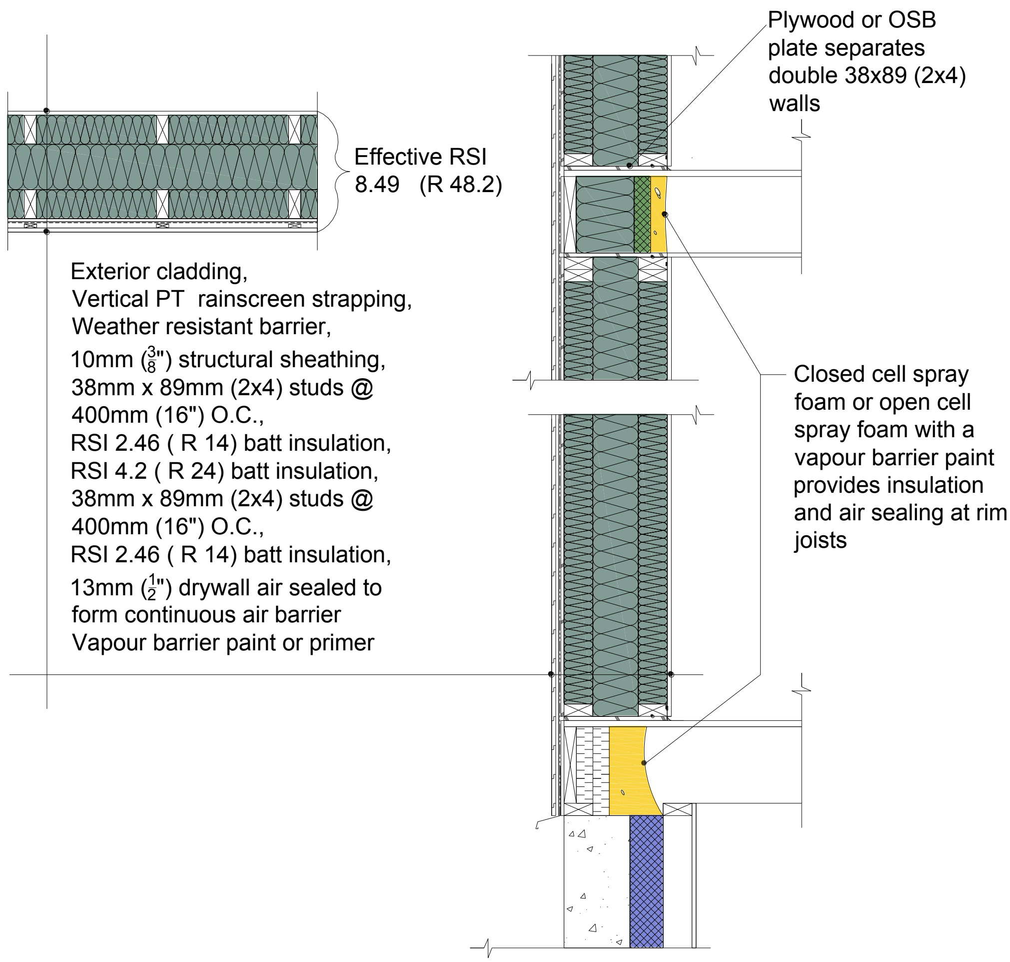

Figure 4-20. An example of a double-stud wall in which two 38x89-mm (nominal 2x4-inch) walls are framed and held apart with plywood or OSB plates. Studs are lined up rather than offset to allow for easier installation of windows and doors. Alternative insulations could be used, such as dense-packed, cellulose fibre, low-density spray foam, or chopped fibreglass. This wall also incorporates a vented rainscreen which is necessary for ensuring long-term durability.

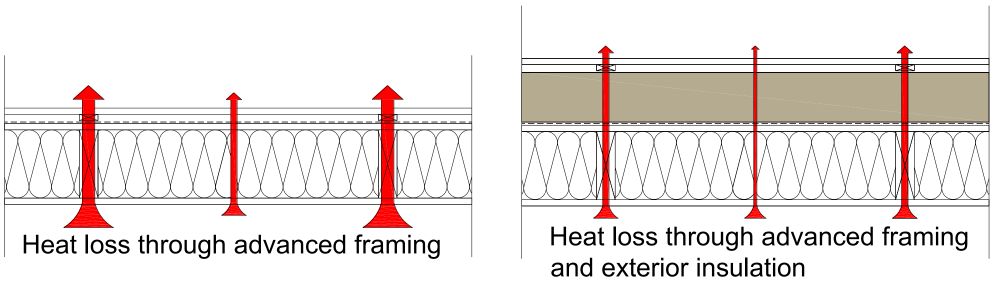

Figure 4-21. Heat loss through an exterior above-grade wall can be reduced by placing a rigid insulation on the outside face of the framing, thereby providing a thermal break in the assembly.

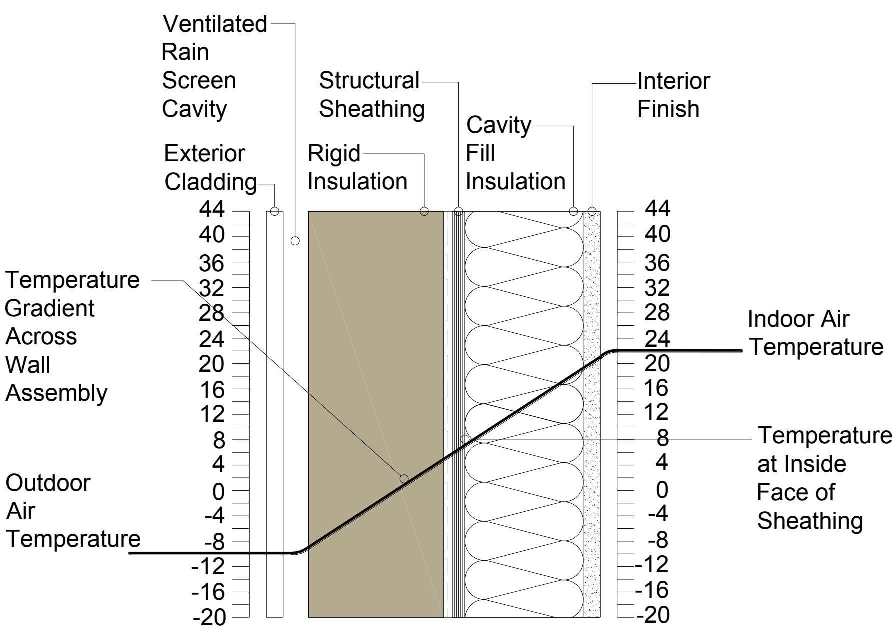

Figure 4-22. This simplified diagram illustrates that the temperature of the structural sheathing and framing is raised when a rigid insulation is applied to the exterior, thereby reducing the potential for condensation formation.

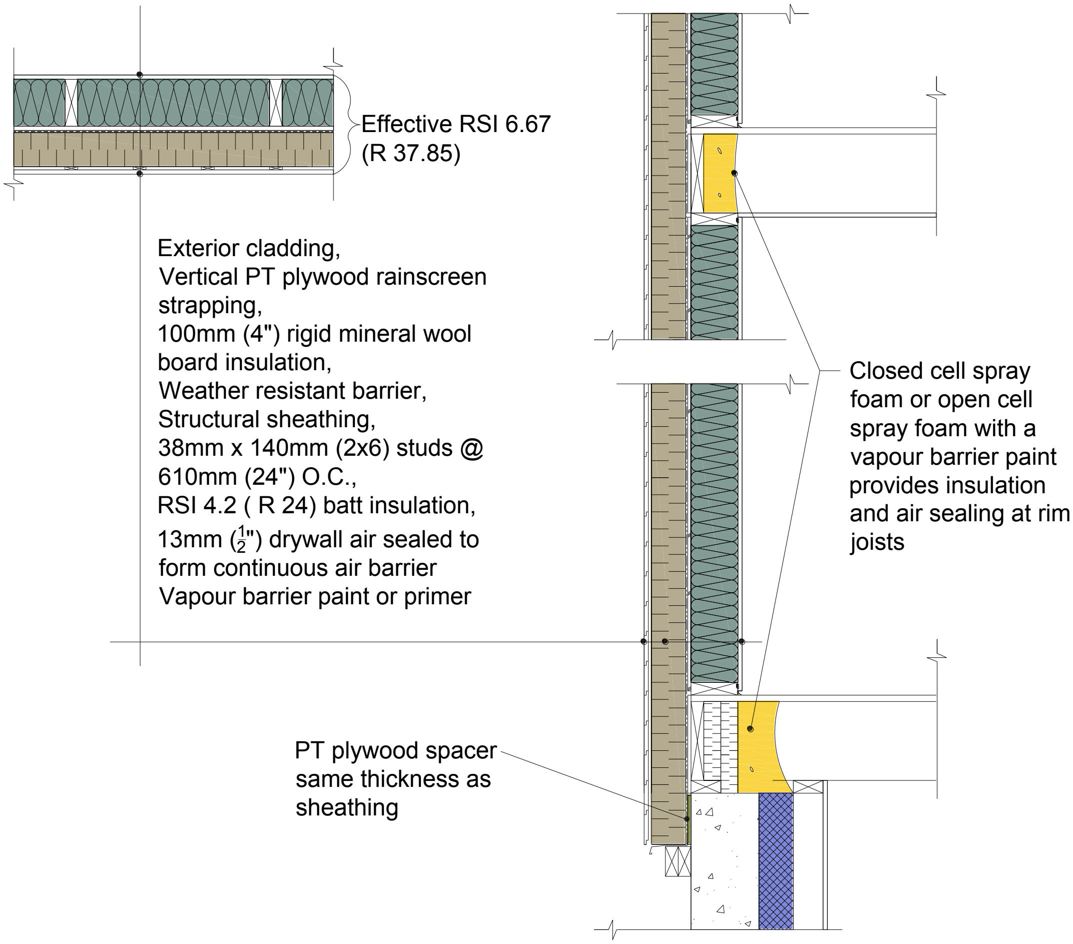

Figure 4-23. Exterior-insulated sheathing wall assembly comprised of a 38x140-mm (nominal 2x6-inch) advanced-frame wall with 100-mm (4-inch) mineral wool board exterior insulated sheathing. The high permeance of mineral wool board insulation will allow sheathing and framing to dry to the exterior if any water entry or moisture accumulation occurs. This wall also incorporates a vented rainscreen which is necessary for ensuring long-term durability.

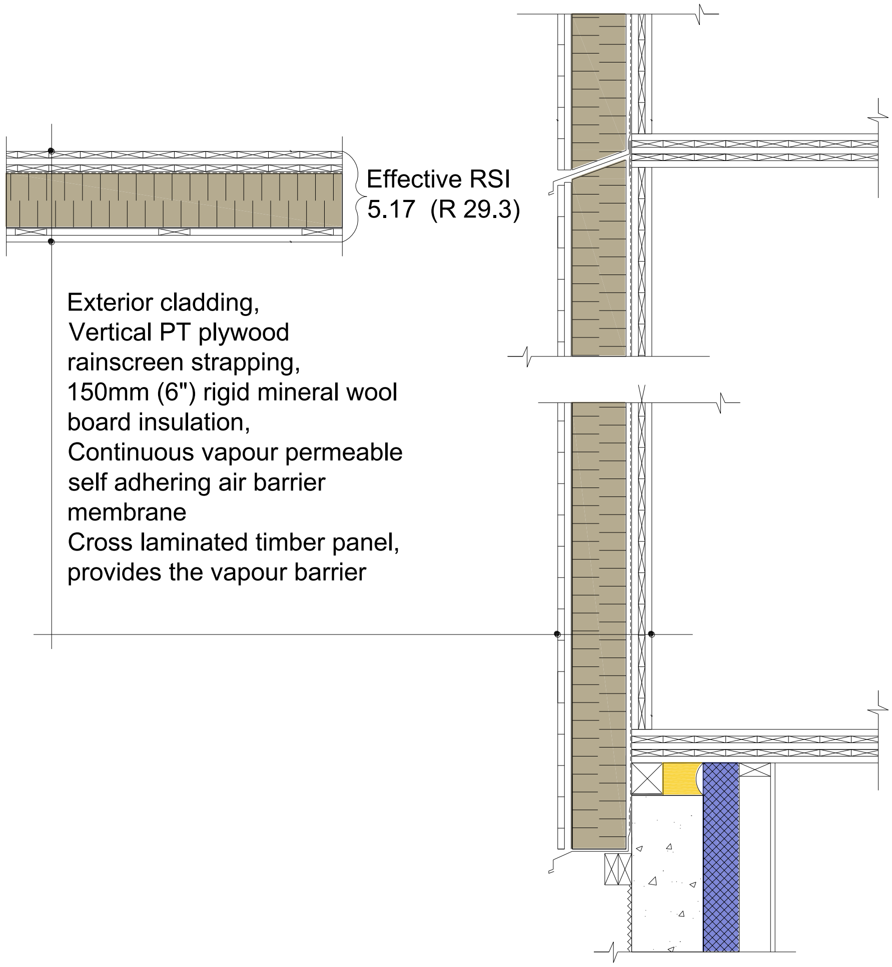

Figure 4-24. A CLT wall with a vapour-permeable, self-adhering, air-barrier membrane and vapour-permeable rigid insulation: plan and section views. This assembly is both energy efficient and durable in that the structural CLT panels are protected from exterior conditions and the assembly can readily dry to the exterior and the interior. This wall also incorporates a vented rainscreen which is necessary for ensuring long-term durability.

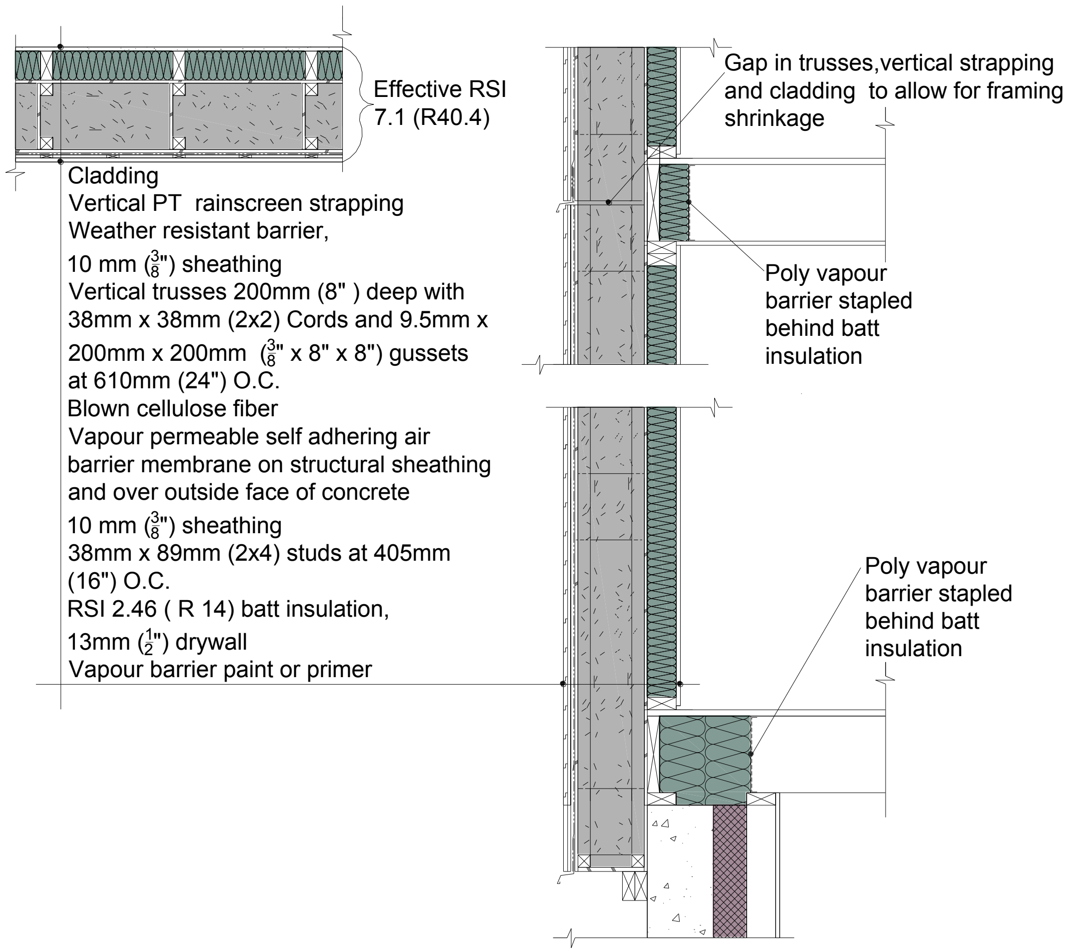

Figure 4-25. Stand-off truss wall in which simple trusses are anchored through the structural sheathing to the conventionally framed 38x89-mm (nominal 2x4-inch) wall behind, thus forming a cavity for blown-in, spray, or batt insulation. This wall also incorporates a vented rainscreen which is necessary for ensuring long-term durability. This drawing is shown for lightweight claddings such as wood and vinyl; for heavier claddings such as stucco and wood-fibre-reinforced cement, the design must be reviewed by a structural engineer.

4.6.3 Combined Interior and Exterior Insulation

Insulation can be placed on the interior of the wall framing in the form of rigid insulation or as horizontal strapping with batt or spray insulation. Horizontal strapping can provide a cavity for wiring and plumbing. Continuous interior insulation will reduce thermal bridging but will also make the framing and sheathing colder in the winter, thus reducing drying potential. A common approach to using interior insulation is to combine it with exterior insulation to produce the “wrap and strap” assembly (Figure 4-26).

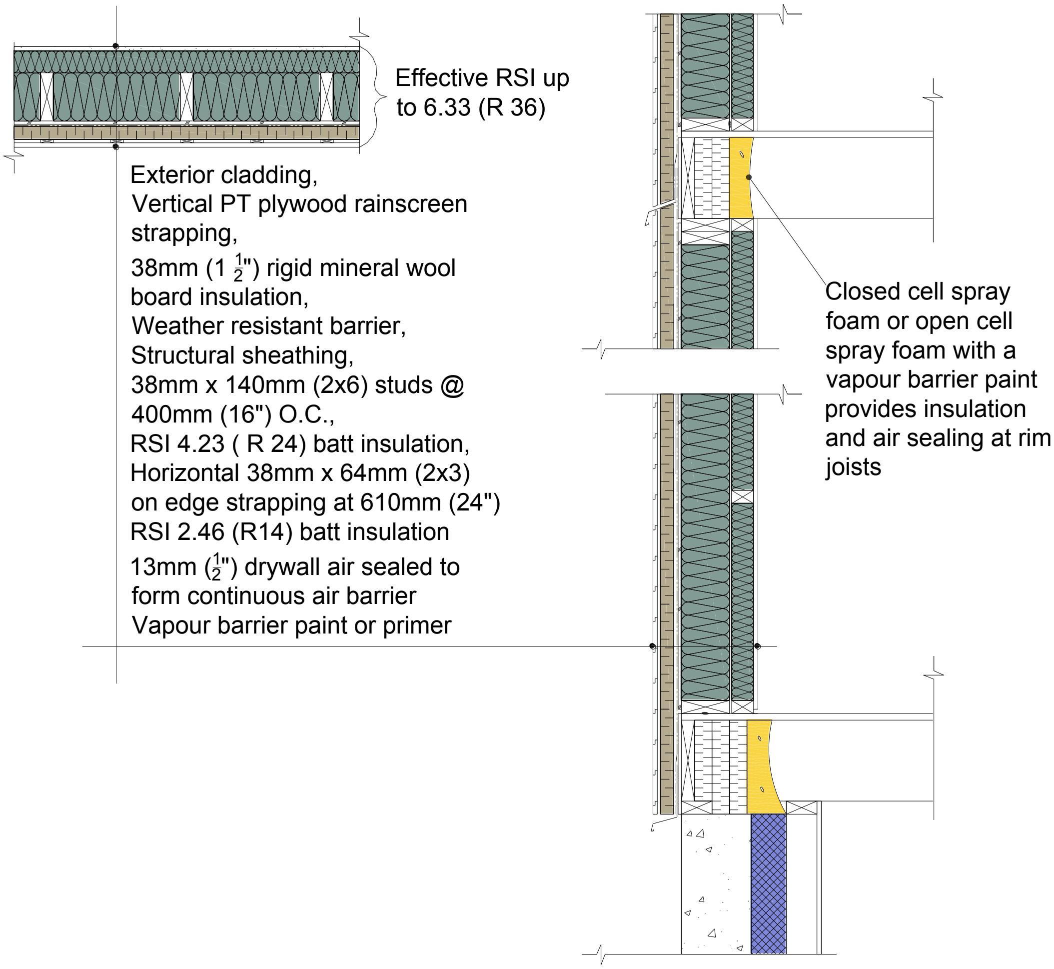

Figure 4-26. A 38x140-mm (nominal 2x6-inch) "wrap and strap" wall assembly using both interior- and exterior-applied insulation.

4.6.4 Other Considerations in Wall Design

4.6.4.1 Rim Joist Treatment

Conventionally framed rim joists have traditionally been a weak point in wall assemblies from the point of view of energy efficiency. They tended to be less well insulated and a location of high air leakage. This has changed with the introduction of closed- and open-cell spray-foam insulations. These products provide both air sealing and insulation and, in many cases, form part of the continuous air-barrier assembly.

The closed-cell spray urethanes also provide a vapour barrier when applied in thicknesses of greater than 50 mm (2 inches) (Figure 4-27). But these products are not vapour permeable and will prevent drying when the wood in the assembly gets wet.

Open-cell spray foams are highly vapour permeable, so they will allow moisture to pass through, which in some applications can be used to promote drying (Figure 4-28). Open-cell spray foams placed behind the rim joist will often be installed in conjunction with interior vapour-barrier paint. When detailing a rim joist, it is important to ensure that lumber with a moisture content lower than 19% is specified and confirmed on site before closing into structure, and that the assembly be designed so that the rim joist can dry, if it gets wet at some point over its life. Spray foam must not be applied to wet building materials otherwise it may fail to adhere and can shrink away from those materials, leaving air gaps. It also should be applied in accordance at the manufacturer's specified application temperature. When using closed-cell spray foam, ensure the exterior-insulated sheathing is highly vapour permeable, to allow the rim to dry to the exterior if needed.

4.6.4.2 Enhanced Rim Joists

Rim joists can also be framed differently to enhance their performance, such as illustrated in Figure 4-29 and Figure 4-30, where a modified balloon framing is used.

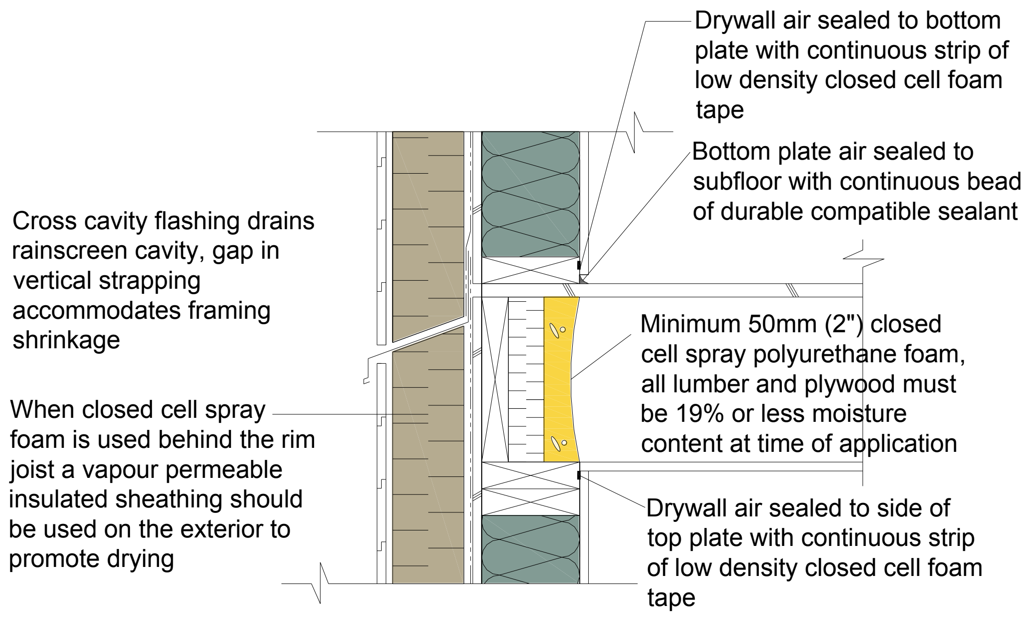

Figure 4-27. Conventional, platform-framed rim joist with exterior insulation and an air seal of spray-foam insulation behind. The air barrier is formed by drywall sealed to the framing and penetrations.

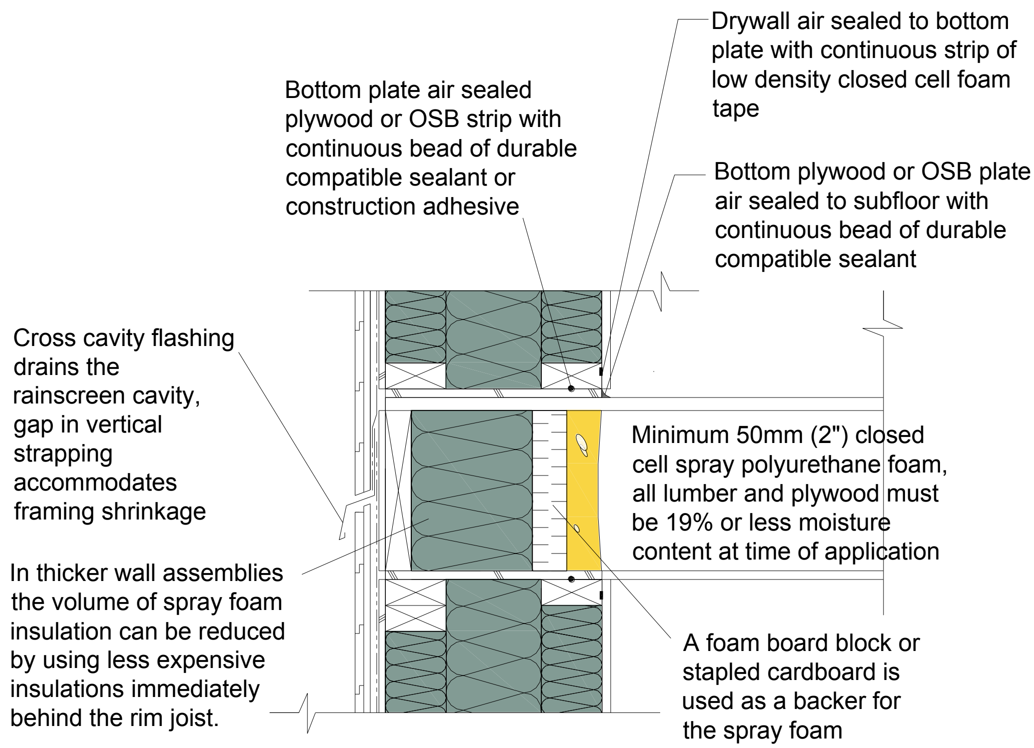

Figure 4-28. The amount of spray foam can be minimized to that needed for air sealing, and to provide a vapour barrier if closed-cell foam is used (50-mm (2-inch) minimum thickness) by packing batt insulation behind the rim joist. A solid backing of foam board or cardboard is needed immediately behind the spray foam.

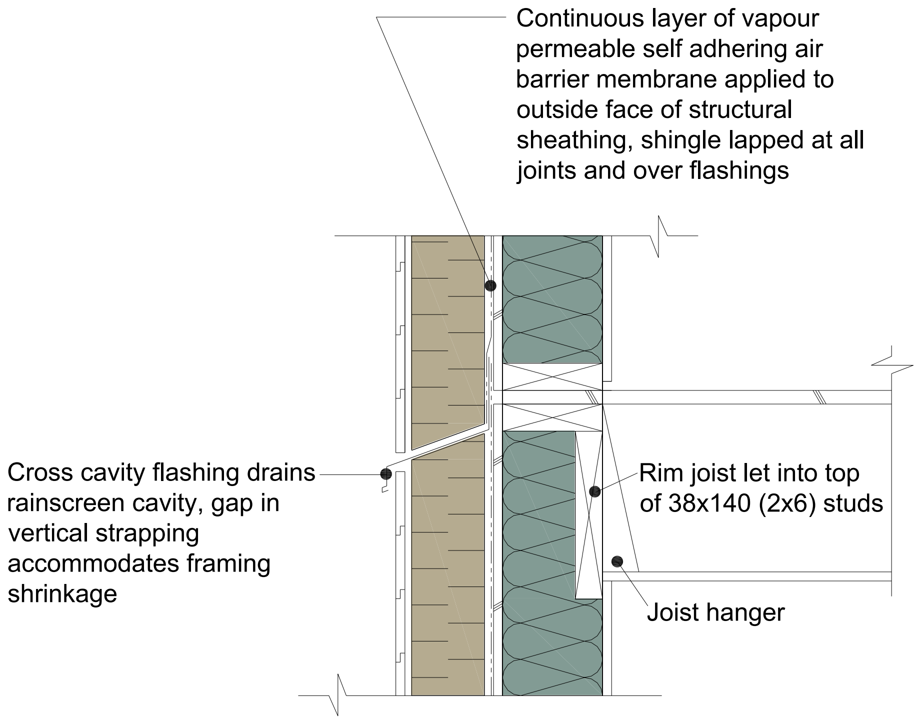

Figure 4-29. Detail of modified balloon framing using 38x140-mm (nominal 2x6-inch) studs, in which the rim joist is let into the studs and close-to-full insulation value is maintained across the floor–wall connection. This detail may require review by a structural engineer to ensure compliance with seismic requirements.

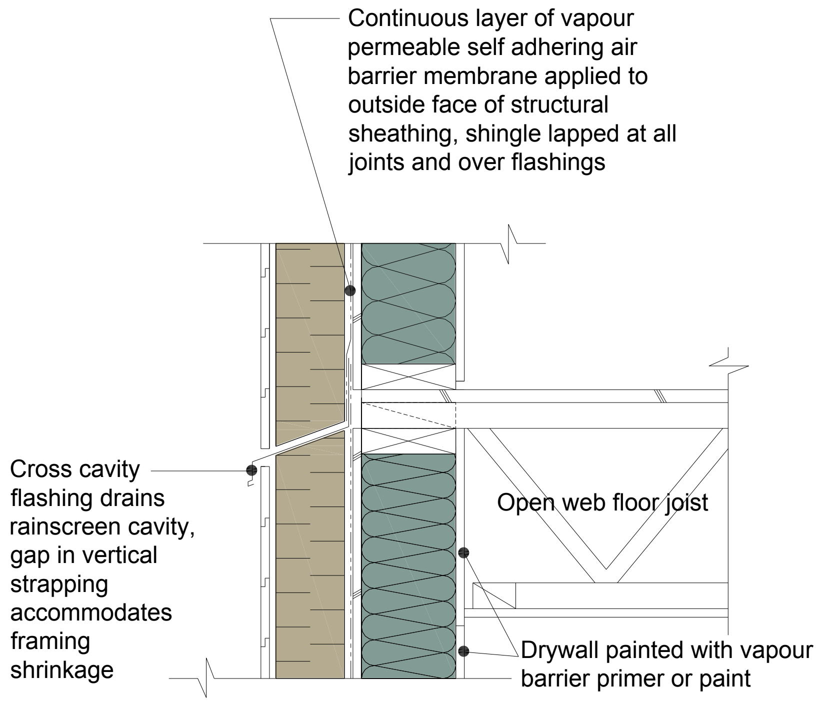

Figure 4-30. Detail of modified balloon framing and an open-web floor joist in which full insulation value of the wall is maintained across the floor–wall connection. This detail may require review by a structural engineer to ensure compliance with seismic requirements.

4.6.4.3 Window Placement

With the thicker wall assemblies used in high-performance housing, windows can be installed in three possible locations within the thickness of the wall: at the inside face, at the outside face, and in the centre of the wall. Locating the window on the outer surface of a thick wall assembly (Figure 4-31) has the following impacts:

- Advantages:
  - Creates a deep window sill that can be an amenity (such as seating area, place for plants, etc.).
  - Allows for conventional window installation and detailing of flashings, rainscreen, etc.
  - Window has wide exposure to sunlight and daylight penetration, thus enhancing solar gain in winter and the potential for daylighting.
- Drawbacks:
  - Outside face of window will be more exposed to wind and wind-driven rain (which can be compensated for by placing an overhang over window).
  - Window glazing and frame will be colder and may lead to condensation.
  - Window has wide exposure to sunlight, potentially leading to overheating in the summer (which can be compensated for by placing an overhang over the window or installing an external shade.)

Locating the window on the inner surface of a thick wall assembly (Figure 4-32) has the following impacts:

- Advantages:
  - Inside surface temperature of glazing will be slightly warmer due to sheltered exterior air film on the window glazing and circulation of room air next to window, thus reducing potential for condensation.
  - Outside face of window will be less exposed to wind and wind-driven rain, thus enhancing durability.
  - Exterior roller shade can be located in the wall above the window.
- Drawbacks:
  - Window installation is not conventional and will require construction of extended exterior sill, jambs, and soffit, with particular attention given to waterproofing.
  - This type of installation will not be possible with a window using a nail-on flange.
  - No amenity area provided on the inside of the window.
  - Southward-facing windows will tend to be shaded by the wall that projects overhead and the extended jambs.

Locating the window in the centre of the wall (Figure 4-33) could present a compromise somewhere between interior and exterior installation. But it is rarely done in practice due to the extra work required. Computer modelling of the thermal performance of window installations indicates that centre wall installation will result in the best thermal performance.

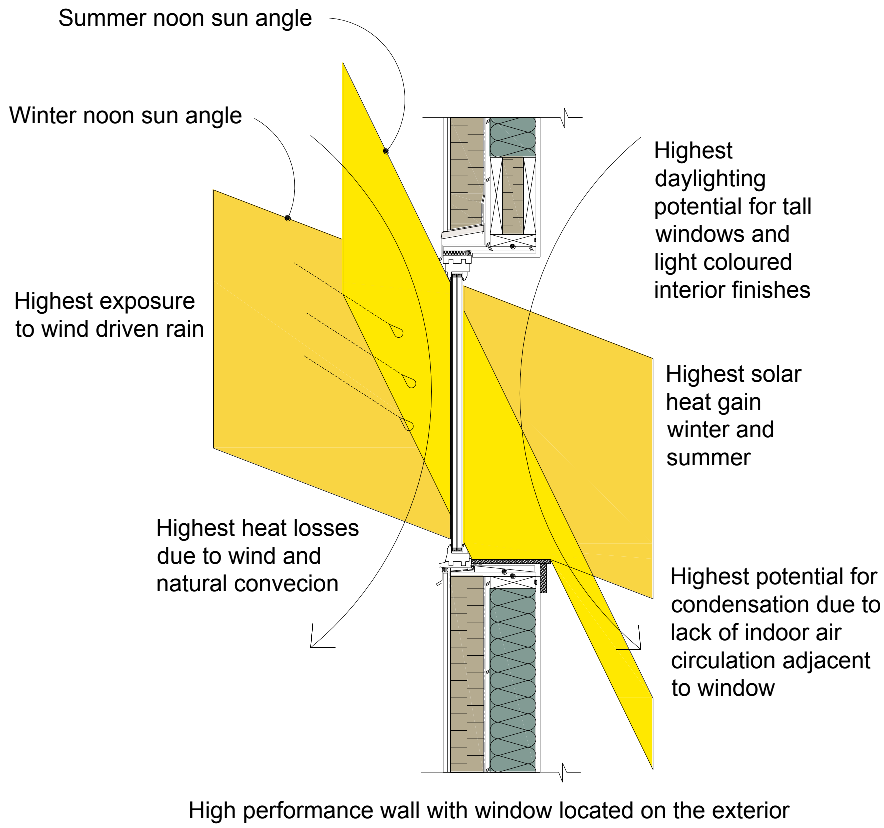

Figure 4-31. High-performance wall with a window located on the exterior.

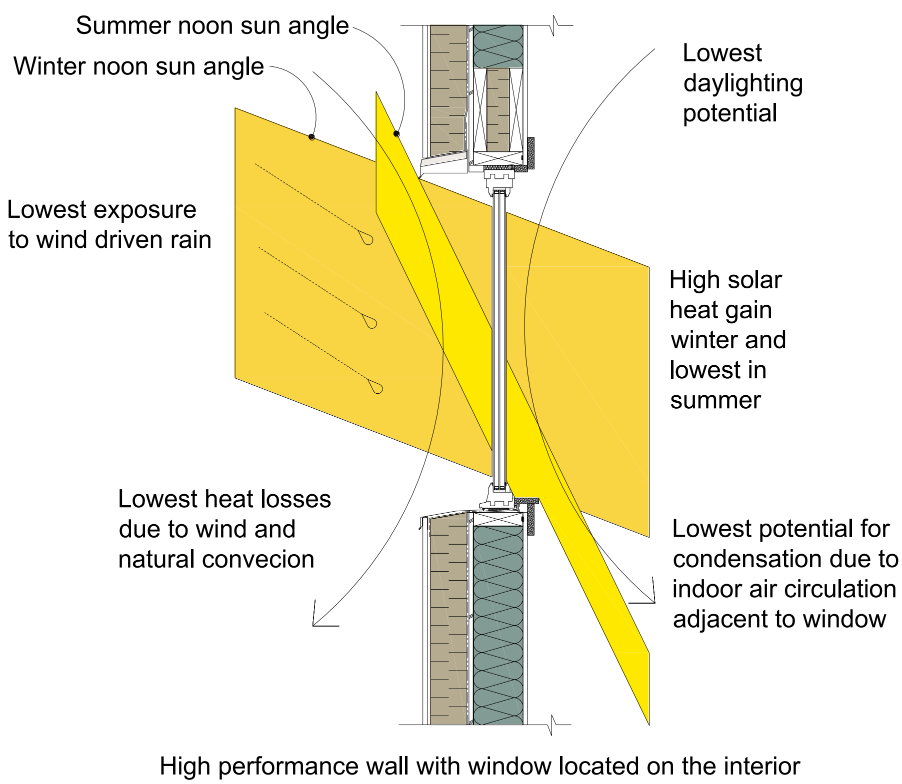

Figure 4-32. High-performance wall with a window located on the interior.

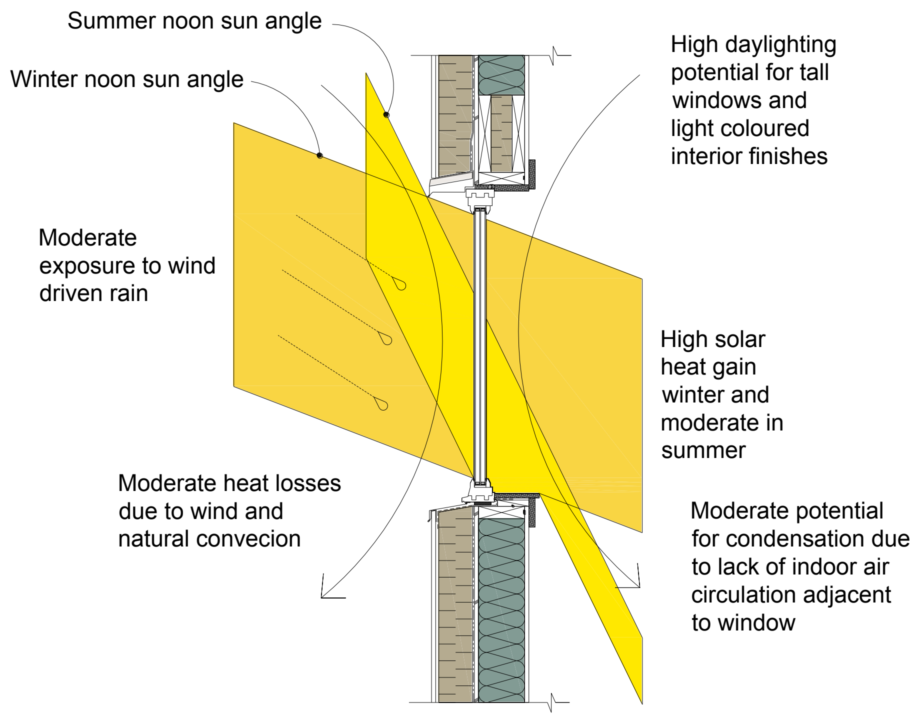

Figure 4-33. High-performance wall with a window located at the centre.

4.6.4.4 Mechanical and Electrical Service Penetrations of Exterior Wall

The key issues that relate to service penetrations of high-performance housing wall systems include (examples shown in Figure 4-34):

- Water-penetration control – Mechanical and electrical wall penetrations can provide an entry point for wind-driven rain and rainwater draining down both the exterior and interior faces of the cladding. Cross-cavity flashings that carry from beneath the weather-resistant barrier slope down and across the rainscreen cavity and drain to the outside must be used above and below all mechanical (supply and exhaust vents) and plumbing penetrations, and above all electrical receptacles.
- Venting moisture – In the case of exhaust vents, it is necessary to ensure that moisture carried in the exhaust air stream is not deposited inside the wall cavity on the adjacent exterior wall or on the soffit above. This involves ensuring the ducting carried through the wall is water and airtight as well as being sloped to the exterior enough to ensure drainage of any condensate that forms in the duct. The plane of the exhaust grille screen must be flush with the exterior cladding.
- Air-barrier detailing – Where plumbing, wiring, or piping penetrates an exterior wall air barrier, penetrations must be air sealed with durable materials that will last the life of the building and accommodate any movement that may occur. Many of these penetrations occur at the rim joist and are typically air sealed with open-cell or closed-cell spray foam, durable compatible sealants, or clamped membranes.

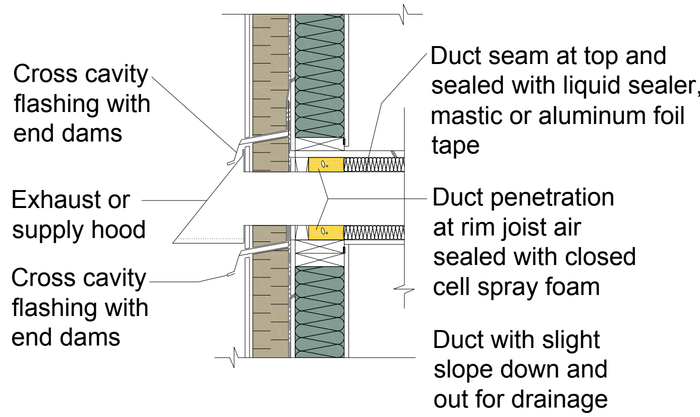

Figure 4-34. Penetration at rim joist for heat-recovery ventilator / energy-recovery ventilator exhaust or supply.

4.7 Roof Assemblies

Roof assemblies for high-performance housing have effective insulation values in the range of RSI-10.57 to 17.6 (R-60 to 100) (Appendix M). These insulation values can be achieved by using deeper framing cavities and, in some cases, using interior or exterior layers of insulation. In all cases the insulation value in the roof should remain the same across the entire assembly, from the outside face of the exterior walls to the centre. Where trusses are used, this calls for raised heels at the exterior walls, a modification that is available from many truss manufacturers at a modest cost. Where roofs are hand framed, framing techniques can be modified to allow for full-depth insulation to the exterior walls. Where sloped ceilings are desired, modified scissors trusses; wood I-joists; or parallel-chord, open-web joists can be used. With the elevated insulation levels used in high-performance housing roofs, it is critically important that the air barrier in the roof assembly be continuous to ensure that warm, moist, indoor air is blocked from entering the insulated roof cavities.

4.7.1 Pitched-Roof Attic Assemblies

4.7.1.1 Vented

This is one of the most common forms of roofs in wood-frame construction and can be made to effectively contain high levels of insulation. The truss design requires modifying to include a raised heel in order to carry full-depth insulation to the exterior walls (Figure 4-35). In high-performance housing, to attain ceiling insulation levels of RSI-10 to 17.6 (R-60 to 100) will require 424 to 705 mm (17 to 28 inches) of blown-in insulation. Venting at the soffit and ridge must comply with the *British Columbia Building Code's* minimum requirements for a vent-to-roof area ratio of 1 to 300 (based on net roof area) (Office of Housing and Construction Standards 2012).

4.7.1.2 Unvented

In an unvented or conditioned attic, open-cell (1/2 pcf), spray-foam insulation can be applied to the underside of roof sheathing and be carried down and connected to the exterior wall top plate, thereby providing continuous insulation and an air barrier (Figure 4-36). This is not strictly code compliant and will typically require an alternative solution to satisfy the code requirements in British Columbia. Consult the authority having jurisdiction before implementing. All lumber and roof sheathing must be dry, with moisture content below 19%, when the foam is installed. Using a vapour-barrier paint or primer with a vapour permeance of about 60 ng/Pa·s·m^2 on the underside of the foam will allow drying to the interior. The vapour barrier paint must be formulated for use with the particular open-cell spray foam used. This assembly may also allow for detection of roof leaks, as opposed to a polyethylene vapour barrier that may conceal moisture accumulation. Such use of ½-pcf spray-foam insulation typically requires a thermal barrier on the warm side of and in contact with the foam. The thermal barrier requirement is typically met using drywall.

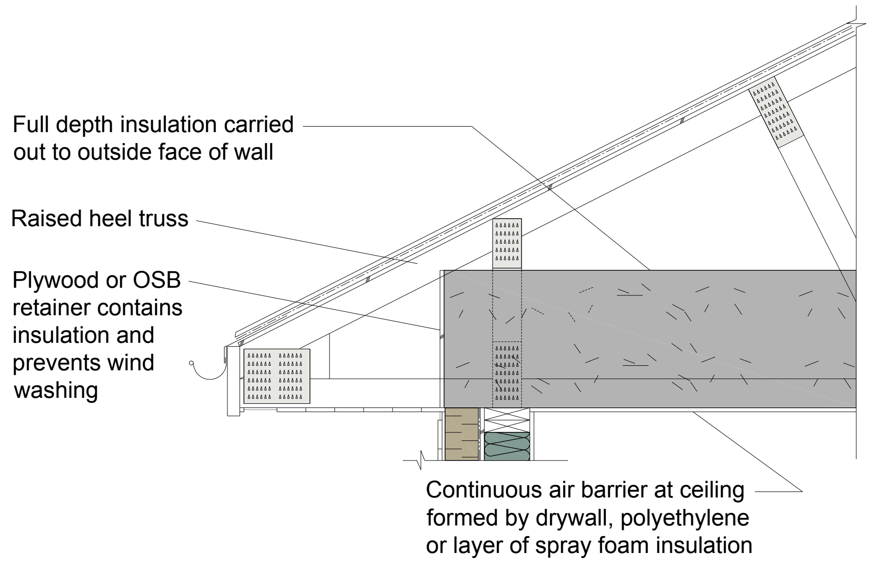

Figure 4-35. Pitched-roof, unvented attic using raised-heel trusses with blown-in cellulose, fibreglass, or mineral wool insulation.

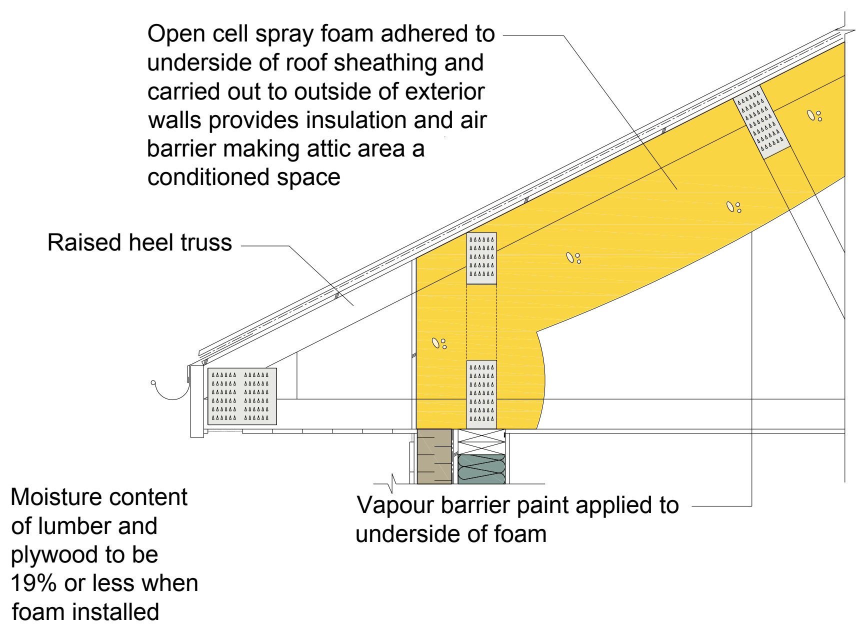

Figure 4-36. Pitched-roof attic assembly with open-cell spray-foam insulation and an air barrier applied to the underside of the roof sheathing. A vapour-barrier paint applied directly on the open-cell spray-foam insulation allows drying to the interior. This is not code compliant and will typically require an alternative solution to satisfy the code requirements in British Columbia.

4.7.2 Open or Cathedral Ceilings

4.7.2.1 Vented

Deeper wood I-joists, i.e., in the range of 508 mm (20 inches) deep; open web joists; or scissors trusses can be used to provide open-ceiling assemblies with enough depth to use blown-in, spray, or batt insulations at levels in the range of RSI-10.6 (R-60), which would meet the requirements for high-performance housing (Figure 4-37). These assemblies will have enough depth to also provide for ventilation above the insulation. For higher insulation levels, additional insulation can be placed on the underside of the ceiling joists in the form of cross strapping with batt insulation or rigid insulation. Using foil-faced isocyanurate or XPS in this application would allow the inside layer of insulation to act as the vapour barrier, and if all the joints and penetrations in the foam board are taped with a durable compatible tape, they could form the ceiling air barrier (Figure 4-38).

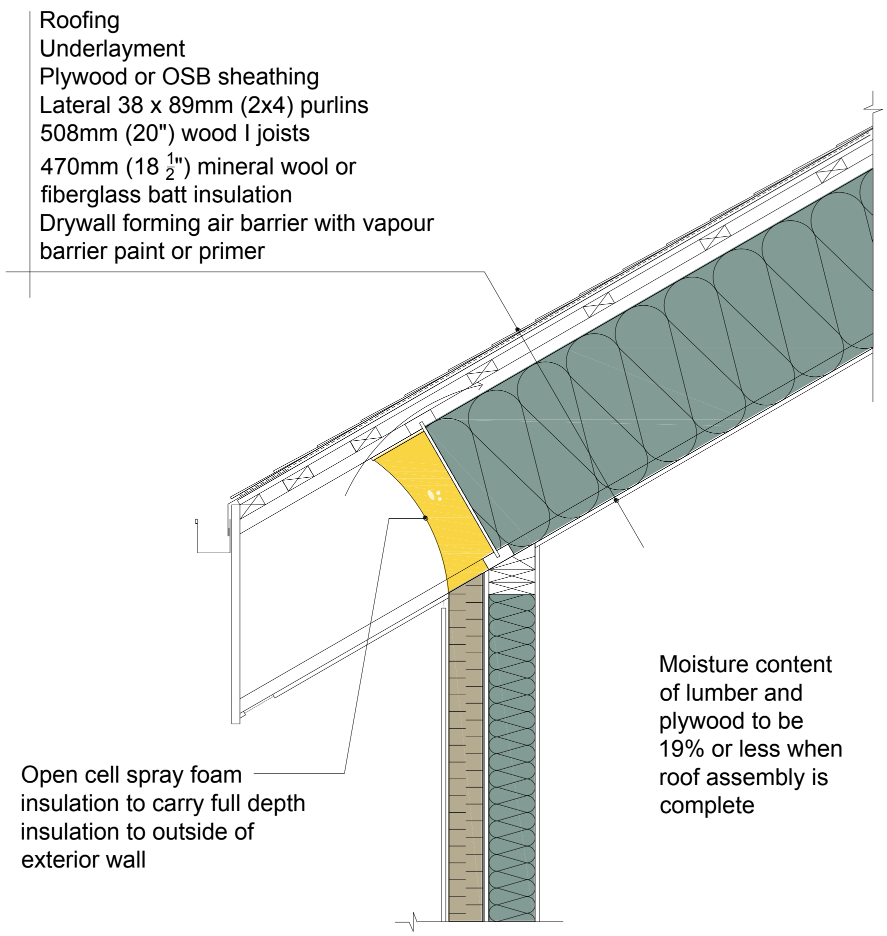

Figure 4-37. Open-sloped roof constructed with a deep, wood I-joist and cross venting above insulation. Effective insulation value is in the RSI-10.56 (R-60) range.

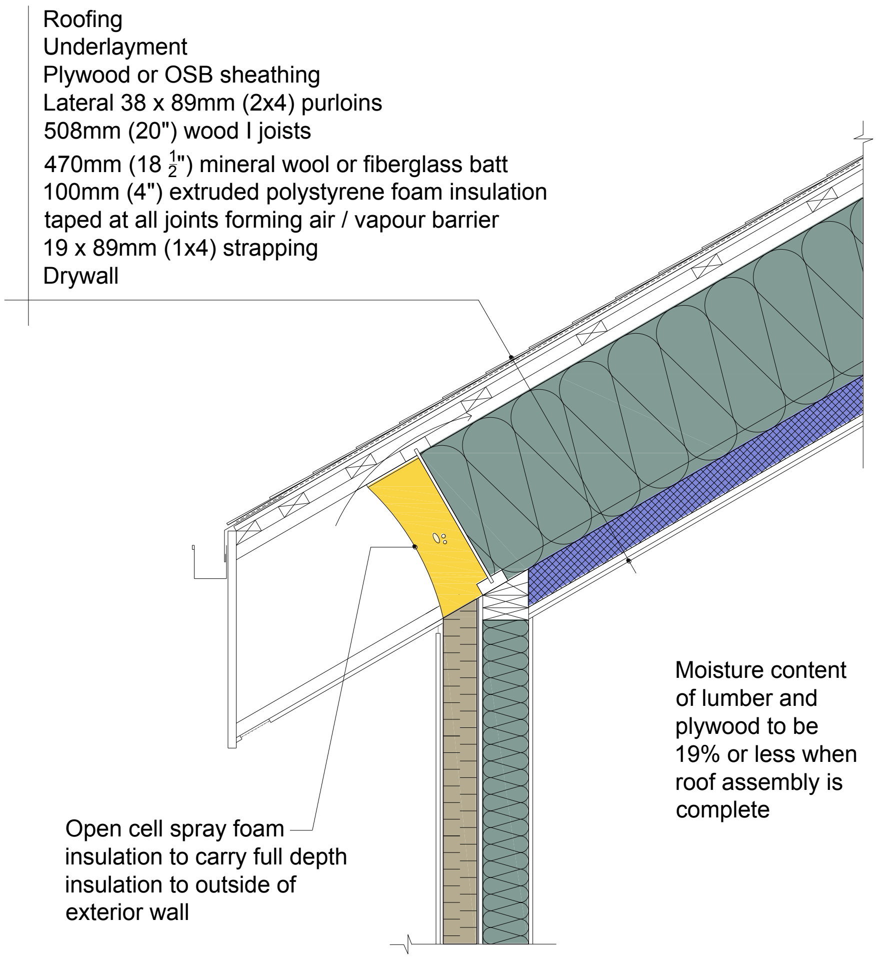

Figure 4-38. Open-sloped roof using a deep, wood I-joist, cavity batt insulation; and XPS below; with cross venting above the cavity insulation. Effective insulation value is in the RSI-14 (R-80) range.

4.7.2.2 Joist Cavity Fill

In order to attain higher insulation values in open ceilings using dimension lumber or wood I-joists, one approach is to fill the joist cavity with insulation, and then place a vapour-permeable rigid insulation over the roof structural sheathing (Figure 4-39 and Figure 4-40). To secure the rigid insulation, 19x89-mm (nominal 1x4-inch) strapping is installed in line with the ceiling joists anchored through the insulation into the joists. 19x89-mm (nominal 1x4-inch) cross strapping is then fastened to the original strapping; this in turn supports a metal roof with a capillary break, underlayment, and roof sheathing beneath, or a roof sheathing and shingle roofing system. The permeable rigid insulation reduces thermal bridging and allows for drying to the exterior, and the strapped cavities provide a pathway for ventilation and potential drainage.

Structural insulated panels (SIPs), as discussed previously in the wall section (see Section 4.6.1), consist of two skins of OSB or plywood, and a core of EPS or urethane foam that is bonded to the skins. SIP panels can also be used for roofs in a variety of configurations.

As with all other elements in the exterior envelope, the joints and penetrations of a SIP roof must be made airtight to prevent condensation and to save energy. Figure 4-41 illustrates one example of SIPs being used for a roof.

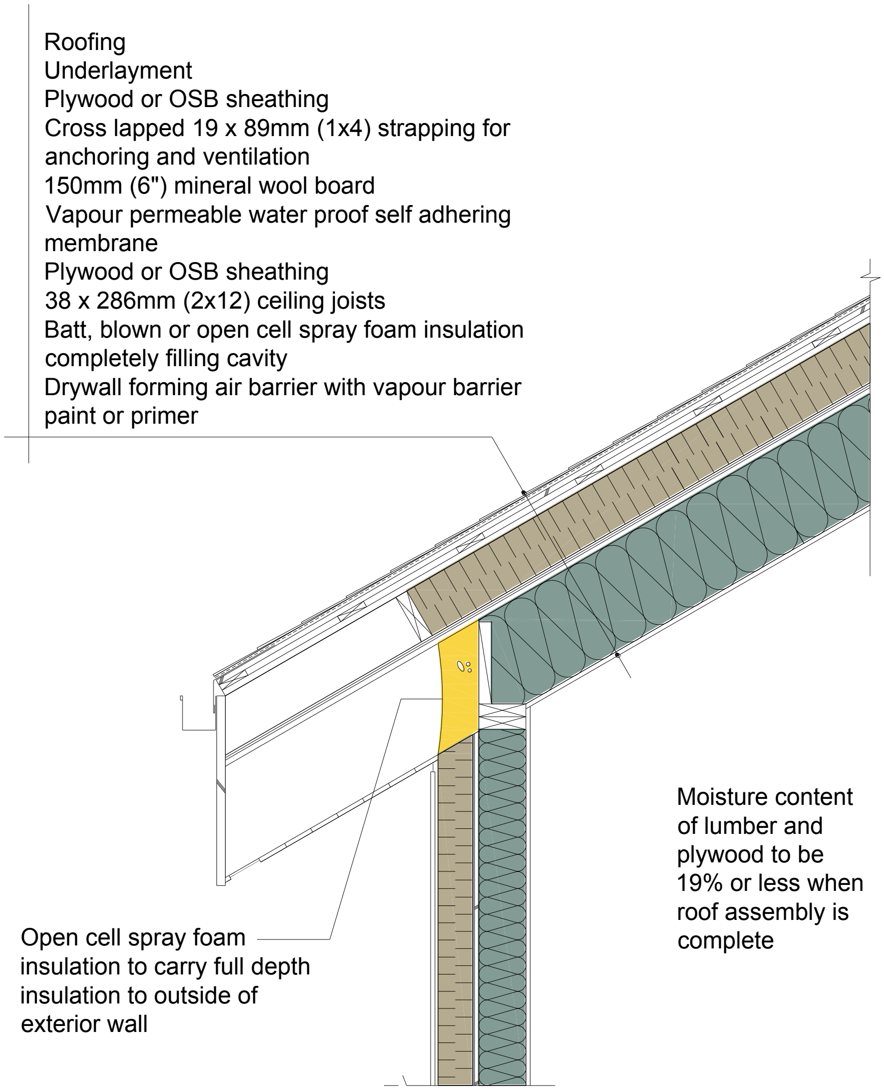

Figure 4-39. Open ceiling constructed with framing lumber, cavity insulation, and exterior insulation. The mineral wool board insulation allows drying of the roof structure to the exterior while providing a thermal break and raising the temperature of the framing. Effective insulation value is in the RSI-10.56 (R-60) range.

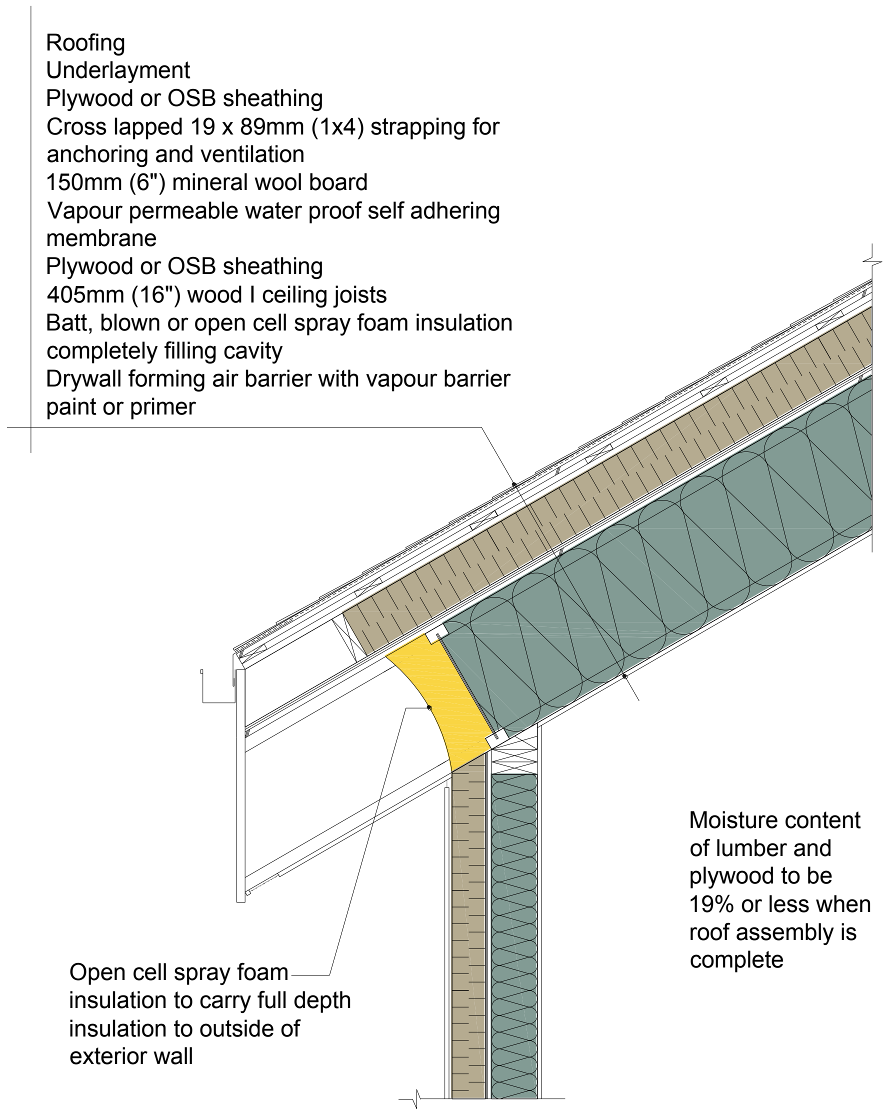

Figure 4-40. Open ceiling constructed with wood I-joists, cavity insulation, and exterior insulation. The mineral wool board insulation allows drying of the roof structure to the exterior while providing a thermal break and raising the temperature of the framing. Depending on the depth of the joists, effective insulation value is in the range of RSI-13.2 to 15.85 (R-75 to 90).

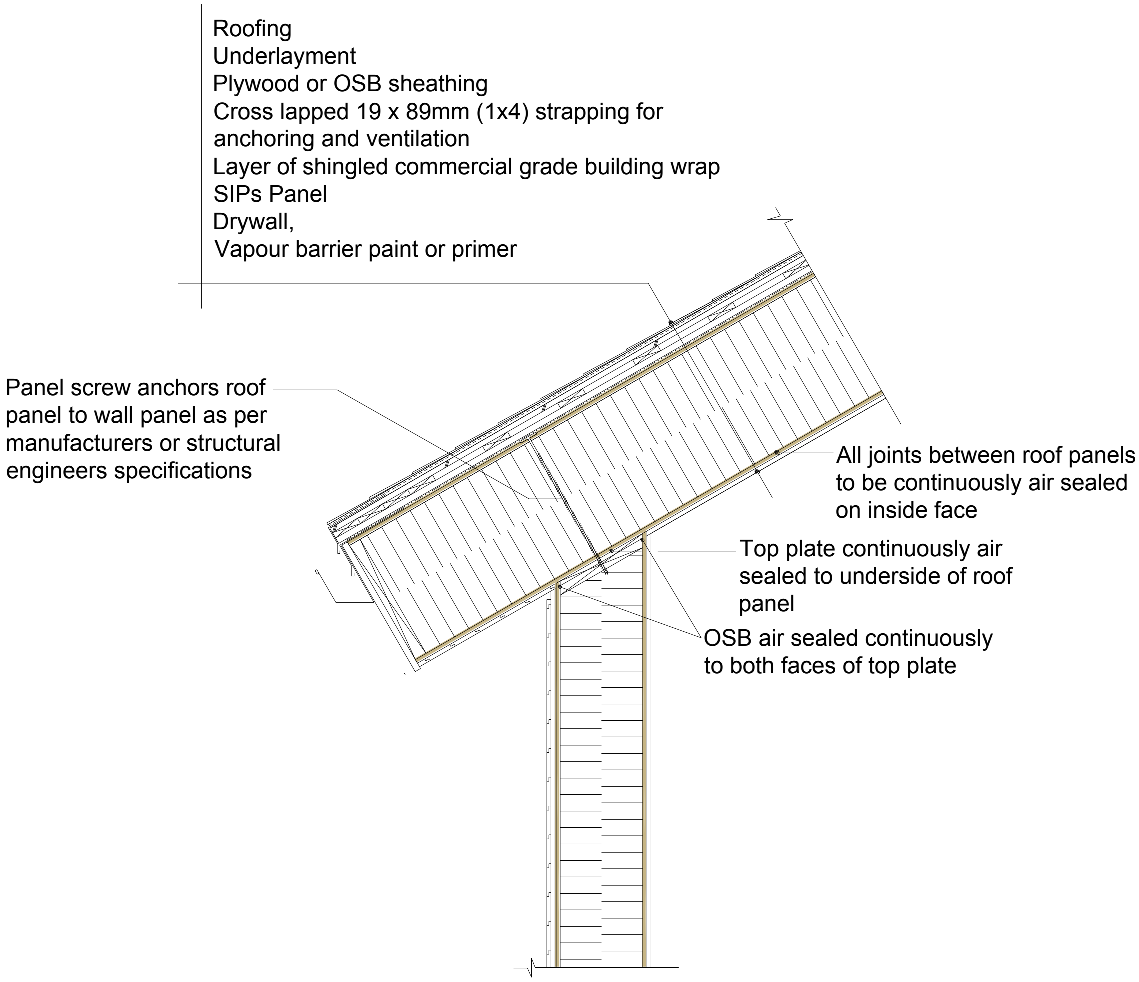

Figure 4-41. Open ceiling using SIP panels.

4.8 Exposed Floors

Cantilevered floors and those located over unconditioned spaces, such as garages, require effective RSI-values (R-values) at least equal to exterior walls. This will typically involve the use of insulations within the framing combined with insulated sheathings (Figure 4-42). Occupants often complain that exposed floors are uncomfortably cold. This is due to the fact that people come in direct contact with floors through their feet and that thermal bridging through framing will reduce the surface temperature of the floor. Exposed floor assemblies that incorporate thermal breaks, such as insulated sheathings, will be more effective at providing a comfortable thermal environment. Refer to Appendix N which contains tables of exposed floor assemblies and effective RSI-values (R-values) for high-performance housing. In most exposed floors the subfloor sheathing is sealed at all joints and penetrations to form the air barrier and the vapour barrier.

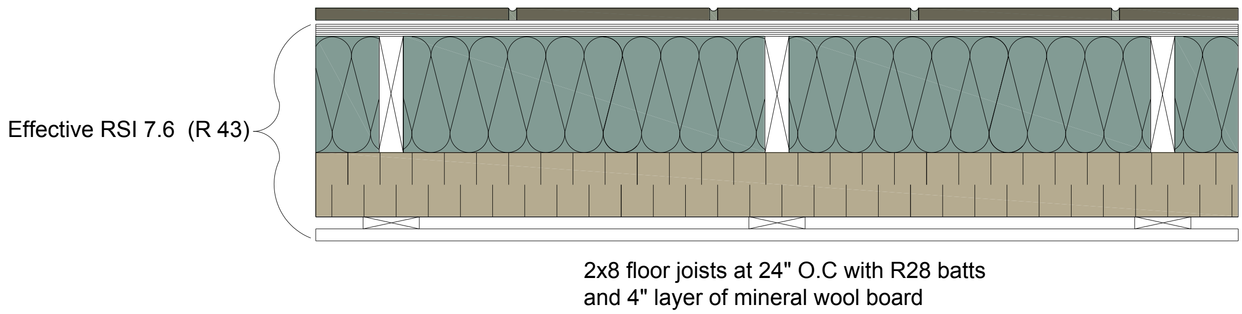

Figure 4-42. Cross section through exposed-floor assembly using batt insulation and mineral wool exterior insulated sheathing.

4.9 Windows, Glass Doors, and Skylights

Windows, glass doors, and skylights fulfill multiple functions in high-performance housing, including:

- providing access to views
- providing interior illumination
- providing ventilation and natural cooling
- providing solar heat gain in winter
- controlling solar heat gain in summer

They also provide similar functions to walls in that they must resist heat losses in winter and heat gain in the summer, and resist wind and wind-driven rain penetration all year round. Heat is transferred through windows by conduction, convection, and radiation (Figure 4-43). The technologies used in high-performance window construction are focused on controlling those mechanisms of heat flow.

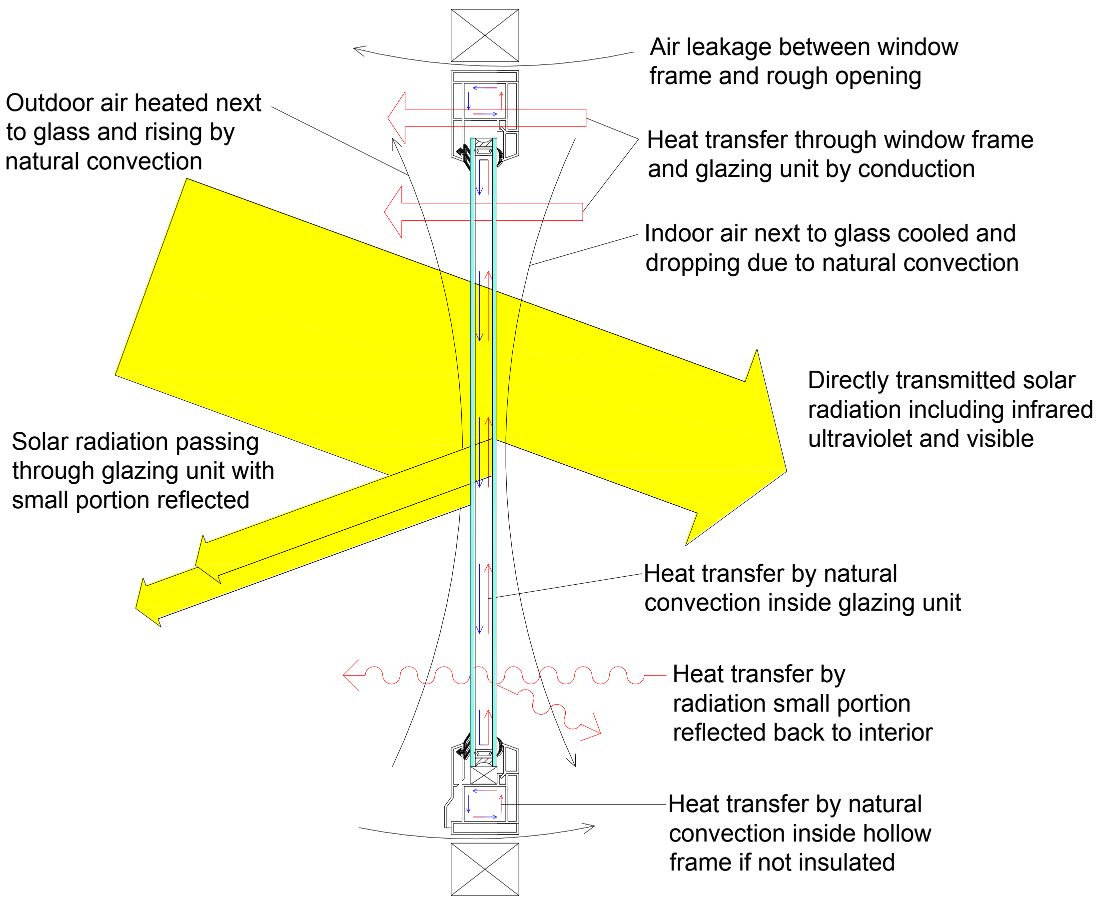

Figure 4-43. Heat gains and losses through a southward-facing window during the heating season, due to convection, conduction, and radiation.

4.9.1 Windows

4.9.1.1 Characteristics

The windows used most commonly in high-performance housing typically have the following characteristics (Figure 4-44):

- Low-conduction frame and sash – Low-conduction frame materials include wood, pultruded fibreglass with foam fill, uPVC vinyl (with fibreglass reinforcing), and foam-filled core. Some high-performance window frames utilize sandwich construction that layers conventional frame materials, such as wood, with strips of foam plastics which then may be partially or fully encased in a protective layer of aluminum or vinyl.
- Multiple glazing – Triple or quadruple glazing consisting of glass, or glass plus plastic films, provide multiple transparent layers. To each glazing is attached a thin layer of air or other gas that provides a thermal resistance.
- Low-emissivity coatings – These are thin metal coatings applied to the glass and plastic films. The coatings can be formulated to control the type of solar radiation (i.e., visible light, infrared radiation, and ultraviolet light) they let pass or reflect. Low-emissivity coatings designed to maximize solar heat gain in winter will let the full solar spectrum

through while reflecting infrared or heat radiation. After sunlight enters and heats the home interior, the heated interior emits infrared radiation that is reflected back inside when it attempts to pass back through the window. Cooling low-emissivity coatings reject those parts of the solar spectrum that contribute to heating the interior but let through 60 to 70% of the visible light.

- Inert gas fill – Inert gases such as argon (the most common), krypton, and xenon are used to replace air between the glazing layers. These gases have lower conductivity than air and thereby increase the thermal resistance of the glazing assembly.
- Insulated spacers – The spacer bars that separate the glazing layers are made of low-conductivity material to resist heat flow around the perimeter of the insulated glazing unit. These spacers are made of such materials as stainless steel, silicone foam, aluminum with a polyurethane break, and plastics.
- Casement assemblies – Casement windows and doors provide the most airtight seal of all operable windows and doors and are used in preference to sliders.
- Weatherstripping – High-quality, durable weatherstripping is essential for doors and operable windows in order to provide airtight seals over time.
- High-performance hardware – Door and window hardware, such as multipoint locking systems, ensure that the opening sash is held tightly against the window or door frame and that it effectively compresses the weatherstripping.

4.9.1.2 Performance and Impacts on Wall Performance

A number of terms are used to describe the energy-related performance of windows and window components.

- Solar heat gain coefficient – This is the fraction of solar radiation admitted through a window or skylight. It is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits, and the greater its shading ability. Solar heat gain coefficient can be expressed in terms of the glass alone or it can refer to the entire window assembly.
- U-value – This is a measure of the rate of non-solar-related heat gain or loss through a material or assembly. It is the inverse of the thermal resistance (RSI-value or R-value) and is expressed in units of $W/m^2 \times °C$ (Usi) or $Btu/h \times ft^2 \times °F$ (Uip). U-values are normally given for winter conditions of −18°C (0°F) outdoor temperature, 21°C (70°F) indoor temperature, 24 km/h (15 mph) wind, and no solar load. The U-value may be expressed for the glass alone or the entire window, which includes the effect of the frame and the spacer materials. This is referred to as the effective U-value of the window. The lower the U-factor, the greater a window's resistance to heat flow, and the better its insulating value.
- Centre-of-glass U-value – This is the U-value calculated for the centre area of the glazing unit, not accounting for the effects of the spacer bar and frame. In many high-performance windows, the centre-of-glass U-value is lower than the overall U-value, where the spacer bar and frame are taken into account. When reviewing the performance of a window, it is important to know what is being quoted: the effective U-value of the entire window or the centre-of-glass U-value. For marketing reasons, sales people and manufacturers may only talk about centre-of-glass U-value or

RSI-values (R-values), when in fact the overall effective U-value or RSI-value (R-value) is a more accurate description of a window's performance.

- Visible transmission (VT) – This is the percentage or fraction of the visible spectrum (380 to 720 nanometres) weighted by the sensitivity of the eye, that is transmitted through the glazing.
- Emissivity (e) – This is the ratio of the radiant energy emitted by a material to that emitted by a blackbody (perfect emitter) at the same temperature and under the same conditions. Emissivity is expressed as a value between 0 and 1; 0 represents no emissivity and 1 represents that of a blackbody. Emissivity of glazing materials is important in window performance because a large portion of heat transfer through a window occurs by radiation.
- Air-leakage rating – This is a measure of the rate of air leakage through a window, door, or skylight assembly in the presence of a specific pressure difference. The lower a window's air-leakage rating is, the better its airtightness and the lower its heat loss in winter and the lower its heat gain in summer. Fixed windows are the typically most airtight. Windows and skylights complying with the newly adopted AAMA/WDMA/CSA 101/I.S.2/A440-08, NAFS—North American Fenestration Standard/Specification for windows, doors, and skylights (commonly referred to as NAFS-08) (American Architectural Manufacturers Association 2008) are tested for air leakage. High-performance housing projects must use windows with a NAFS-08-tested, Canadian Air Infiltration/Exfiltration rate of A3 0.5 L/(s.m^2) and fixed 0.2L/(s.m^2) (American Architectural Manufacturers Association 2008).
- Energy rating (ER) – This value is calculated using a formula that balances a product's U-value with its potential solar heat-gain coefficient and its airtightness. The higher the number, the more energy efficient the product. Energy rating values normally range from 0 to 50. High-performance housing projects will typically use fixed and operable windows with energy ratings between 30 and 50. The energy rating is used only by Canadian manufacturers.

In addition, a window's size and proportions will also influence its thermal performance. Smaller windows have a higher ratio of frame area to glass area than larger windows, resulting in a higher effective U-value (lower RSI-value (R-value)). For this reason it is more thermally efficient to use fewer large windows than many smaller windows in order to provide the same amount of window area. A window's proportions will also influence its thermal performance. For example, a square window will have a lower U-value (higher RSI-value (R-value)) than a rectangular window of the same area (Figure 4-45).

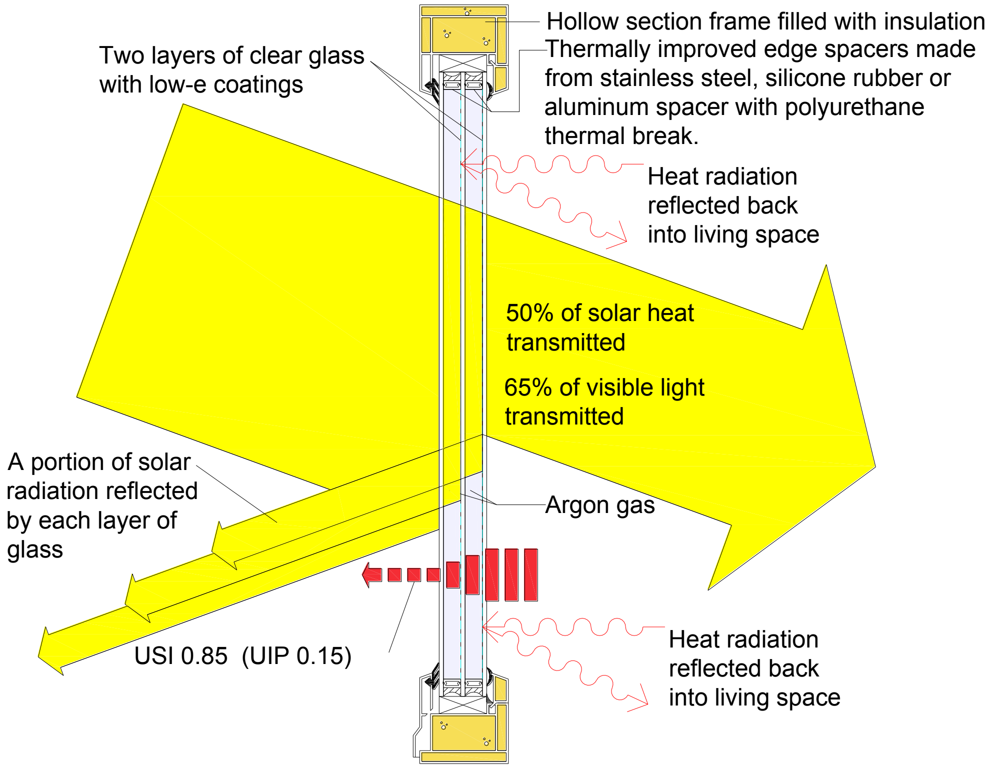

Figure 4-44. Features of a high-performance, triple-glazed window.

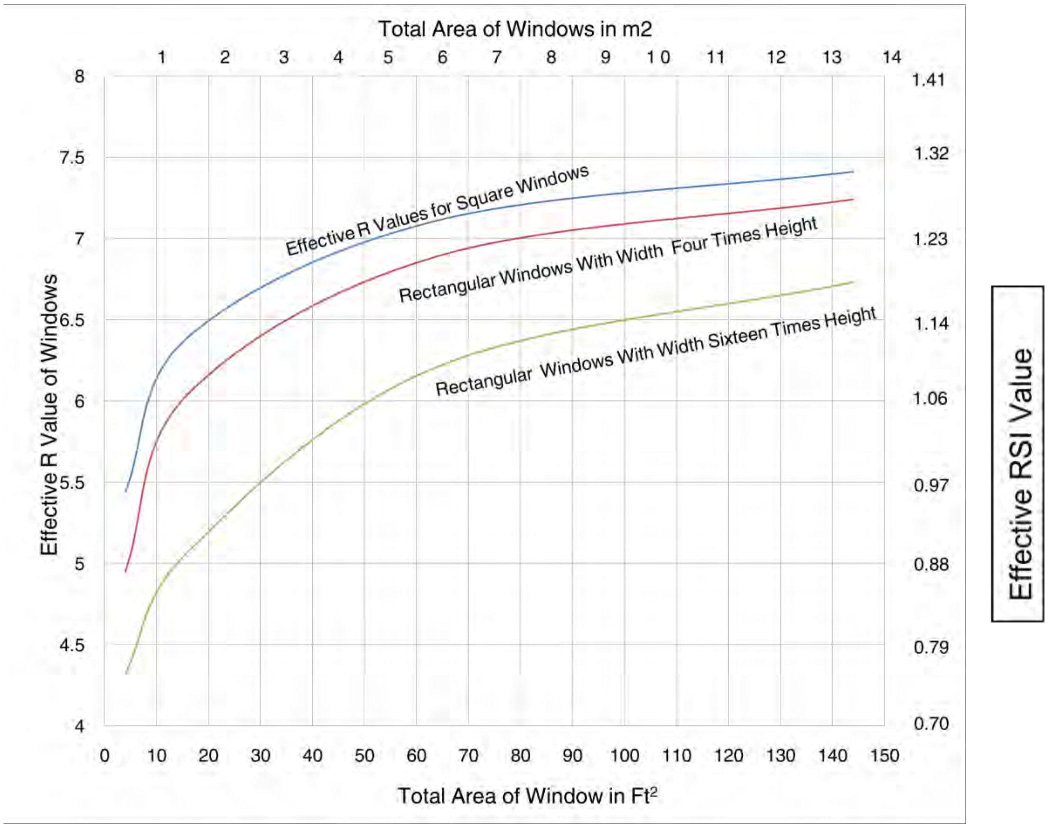

Figure 4-45. Effects of window size and proportion on effective RSI-value (R-value) for a triple-glazed, double, low-emissivity, argon gas fill, insulated spacer, insulated glass unit in a pultruded fibreglass frame. Calculated using window-effective RSI calculation subroutine in HOT2000 Ver. 10.51 (Natural Resources Canada 2010).

The thermal performance of a window, and the ratio of window area to total wall area, have large impacts on the effective thermal resistance of a building façade. As can be seen in Figure 4-46, for a highly insulated double-stud wall, the overall effective thermal resistance of a building façade drops quickly as the window area increases. For example, for an RSI-0.53 (R-3) window, when the window is 10% of the total façade area, the wall's total effective thermal resistance drops by 60%. Using higher-performance windows significantly changes this with the same highly insulated wall. For example, when a window with an effective RSI value of 1.4 (R-8) is used instead, the effective thermal resistance of the entire wall drops by only 33%.

The thermal performance of windows used in high-performance housing is usually in the range of U_{si} 0.94 to 0.71 (U_{ip} 0.17 to 0.125) (otherwise expressed as thermal resistance RSI-1.06 to 1.4 (R-6 to 8)) for centre of glass, and U_{si} 1.25 to 0.94 (U_{ip} 0.22 to 0.17) (otherwise expressed as thermal resistance RSI-0.80 to 1.06 (R-4.5 to 6)) for the entire window assembly. The visible light transmission is typically in the range of 60 to 70% (Figure 4-44). Types of windows and their exact specifications are determined at the design stage through energy analysis modelling, costing, and in consultation with window suppliers.

Generally speaking, sashless (i.e., picture) windows will be more energy efficient than windows with sashes (i.e., casement, awning, fixed, etc.) because the glazed portion of the window usually performs better than the frame and the frames in sashless windows make up a smaller percentage of the window's total area. In addition, sashless windows cost 25 to 50% less than equivalent-sized sash windows because the sash, hinges, and other hardware are not required.

An ENERGY STAR standard has been developed for windows based on Canada's four climate zones (Natural Resources Canada 2010b); three of those climate zones exist in British Columbia. ENERGY STAR windows must meet the minimum prescribed standards for the particular zone in which they are installed. Technical information about ENERGY STAR windows is available from the NRCan's Office of Energy Efficiency.[11] A good resource for identifying windows by their performance is the NRCan ENERGY STAR database on the same website. For an extensive discussion of window technologies refer to *Residential Windows* (Carmody et al. 2007). The Efficient Windows Collaborative[12] is also a very helpful source of information on window technologies. Useful information can also be found in an Energy Rating review report for selecting energy efficient windows and doors (RDH Building Engineering 2013).

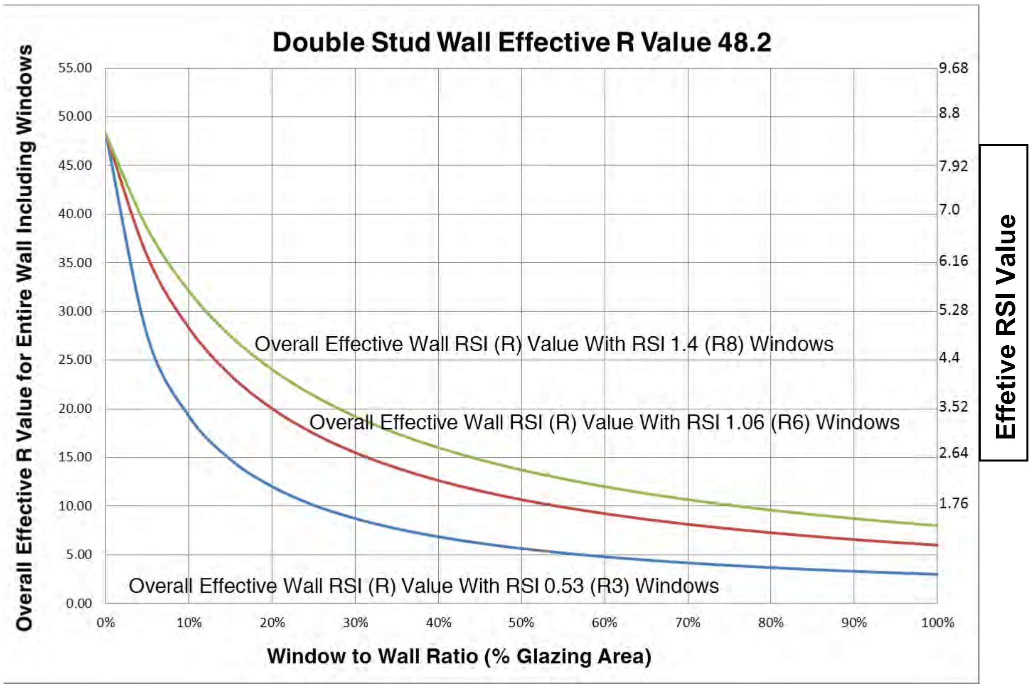

Figure 4-46. Comparison of the effective RSI (R) values of an entire building façade constructed with RSI-8.48 (R-48.2) double-stud walls and windows with effective thermal resistances of RSI-0.53 (R-3), RSI-1.06 (R-6), and RSI-1.4 (R-8).

4.9.2 Glass Doors

Glazed doors essentially function like operable windows and are rated in the same way windows are rated. Due to the need for airtightness, only casement-type glazed doors, or glass sliding doors that are mounted with "pop in" hardware that allows for compression of gaskets, should be considered for use in high-performance housing projects. Multipoint locking hardware will further enhance the airtightness of glass doors.

4.9.3 Skylights

Skylights can play an important role in providing daylight illumination, as well as natural cooling and ventilation if they are operable. They will typically provide greater illumination than windows of the same size, and even a small skylight can be make a significant contribution to daylight illumination of a room. Care must be taken in the orientation, selection, and installation of a

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[11] See https://www.nrcan.gc.ca

[12] See www.efficientwindows.org.

skylight to ensure that it minimizes heating and cooling loads while still providing daylighting and ventilation benefits. Skylights should be located on north-sloping roofs unless they incorporate exterior shading. This provides the best-quality daylight illumination, at a constant level over the day, and prevents overheating due to direct sunlight penetration that occurs with skylights oriented in other directions. Heat losses through skylights tend to be higher than heat losses through windows of an equivalent area and construction. Movement of indoor air by natural convection due to the sloped or horizontal colder interior surface of a skylight tends to be more pronounced than that which occurs due to heat losses through vertical windows. In addition, on clear nights, heat losses through a skylight due to radiation to the night sky will tend to be higher than heat losses through a window. In most cases, the energy-efficiency technologies for skylights are the same as those for windows, i.e., using thermally improved spacers, multiple glazing layers, low-emissivity coatings, inert gas fills, and low-conduction frames. One area of difference is in diffuse skylights, which provide just illumination and no views. In these types of skylights, technologies such as transparent honeycombs and aerogels[13] can be used to lower the U-value (thus raising the RSI-value (R-value)) of the assembly. Using these technologies, the centre-of-glazing thermal resistances are in the range of RSI-0.88 to 3.17 (R-5 to 18), with visible light transmission in the range of 10 to 45%.

Skylights come in three types:

- Flat, glazed skylights – These are available in double glazed with one low-emissivity coating, and as triple glazed with two low-emissivity coatings, plus as glazing units that encase honeycombs and/or aerogels. Frames are made of wood or vinyl, which are usually covered with sheet-metal flashings, fibreglass, or aluminum extrusions. These typically incorporate an internal condensation gutter at the frame perimeter that drains through weep holes. Opening units are either electrically operated, or manually operated. Some are available with rain sensors and will automatically close when rain falls. For high-performance housing, where possible, triple-glazed units or skylights that use transparent insulations should be used to minimize heat losses. Skylight frames of wood, foam-filled vinyl, or pultruded fibreglass will reduce heat losses at the perimeter of the skylight.
- Tubular skylights, also known as tubular daylighting devices – These utilize a clear acrylic dome or flat glass cover, a shaft made of sheet-metal pipe that is 254 to 356 mm (10 to 14 inches) in diameter with a highly reflective interior and an acrylic ceiling diffuser. These are commonly used for illuminating interior rooms, closets, and bathrooms. Where the tube passes through the ceiling air barrier, there must be an airtight seal. The seam in the tube must be air sealed and where the tube passes through unheated attic spaces it must be insulated to the same levels as exterior walls. Some manufacturers supply dual interior diffusers to reduce heat losses, thereby raising the surface temperature and reducing condensation.
- Circular- and rectangular-based acrylic dome skylights – These are available in double-glazed models, and in some cases triple-glazed models. Low-emissivity coatings are not available with acrylic, and therefore the thermal resistance of these types of skylights is

[13] Aerogel is among the lightest and most effective insulating materials currently available. It is a solid that consists largely of air (greater than 90%) contained in a structure with pore sizes less than the mean free path of air molecules, which severely inhibits heat transfer through the material. This material has an RSI/mm of 0.055 to 0.56 (R-8 to 10/inch) and can very effectively diffuse light.

lower than flat, glazed, glass skylights that have low-emissivity coatings and the same number of glazing layers. Acrylic skylights are available with tinted glazings to provide solar control.

Skylights can be mounted in three different ways:

- Flush mount – A flush-mounted skylight is placed on the roof deck with no curb. It is overlapped by and sealed to the roofing material. However, this is not a recommended detail, because it is hard to maintain.
- Curb mount – A curb-mounted skylight (Figure 4-47) is placed on a curb raised above the roof plane. This type of curb is not supplied with the skylight. The skylight may be fixed or operable. Curb-mounted skylights, rising 150 to 300 mm (6 to 12 inches) above the roof, create additional heat-loss surfaces right where the warmest air of the home tends to collect. Care should be taken in detailing this area to ensure it is insulated and that the connection to the skylight is airtight.
- Integral curb – In this case, the curb is supplied with the skylight as a complete unit. The skylight may also be fixed or operable. Some manufacturers provide a curb that is prefabricated out of rigid insulating foam.

When a skylight is installed in a ceiling, the seal between the rough opening and the skylight frame must be made airtight with sealants and backer rods, or with spray-foam insulation. If a skylight is installed at the top of a shaft that passes through an unheated attic space, the walls of the shaft must be insulated and made airtight to the same levels as the exterior above-grade walls. Where a skylight is mounted in an open, sloped ceiling, additional insulation must be used to reduce heat losses through the curb.

Skylights are tested for their energy performance using the NAFS-08 standard (American Architectural Manufacturers Association 2008). An ENERGY STAR standard has been developed for skylights based on the four climate zones across Canada (Natural Resources Canada 2010b); three of those climate zones exist in British Columbia. ENERGY STAR skylights must meet the minimum prescribed standards for the particular zone in which they are installed.

Technical information about ENERGY STAR skylights is available from NRCan's Office of Energy Efficiency.[14] A good resource for identifying skylights by their performance is the NRCan ENERGY STAR database on the same website.[15]

[14] http://www.nrcan.gc.ca/energy/products/for-participants/specifications/13720

[15] http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.search-recherche&appliance=SKYLIGHTS

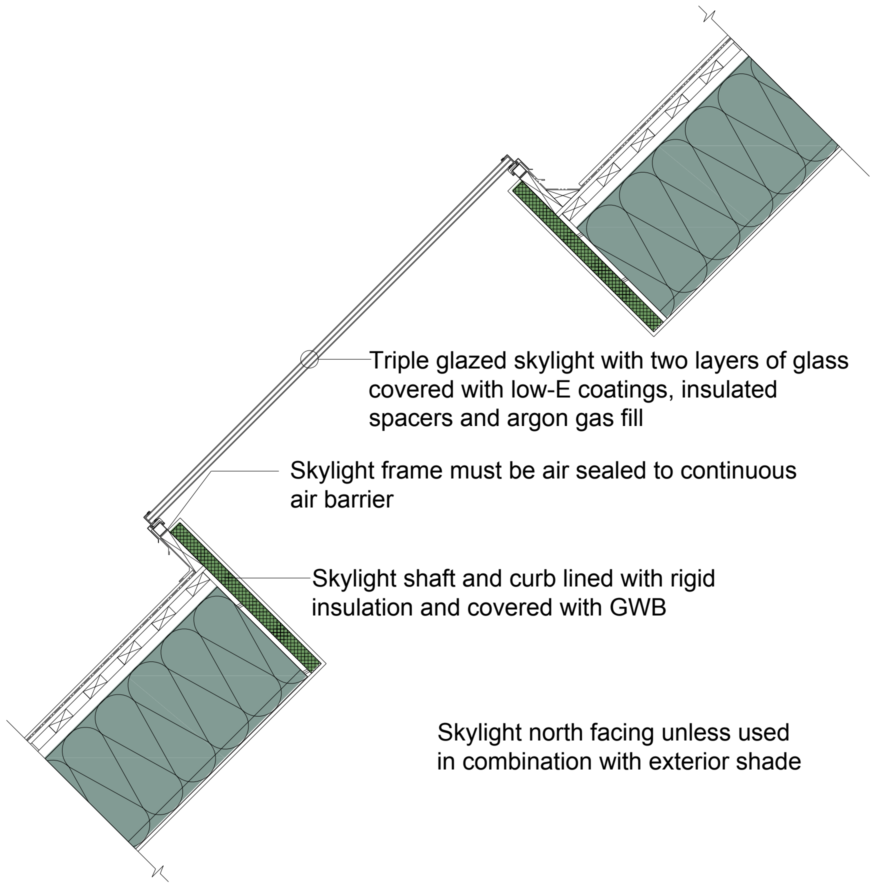

Figure 4-47. Energy-efficient skylight.

4.10 Exterior Doors

Heat gains and losses through doors occur due to:

- conduction through the door frame
- conduction through the door panel
- air leakage between the rough opening and the frame
- air leakage between the door panel and the door frame
- conduction, convection, and radiation through any glazed portion of the door panel or side lights

Much of the heat loss or gain through a door will occur through the door panel itself. Solid wood doors will have insulating values ranging between RSI-0.35 and 0.44 (R-2 and 2.5). Composite wood, metal, or fibreglass-clad doors often have improved thermal performance due to the integration of insulation layers. An exterior storm door may be added to provide additional R-values.

To minimize air leakage between the door frame and the rough opening, a combination of a durable sealant and backer rod should be used, and particular attention should be given to the continuity of airtightness and the cladding capillary break. To minimize air leakage between the door panel and the door frame, good-quality compression weatherstripping and sweeps must be used that will adapt to annual warping of the door panel than can occur due to moisture and temperature changes. The sill of the rough opening should be treated in a similar manner to windows, i.e., equipped with a waterproof membrane to direct water out if it penetrates the door frame. Windows within the door, side lites, and transom lites should be constructed the same or in a similar manner to all the other windows used in the home.

Doors are tested for their energy performance using the NAFS-08 standard (American Architectural Manufacturers Association 2008). Door manufacturers are required to label their products with the results of this testing. An ENERGY STAR standard has also been developed for exterior doors.[16] A good resource for identifying doors by their performance is the NRCan ENERGY STAR database.[17]

For information about the building envelope detailing of exterior doors, refer to *Building Envelope Guide for Houses—Part 9 Residential Construction* (Homeowner Protection Office 2007).

For more information on building envelope design and detailing see the *Building Enclosure Design Guide—Wood-Frame Multi-Unit Residential Buildings* (Homeowner Protection Office 2011), and the *Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America* (Finch et al. 2013).

[16] See http://www.nrcan.gc.ca

[17] See http://www.nrcan.gc.ca

Chapter 5 – Space Heating, Ventilation, and Water Heating

5.1 General Considerations

High-performance housing typically uses high-efficiency space-heating systems to further reduce energy consumption, reduce environmental impacts, and, if the home is to be net-zero energy, to reduce the size of the renewable energy system that will power the space-heating system or compensate for the fuels used in the heating system. The space-heating systems will be smaller than systems used in conventional housing due to the significantly lower heating requirements of a high-performance home. Depending on the heating system used, savings in the capital cost of heating equipment and the heating distribution system may help to offset the additional costs of the high-performance building envelope and the use of a heat-recovery ventilation system. Some considerations to keep in mind when selecting the heating plant and distribution system include:

- Sizing – The furnace, boiler, heat pump, or baseboards should be sized as closely as possible to the design heating requirements of the home (i.e., not oversized). This will minimize cycling of the equipment and increase operating efficiency.
- Location of supplies – In a high-performance home the windows are high performance and the walls, floors, and ceilings are super insulated, therefore the heating system supply grilles, convectors, baseboards, or radiators can be located in more places in the room than is the case with conventional construction. They do not have to be located under windows. This can result in shorter distribution runs and provide greater flexibility for furniture placement. In the case of forced-air-heating systems, supplies are often located high in interior partition walls.
- Compatibility – Compatibility of the heating system with the passive solar heating system needs to be taken into account. Passive solar heating relies on heating the structure of the building to store energy from day to night. For this reason, a radiant-floor heating system should not be used in rooms that receive large amounts of passive solar heat gains, although radiant-floor heating could still be used elsewhere in the home. Another example, a forced-air heating system can complement passive solar heating by redistributing heat gains from south-facing rooms to the rest of the home. This involves locating return-air grilles in the larger south-facing rooms and programming the air handler or furnace fan to operate when the air temperature in those rooms rises 4°C above that of the north-facing rooms.
- Trained installers – Heating equipment and systems are best installed and maintained by qualified HVAC contractors who have successfully completed specific training, such as the Quality First™ training programs offered by the Thermal and Environmental Comfort Association (TECA).[18,19]

[18] See http://www.teca.ca/.

[19] Also, a residential HRV installation and design guide is in development by the Homeowner Protection Office, Branch of BC Housing.

5.2 Heating Systems

5.2.1 Natural-Gas Forced-Air Heating

Natural-gas, forced-air heating systems include high-efficiency, modulating, condensing gas furnaces. These furnaces utilize burners that vary output to more closely match the heating load. The hot-air-distribution fan must utilize an electrically commutated motor to minimize electrical power consumption and the production of waste heat that could lead to overheating in the summer.

The energy-efficiency performance for a gas-fired furnace over a heating season is called the annual fuel utilization efficiency (AFUE). The higher the percentage, the more efficient the furnace is. Condensing gas furnaces typically have AFUEs in the range of 90 to 98%.

Specific information about high-efficiency residential gas furnaces is available from the Consortium for Energy Efficiency (CEE). [20] The most efficient furnaces will be listed as Tier 3 units.

They are referred to as condensing gas furnaces because they use a secondary heat exchanger that extracts so much heat out of the exhaust gases that the water in the exhaust gases condenses. This releases additional heat as the water vapour goes through a phase change from vapour to liquid. The condensate must then be drained. The low temperature of the flue gases allows the use of plastic pipe which can be vented through the roof or a wall.

In a sealed combustion furnace, outside air is piped directly to the combustion chamber; the furnace does not draw air from inside the home for either combustion or vent gas dilution. In addition, sealed combustion furnaces typically use a draft-inducer fan to force the flue gases out of the flue. The advantage of sealed combustion is that it isolates the combustion air system from the home so that the furnace is not affected by the operation of other appliances in the home. The tight construction of an energy-efficient home, combined with the operation of exhaust fans, such as in the kitchen range hood and the clothes dryer, could potentially cause spillage of flue gases (backdrafting) by naturally aspirated combustion equipment, but sealed combustion units prevent this potential safety problem from occurring.

Most high-efficiency furnaces are designed as sealed combustion systems, and therefore are well suited to the tight construction of a modern energy-efficient home.

Due to the low heating requirements of high-performance homes, many standard furnaces will be oversized, particularly for small- and mid-sized homes. This issue will have to be recognized and accounted for by the HVAC contractor in the selection of heating equipment.

5.2.2 Natural-Gas Hydronic Heating

High-efficiency, modulating, condensing gas boilers are also available and can supply both domestic hot water and space heating. Many of these units are very compact and can be wall mounted. For high-efficiency boilers, the AFUEs typically range from 90 to 96%.

Specific information about high-efficiency residential gas boilers is available from the Consortium for Energy Efficiency (CEE). [21] The most efficient boilers will be listed as Tier 2 units.

Condensing gas boilers employ either a naturally aspirating burner with an induced draft fan or a power burner. They also have an additional heat exchanger made of corrosion-resistant

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[20] See http://library.cee1.org/content/natural-gas-residential-furnaces-qualifying-products-list/.

[21] See http://library.cee1.org/content/natural-gas-residential-boilers-qualifying-products-list/.

materials (usually stainless steel) that extracts latent heat from water contained in the flue gases by condensing the water before it is exhausted. A conventional chimney is not needed, and because the flue gas temperature is low, the gases can be vented through a plastic pipe, which should always be vented through the roof.

A condensing boiler can have an AFUE rating of 90% or higher. Achieving these high efficiencies requires not only an efficient boiler but also the correct heating system design. For the condensing boiler's heat exchanger to extract the latent heat effectively and attain the highest operating efficiency, the system has to run with the lowest possible return water temperatures, preferably not exceeding 45 to 50°C (113 to 122°F). Residential applications that help reduce the return water temperatures include radiant-floor heating and pool-water heating.

Due to the low heating requirements of high-performance housing, many standard boilers will be oversized, particularly for small- and mid-sized homes. This issue will have to be recognized and accounted for by the HVAC contractor in the selection of heating equipment. More information related to hydronic heating for low-energy and net-zero houses is available in the literature (such as, Siegenthaler and Patent 2012).

For radiator systems, there are some techniques that may make it possible to lower the return water temperature including:

- Use an outdoor reset controller to lower the supply water temperature in late spring and early fall, to get efficiencies up during these periods. (This method is not effective in the peak heating season.)
- Use a radiator system that has sufficient heat-exchange surface to operate effectively at lower temperatures.
- Use a lower water-pump speed to help lower return water temperatures.
- Use the return water to preheat the water used in the combined space- and water-heating systems.

Boilers designed for space heating can also provide domestic hot water. There are two basic methods:

- Indirect storage – In this type of system a separate, well-insulated tank is heated by the boiler. These systems have substantially reduced heat losses and higher efficiencies compared to tankless coils.
- Tankless coil – In these systems the water is very rapidly raised from the mains supply temperature (about 10°C) to around 60°C. Operating a boiler with a tankless coil like this will reduce the overall energy efficiency of the boiler.

5.2.3 Combined Heat and Power

A combined heat and power system utilizes natural gas or propane to generate electricity and it also uses the waste heat from the power generation process to supply domestic hot-water and space heating. This has the advantage of getting more useful energy out of the fuel than the conventional approach of using a gas furnace or boiler for heating and purchasing electricity from the electric grid. The combined heat and power system is often grid connected so if excess electricity is being produced it can be supplied to the electrical grid. Residential combined heat and power systems are relatively new to Canada, although some installations currently exist.

5.2.4 Electric Baseboards

Some designers and builders choose to use electric baseboard heating in high-performance housing for the following reasons:

- Capital cost is low.
- Maintenance costs are low.
- The low heating loads of high-performance housing can be closely matched with baseboards.
- Baseboard systems are easily zoned on a room-by-room basis, although experience has shown that due to the highly insulated envelopes in high-performance housing, the heat movement through interior partition walls tends to even out temperature differences across a home over a period of time.

Although electric baseboards are very efficient at converting electricity to heat, they are one-quarter to one half as efficient as air-source and ground-source heat pump systems. This can be partially compensated for through the use of higher insulation values in the building envelope. But due to the law of diminishing returns, a home heated with baseboards is not likely to ever meet the same level of performance as a home heated with a heat pump. This becomes a bigger consideration when the goal is to construct a net-zero energy home.

Other considerations to keep in mind with electric baseboard heating is that, unlike forced-air systems, there is no redistribution of solar heat gains, and the burning of settled dust inside baseboards can affect indoor air quality.

5.2.5 Heat Pumps

Heat pumps utilize a vapour compression cycle, like a refrigerator, to extract heat from one area and upgrade and then transfer the heat to another area.

- High-efficiency, cold-climate, air-source heat pumps – The average coefficient of performance for these systems in the heating season is in the range of 2 to 3, meaning for every watt of electricity used to power the heat pump, 2 to 3 watts of heat are produced. They use outdoor air as their source of heat so their performance declines as outdoor temperatures drop. These systems can also be used for cooling in the summer. Heat can be distributed by way of hot water or hot air. With forced-air heating systems the air handler must use an electrically commutated motor in the fan to minimize electricity consumption and the production of waste heat that could lead to overheating in the summer. Air-source, heat-pump, water-heating units can be upsized from space-heating requirements to also provide domestic hot water. Only the quietest exterior units should be used in order to prevent complaints from the neighbours and the occupants. Natural Resources Canada maintains a database of air-source heat pumps.[22] A reference for the most efficient air-source heat pumps is maintained by the U.S. Department of Energy.[23]
- Air-source, ductless heat pumps or mini split systems – These systems consist of an exterior evaporator/condenser unit, refrigeration lines, and indoor condenser/evaporator units that are typically high-wall or ceiling mounted. The interior units re-circulate air within the room while heating or cooling it. Heat is transferred between the interior and

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[22] See http://www.energystar.gov/index.cfm?c=most_efficient.me_cac_ashp.

[23] See https://data.energystar.gov/Government/ENERGY-STAR-Certified-Non-AHRI-Central-Air-Conditi/cker-n33t.

exterior units using refrigerant. These have been widely used in Asia for many years and are becoming increasingly popular in North America.

- Ground-source heat pumps – These systems have a coefficient of performance in the range of 3 to 4, meaning for every watt of energy they consume they produce 3 to 4 watts of heat. They extract heat from the ground, a local body of water, or a well; this requires installation of a ground loop. They are more efficient than air-source heat pumps, and are more expensive to install because of the ground loop(s). Local geological conditions can affect system performance and must be thoroughly investigated before installation. These systems can also supply domestic hot water using a desuperheater. Natural Resources Canada maintains a database about the energy efficiency of ground-source heat pumps.[24]

5.3 Ventilation Systems

In order to ensure high-quality indoor air and control of indoor humidity levels, and to provide ventilation without incurring large heat losses, a central heat-recovery ventilation system is used (Figure 5-1). A heat-recovery ventilator (HRV) continuously draws stale, moist air from the bathrooms and kitchens in the home and exhausts it outside. At the same time the HRV continuously draws outdoor air in and transfers the heat from the exhaust air to the incoming outdoor supply air without mixing. This is done with efficiency, typically in the range of 60 to 70%. The preheated outdoor supply air is also filtered in the HRV and distributed to all the other living spaces around the home. The distribution of the filtered and preheated outdoor air can occur through a forced-air heating system by connecting the HRV's supply duct to the furnace's return-air plenum, or the HRV can supply air through independent supply ductwork and grilles (Figure 5-2; Figure 5-3). Independently ducted systems use less operating energy because only the smaller HRV motors need to operate to provide ventilation. HRV energy consumption can be further reduced by using a HRV that has electrically commutated fan motors. Independently ducted systems also allow supply grilles to be best located for high ventilation effectiveness. HRVs are operated in a balanced mode which means that the amount of air exhausted by the exhaust fan equals the amount of air supplied by the supply fan. This means the home can operate under a neutral pressure differential, thus reducing the possibility of backdrafting by fireplaces, woodstoves, or other naturally aspirated combustion appliances, and reducing the possible entry of soil gases.[25]

In order to gain the full benefits that HRVs have to offer, it is essential that the HRV ductwork is correctly sized and laid out to minimize airflow resistance (friction). All seams and joints in the ductwork must be air sealed and all supply and exhaust grills must be selected and located to provide high ventilation effectiveness and ensure thermal comfort. The exterior supply and exhaust hoods for the HRV must be located to minimize cross contamination and entry of outdoor air pollutants and to ensure easy access for cleaning.

When HRVs are used for whole-house ventilation, conventional range hoods are still used in the kitchen to vent cooking odours, air-borne moisture, and grease. The HRV exhaust grill installed in the kitchen must be located a minimum distance of 1.2 m (4 ft) horizontally from the range in order to minimize grease entry. The HRV typically replaces the bathroom fans for moisture and

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[24] See http://www.energystar.gov/index.cfm?c=most_efficient.me_geothermal_heat_pumps.

[25] Electrical consumption and effectiveness of HRV products are available from the Home Ventilating Institute. See http://www.hvi.org/proddirectory/index.cfm.

odour extraction. When installing a HRV, provision has to be made for drainage because condensate is produced during its operation.

An energy-recovery ventilator (ERV) is similar to a HRV but in addition to transferring heat between exhaust and supply air streams, it also transfers moisture. This has the benefit of minimizing over drying in the winter during colder weather and of dehumidifying the incoming air in summer in hot humid climates if the home is air conditioned.

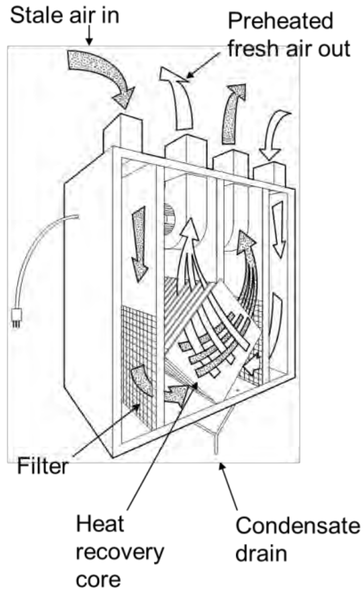

Figure 5-1. A heat-recovery ventilator that extracts heat from exhaust air to preheat incoming air.

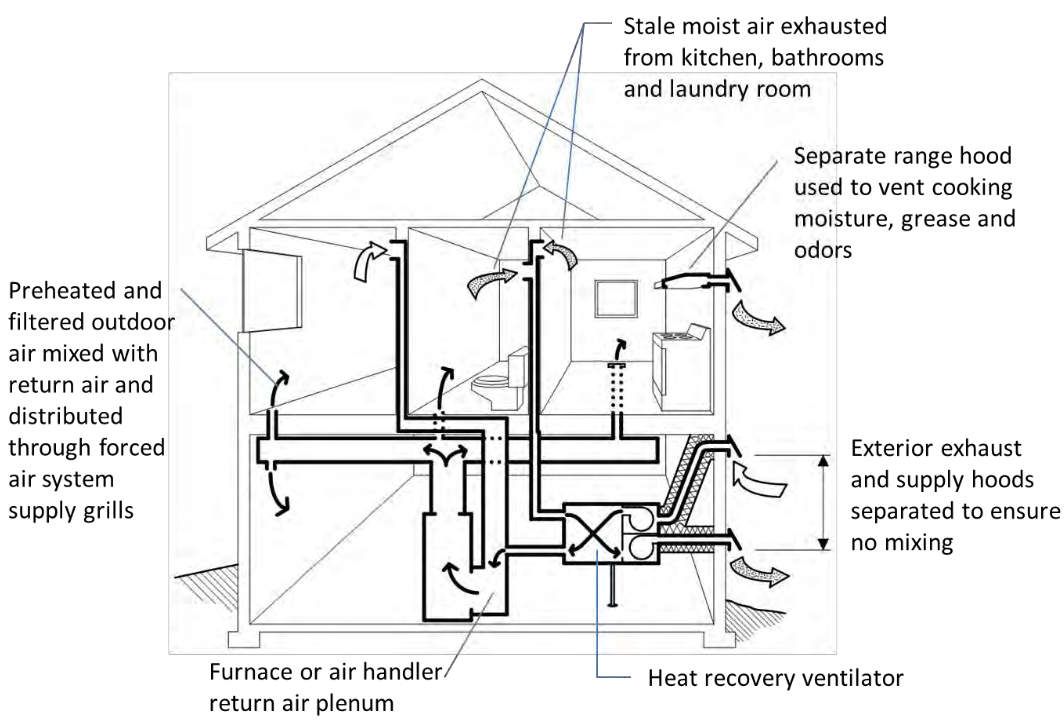

Figure 5-2. A heat-recovery ventilator with a forced-air heating system for distribution of supply air.

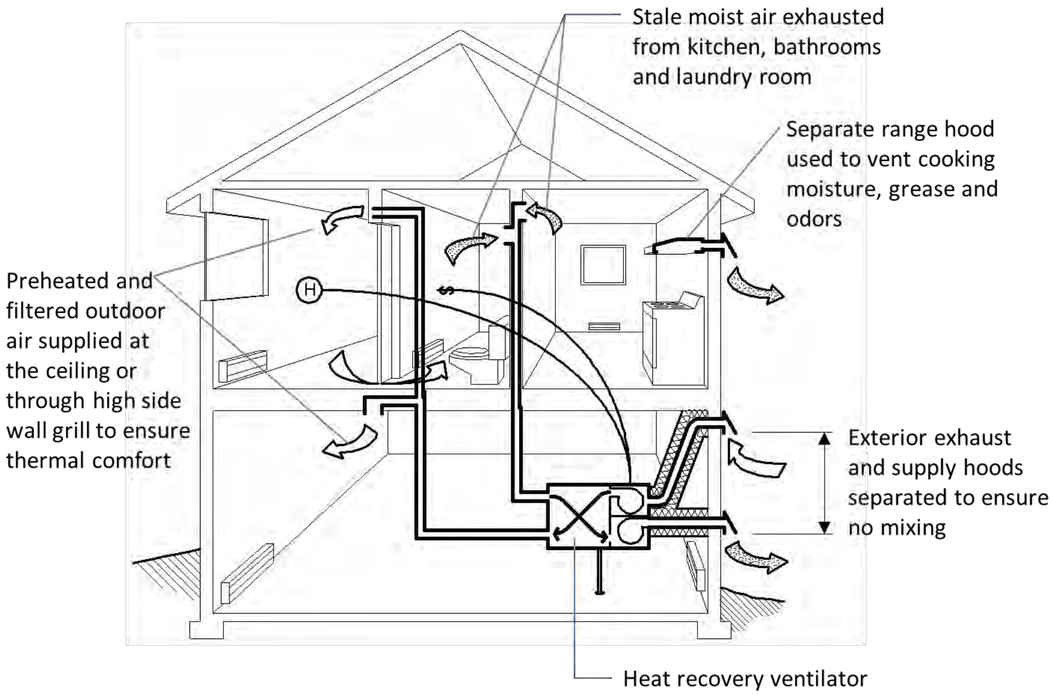

Figure 5-3. A heat-recovery ventilator with dedicated supply and exhaust ductwork.

5.4 Domestic Water-Heating Systems

The conventional domestic water heater will supply all of the domestic hot water or will act as a backup system for a solar water-heating system. The standard measure of water-heater efficiency is the energy factor, which is based on heating efficiency and standby heat loss. The higher the energy factor is, the more efficient the appliance and the less energy it wastes. It is very important that domestic hot-water heating systems be highly efficient in order to reduce energy consumption.

5.4.1 Gas

A condensing natural-gas tank water heater, with a thermal efficiency in the range of 95% and an energy factor rating of greater than 0.82, can provide all of the water-heating requirements, or provide backup for a solar water-heating system. This type of water heater uses a draft inducer fan that forces the flue gases out of the flue, preventing the possibility of back drafting. A dedicated outside combustion air supply must be used.

The Consortium for Energy Efficiency (CEE) provides specific information on high-efficiency, residential, gas, tank water heaters.[26]

A condensing natural-gas, tankless water heater, with thermal efficiency in the rage of 94% and an energy factor rating greater than 0.82, can provide all of the water-heating requirements, or provide backup for a solar water-heating system. Some manufacturers produce models that are specifically designed to work with solar water-heating systems.

[26] See http://library.cee1.org/content/natural-gas-residential-water-heaters-storage-qualifying-products-list.

The Consortium for Energy Efficiency (CEE) provides specific information on high-efficiency, residential, gas, tankless water heaters.[27]

If a condensing gas boiler is used for space heating, it could also provide domestic water heating through the use of a heat exchanger and a separate hot-water storage tank (range boiler).

5.4.2 Electric

If an air-source heat pump is being used to provide space heating, an option is to upsize the unit and to use it to provide domestic water heating as well.

A stand-alone, air-source, heat-pump water heater can be used, but it must extract heat from outdoor air, not from the air within the home. This type of water heater typically has an annual coefficient of performance in the range of 1.5 in mild coastal climates.

If a ground-source heat pump is used for space heating, a desuperheater can be added for heating domestic water.

A high-efficiency, electric hot-water tank, with an energy factor rating of 0.9 to 0.95, can be used. This type of tank is typically used in conjunction with a solar water-heating system.

5.4.3 Solar

The primary function of solar water heating is to supply domestic hot water for showers, bathing, and washing. In British Columbia's climates, this type of system typically supplies 50 to 60% of a home's water-heating load on an annual basis; it therefore requires a backup water heater to cover periods of low solar radiation. A solar water-heating system typically consists of one or more solar collectors, a pump, a storage tank, connecting piping, a differential thermostat pump controller, and a heat exchanger. Solar collectors vary in design but typically consist of a black absorbing surface that receives sunlight and converts it into heat, a glazing the helps retain the heat, insulation behind the absorber, and a case to contain all the components.

A solar collector area is typically in the range of 6 to 9 m^2 (64 to 96 ft^2). The solar collectors are typically roof mounted at slopes ranging from 30 to 60 degrees for the horizontal and are oriented south, southeast, or southwest. The optimum slope for the geographic location, as well as the type of solar collector and its orientation, can be determined using RETScreen's model for solar water heating (CanmetENERGY 2011). The solar-water-heater storage tank typically ranges in size from 275 to 410 L (60 to 90 imp gal). Water or an anti-freeze solution is circulated through the solar collector absorber when the absorber temperature is high enough, and the heat is then stored in an insulated water storage tank. Solar water heaters are most efficient when the temperature of the water or anti-freeze entering the solar collector is low; for this reason the solar water heater is the first to heat the domestic water supply, followed by the backup heater. Due to the fact that in winter water can freeze inside the solar collectors and cause damage, a freeze-protection strategy must be employed. This can consist of using an anti-freeze solution in the solar collector(s), or of draining the water out of the solar collector(s) when it is not providing heat, which is referred to as a drain-back system (Figure 5-4). A system that uses antifreeze would typically use food-grade antifreeze and have a heat exchanger that transfers heat from the antifreeze to the water-storage tank (Figure 5-5). All municipalities will require a double-walled heat exchanger and/or a back-flow preventer in the domestic water supply line to ensure the antifreeze cannot enter the municipal water-supply system. It is advisable to speak to the local plumbing inspector about what types of solar water-heating

[27] See http://library.cee1.org/content/natural-gas-residential-water-heaters-tankless-qualifying-products-list.

systems are considered acceptable before selecting equipment and designing a system. Some packaged solar water-heating systems are supplied with a small PV panel and a low-voltage, DC-powered pump. In this approach the system is completely powered and controlled by the sun and does not require a connection to the electric utility to operate.

More information on solar water-heating systems is provided in NRCan's *Solar Water Heating Systems: A Buyer's Guide* (Natural Resources Canada 2000).

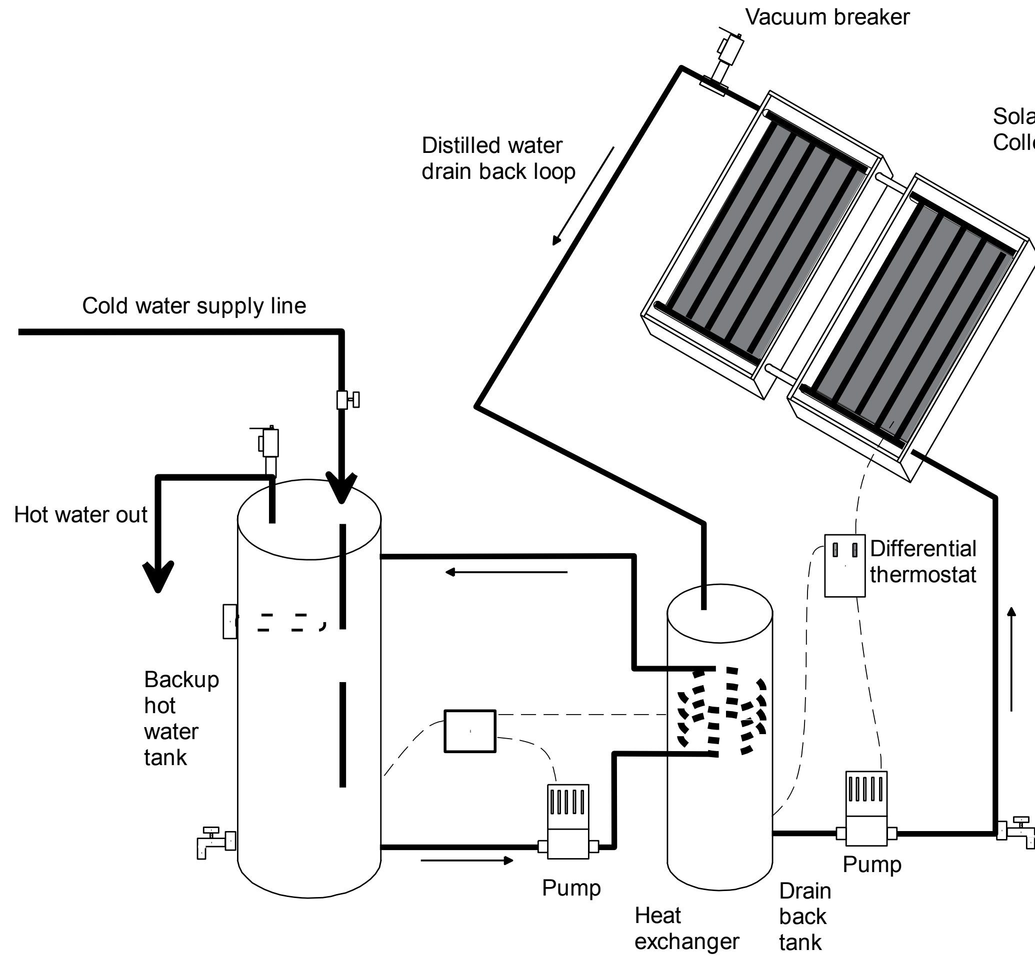

Figure 5-4. A solar water-heating system with a drain-back component to prevent the freezing of water in the solar collectors during winter.

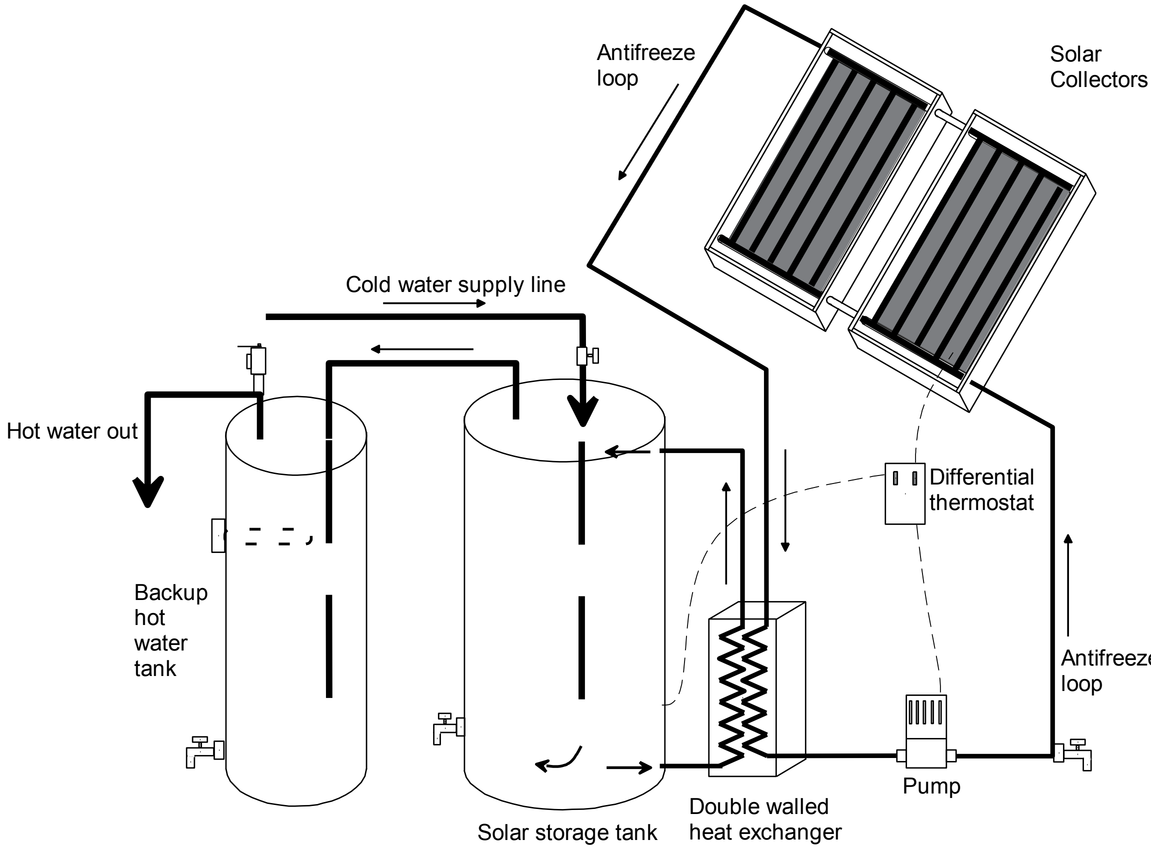

Figure 5-5. A closed-loop, solar water-heating system that uses a food-grade antifreeze solution to prevent the freezing of water in the solar collectors during winter. A heat exchanger transfers heat from the solution to the water-storage tank.

5.4.4 Drain-Water Heat-Recovery Systems

A drain-water heat-recovery system transfers heat from hot or warm waste water to incoming fresh water. This is typically done by installing the drain-water heat-recovery system's heat exchanger in the main waste-water pipe of the home. The waste water flows down the centre pipe of the system while the fresh incoming water flows through pipes that are wrapped around and bonded to the outside of the centre pipe. As the two streams of water pass by each other, heat is transferred. This device works most effectively when there are simultaneous flows of hot waste water and fresh supply water, such as when the shower is being used. The actual percentage of heat recovered by a device like this will depend on a range of factors, including system design, the hot-water-use habits of the home's occupants, temperature of the waste water and of the incoming water, etc. More information about drain-water heat recovery is available from NRCan's Office of Energy Efficiency.[28]

[28] See http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.search-recherche&appliance=DWHR.

Chapter 6 – Photovoltaic Systems

A photovoltaic (PV) system is a silicon device that produces electricity from sunlight. Increasingly, PVs are being used in high-performance housing to supply some or all of a home's electrical power requirements. As of 2013, PV systems are not yet cost competitive with conventional utility electricity, but they are being used more and more in off-grid applications. The cost of components is dropping and their efficiency in converting light to electricity is rising. Most electric utilities are now recognizing PV systems installed on buildings that are interconnected with the electrical grid as a practical, supplementary source of utility energy. These utilities have adopted technical standards for interconnection and have established feed-in-tariffs for purchasing excess PV energy from small producers, including homeowners.

6.1 Typical Conversion Efficiencies

Different types of PV systems have their own characteristics and conversion efficiencies. The conversion efficiency is the percentage of solar energy falling on the PV panel that is converted to electricity. The remainder is dissipated as heat. The most efficient conversion today, for commercially available PV panels, was still around 20% in 2014. Conversion efficiency is also affected by sky conditions, solar angle, and operating temperature. PV power capacity is measured as maximum power output under standardized test conditions in "Wp" (watts peak). This rated value is labelled on the panel and stated in manufacturer's literature, so the customer can use it to compare products. The actual power output at a particular point in time may be less than or greater than this standardized, or "rated", value, depending on geographical location, time of day, weather conditions, and other factors. The typical annual conversion efficiency for sunlight to electricity for an entire PV system for a particular geographic location can be calculated with RETScreen software (CanmetENERGY 2011). When comparing various PV systems, it is the capital and operating costs that should be compared to power output over the system's life, rather than just simply comparing conversion efficiency.

6.2 Grid-Connected Systems

Although it is possible to store electricity from PV arrays in batteries, the most common approach is to connect the residential PV system to the electrical grid (Figure 6-1). A grid-connected system employs an inverter/controller that converts the DC electricity output of the PV array into the standard AC current. The grid, in effect, acts as a large battery, absorbing excess electricity during periods of high solar radiation and then supplying power at night and during periods of low solar radiation.

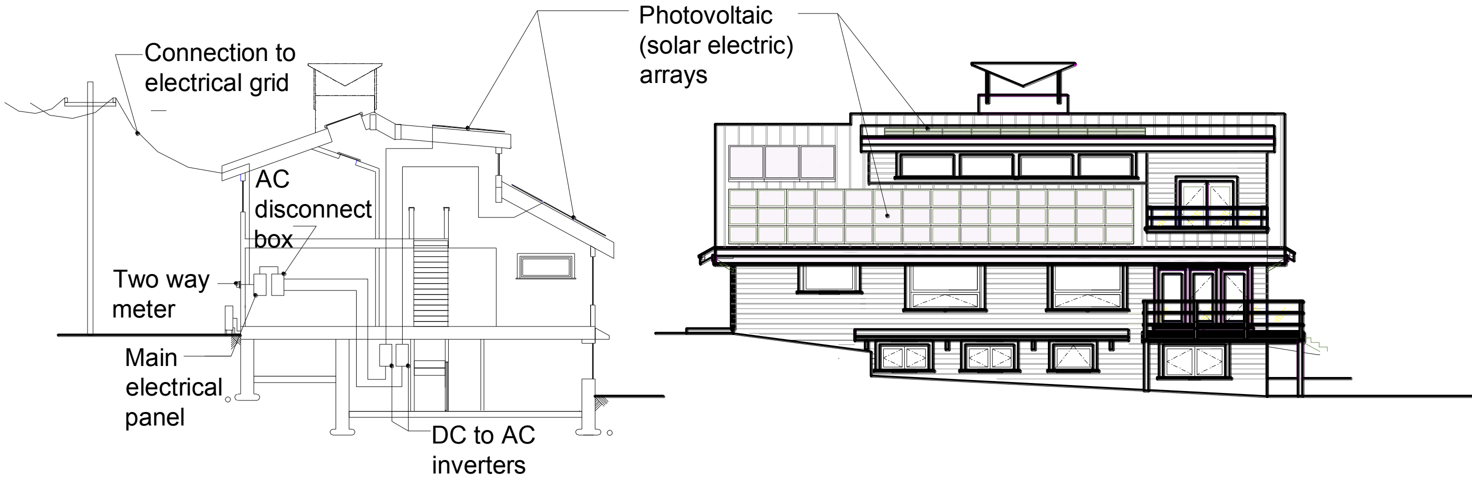

Figure 6-1. A grid-connected residential PV system: cross section and south elevation.

6.3 Building-Integrated Systems

More benefits can be obtained by integrating PV modules into roof or wall materials than by installing them with free-standing support structures. Roofing-integrated PV modules are available as roof shingles, skylights, and awnings/sunshades. Wall-integrated PV systems are also available in window glass. The cost of a building-integrated PV system is partially offset by the avoided costs associated with support structures and/or materials for the roof, walls, and enclosure.

A roof-mounted PV system is generally located on a south or southeast-to-southwest sloping roof, between 25 and 60 degrees to the horizontal. In colder climates steeper slopes are necessary to shed snow and receive winter sun effectively. In coastal areas the largest portion of annual solar radiation occurs in late spring, summer, and early fall, resulting in an optimum slope of 25 to 30 degrees to the horizontal. The precise angle and orientation for a particular location can be tested in RETScreen (CanmetENERGY 2011) to determine the effects on PV output.

Once the electrical requirements are known, software programs such as RETScreen (CanmetENERGY 2011) can determine the system size by allowing the modelling of various sizes, configurations, orientations, and hardware types for a particular geographic location, either as a grid-connected or an independent system. RETScreen also offers cost and payback analysis. For grid-tied systems, check with the local electric utility to determine the feed-in tariff that the homeowner would be paid for feeding any excess into the grid, and to determine all other costs related to grid interconnectivity. The RETScreen software will estimate the excess production by the PV system that would be available for sale.

Photovoltaics for Buildings: Opportunities for Canada (Ayoub et al. 2001) provides further details about the design of building-integrated PV systems.

More detailed information on calculating household electrical loads is in Appendix E.

6.5 Making a Project PV Ready

Even though PV may not be a suitable option for a high-performance housing project now because of the cost, a project can be designed and constructed to allow installation of a PV system in the future.

The basic requirements for making a project PV ready are:

- Roof area allocation – A southward-facing roof area, on the home or garage, of between 80 and 120 m^2 (850 and 1300 ft^2) should be allocated for the PV array; with the roof slope being between 20 and 30 degrees for southwestern British Columbia, 30 and 45 degrees for the south–central part of the province, and 40 and 50 degrees for northern British Columbia. This area must have minimal shading from adjacent buildings and trees throughout most of the year.
- Point loads – Depending on how the PV array is mounted on the roof, point loads may have to be accounted for in the design of the roof structure.
- Inverter location allocated – Designate a space the size of a large closet for inverters and controls, or leave extra wall space in a utility room or the attached garage. If the system is likely to be grid-connected, locate the inverter space so that it is convenient to the electrical service and metering point. In many cases the inverter(s) is located on the home exterior due to possible noise concerns and heat being released in the summer.
- Wiring chase or conduit installed – Install chases or electrical conduits for connecting the locations of the PV modules, the inverter/controller, and the electrical service room. This is inexpensive during construction but can be expensive and difficult to retrofit later. An electrical contractor can advise you on the size of conduit required.

An excellent reference for making a home ready for the future use of PV and solar thermal systems is the NRCan's *Solar Ready Guidelines for Solar Domestic Hot Water and Photovoltaic Systems* (CanmetENERGY 2013).

Chapter 7 – References and Other Resources

This publication draws on national and international experience gained in the field of high-performance housing over the past 30 years. In addition to local building codes and bylaws, a number of information sources are relevant, many of which are cited in this document. These are listed below in the References subsection. In addition, other sources of helpful information are listed in the Other Resources subsection.

7.1 References

American Architectural Manufacturers Association. 2008. *NAFS — North American Fenestration Standard / Specification for Windows, Doors, and Skylights*. AAMA/WDMA/CSA 101/I.S.2/A440-08. American Architectural Manufacturers Association, Schaumburg, Illinois, USA; Window & Door Manufacturers Association, Des Plaines, Illinois, USA; Canadian Standards Association, Ottawa, Ontario.

Angus Reid Public Opinion. 2010. TD Canada Trust Green Home Poll. TD Canada Trust, Toronto Ontario. [online] URL: http://www.td.com/about-tdbfg/media-room/press-kits/2010-tdct-Green-Home-Poll-bc.jsp

APA — The Engineered Wood Association. 2012. *Advanced Framing Construction Guide*. Tacoma, Washington.
[online] URL: http://www.apawood.org

Athena Sustainable Materials Institute. 2012. *Athena EcoCalculator for Residential Assemblies*. V1.21. Ottawa, Ontario, Canada.
[online] URL: http://calculatelca.com/software/ecocalculator/ecocalculator-for-residential-assemblies/

Ayoub, J., L. Dignard-Bailey, and A. Filion. *Photovoltaics for Buildings: Opportunities for Canada*. Report #CEDRL-2000-72 (TR). CANMET Energy Diversification Research Laboratory, Natural Resources Canada, Varennes, Québec.
[online] URL: https://www.nrcan.gc.ca

Baechler, M. C., T. L. Gilbride, M. G. Hefty, P. C. Cole, and P. M. Love. 2011. *Builders Challenge Guide to 40% Whole-House Energy Savings in the Cold and Very Cold Climates*. Building America Best Practices Series, Volume 12. PNNL-20139. Pacific Northwest National Laboratory, Building Technologies Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, Richland, Washington.
[online] URL: https://www.energy.gov

Behidj, N., Y. Liu, M. Brugger, M. Warbanski, S. Leblanc, F. Yamada, and R. Kwan. 2013. *Energy Use Handbook 1990 to 2010*. Office of Energy Efficiency, Natural Resources Canada, Ottawa, Ontario.
[online] URL: http://www.nrcan.gc.ca

British Columbia Ministry of Environment. *British Columbia Greenhouse Gas Inventory Report 2010*. Victoria, British Columbia.
[online] URL: http://www.gov.bc.ca

Building and Safety Standards Branch. 2012. *British Columbia Building Code 2012*. Office of Housing and Construction Standards, British Columbia Ministry of Mines and Energy, Victoria, British Columbia.

Burgess, B. 2012. *Rainwater Harvesting Best Practices Guidebook—Residential Rainwater Harvesting Design and Installation*. Green Building Series. Regional District of Nanaimo, British Columbia.
[online] URL: http://rdn.bc.ca

Canada Mortgage and Housing Corporation (CMHC). 1996. *Survey of Building Envelope Failures in the Coastal Climate of British Columbia*. B.C. and Yukon Regional Office, Vancouver, British Columbia.
[online] URL: https://www.cmhc-schl.gc.ca

Canada Mortgage and Housing Corporation (CMHC). 2007a. *EQuilibrium™ Healthy Housing for a Healthy Environment: New Housing for a Changing World*. Ottawa, Ontario. [online] URL: https://www.cmhc-schl.gc.ca

Canada Mortgage and Housing Corporation (CMHC). 2007b. *A Plan for Rainy Days: Water Runoff and Site Planning.* Socio-Economic Series 07-013. Ottawa, Ontario. [online] URL: http://www.cmhc-schl.gc.ca

Canada Mortgage and Housing Corporation (CMHC). 2007c. *Air Leakage Control Manual: Existing Multi-Unit Residential Buildings*. Research Report, Housing Technology Series. Ottawa, Ontario. [online] URL: http://www.cmhc-schl.gc.ca

Canada Mortgage and Housing Corporation. 2008. *Tap the Sun Passive Solar Techniques and Home Designs*. Canada Mortgage and Housing Corporation (CMHC), Ottawa, Ontario.

Canada Mortgage and Housing Corporation (CMHC). 2010. *Riverdale NetZero Deep Wall System*. EQuilibrium™ Housing Insight. Ottawa, Ontario. [online] URL: http://www.cmhc-schl.gc.ca

Canada Mortgage and Housing Corporation (CMHC). 2011. *Rain Gardens: Improve Stormwater Management in Your Yard.* About Your House Fact Sheet, Landscaping Series. Ottawa, Ontario. [online] URL: http://www.cmhc-schl.gc.ca

Canadian Home Builders' Association. 2013. *Canadian Home Builders' Association: Builders' Manual*. Sixth Edition. Ottawa, Ontario.

Canadian Standards Association. 2008. CSA O80 Series. *Wood Preservation*. Etobicoke, Ontario.

Canadian Wood Council. 2013. *Wall Thermal Design Calculator*. [online tool]. Ottawa, Ontario. [online] URL: http://cwc.ca/resources/wall-thermal-design/

CanmetENERGY. 2011. *RETScreen Software Suite*. [software]. Natural Resources Canada, Varennes, Quebec, Canada. [online] URL: http://www.nrcan.gc.ca/energy/software-tools/7465

CanmetENERGY. 2013. *Solar Ready Guidelines for Solar Domestic Hot Water and Photovoltaic Systems*. Version 1.1. Natural Resources Canada, Varennes, Quebec, Canada. [online] URL: https://www.nrcan.gc.ca

Carmody, J., S. Selkowitz, D. Arasteh, and L. Heschong. 2007. *Residential Windows*. Third Edition. W.W. Norton & Company Ltd., New York, New York.

City of Vancouver. 2009. *Passive Design Toolkit for Homes*. Vancouver, British Columbia. [online] URL: https://vancouver.ca

Cooper, K. 1997. *House Comfort Design Checker for Winter Solar Overheating*. [software]. SAR Engineering Ltd., Burnaby, British Columbia.

Ecotope, Inc. *SUNCODE (SERI-RES)*. [software.] Seattle, Washington.

Enermodal Engineering. *ENERPASS*. [software]. Kitchener, Ontario.

Finch, G., J. Wang, and D. Ricketts. 2013. *Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America*. FPInnovations Special Publication SP-53. FPInnovations, Vancouver, British Columbia, Canada; RDH Building Engineering Ltd., Vancouver, British Columbia, Canada; Homeowner Protection Office, Branch of BC Housing, Burnaby, British Columbia, Canada; Canadian Wood Council, Ottawa, Ontario. [online] URL: http://www.fpinnovations.ca

Fox, M. 2014. *Hygrothermal Performance of Highly Insulated Wood Frame Walls with Air Leakage: Field Measurements and Simulations*. Master's Thesis. Master of Building Science Program, Department of Architectural Science, Ryerson University, Toronto, Ontario.

Gagnon, S. and C. Pirvu, editors. 2011. *CLT Handbook*. Canadian Edition. FPInnovations. Special Publication SP-528E. FPInnovations, Point Claire, Quebec.

Hazleden, D.G., and P. I. Morris. 2003. *Evaluation of Vapour Diffusion Ports on Drying of Wood-Frame Walls Under Controlled Conditions*. Technical Series 02-130. Canada Mortgage and Housing Corporation (CMHC), Ottawa, Ontario.

Homeowner Protection Office (HPO), Branch of BC Housing. 2007. *Building Envelope Guide for Houses—Part 9 Residential Construction.* Burnaby, British Columbia.

Homeowner Protection Office (HPO), Branch of BC Housing. 2011. *Building Enclosure Design Guide—Wood-Frame Multi-Unit Residential Buildings*. Burnaby, British Columbia.

Karacabeyli, E., and B. Douglas, editors. 2013. *CLT Handbook*. U.S. Edition. Special Publication SP-529E. FPInnovations, Point Claire, Quebec; Forest Products Laboratory, Forest Service, U.S. Department of Agriculture, Madison, Wisconsin; and Binational Softwood Lumber Council, Surrey, British Columbia.

Morrison Hershfield. 2014. *Building Envelope Thermal Bridging Guide: Analysis, Applications, & Insights*. BC Hydro, Vancouver, British Columbia.

National Research Council Canada (NRC). 2010. *National Building Code of Canada 2010*. National Research Council Canada, Ottawa, Ontario.

Natural Resources Canada (NRCan). 2000. *Solar Water Heating Systems: A Buyer's Guide*. Ottawa, Ontario. [online] URL: http://publications.gc.ca/collections/Collection/M92-179-2000E.pdf

Natural Resources Canada (NRCan). 2010a. *HOT2000.* Ver 10.51. [software]. Ottawa, Ontario, Canada. [online] URL: http://www.nrcan.gc.ca

Natural Resources Canada (NRCan). 2010b. Energy Efficient Residential Windows, Doors, and Skylights. Ottawa, Ontario, Canada. [online] URL: http://www.nrcan.gc.ca

Orr, H., J. Wang, D. Fesch, and R. Dumont. 2012. Airtightness of Older-Generation Energy-Efficient Houses in Saskatoon. *Journal of Building Physics* 36(3):294-307.

Parekh, A., L. Rox, and P. Gallant. 2007. *Thermal and Air Leakage Characteristics of Canadian Housing*. Paper presented at 11th Canadian Conference on Building Science and Technology, Banff, Alberta, Canada.
[online] URL:
http://www.nbec.net

Proskiw G., and A. Parekh. 2004. *Airtightness Performance of Wood-Framed Houses over a 14-Year Period*. Paper presented at Thermal Performance of Exterior Envelopes of Whole Buildings IX Conference, ASHRAE, Clearwater Beach, Florida, December 2004.

Proskiw, G., and A. Parekh. 2010. *Optimization of Net Zero Energy Houses*. Paper presented at Building Enclosure Science and Technology (BEST 2) Conference, Portland, Oregon. [online] URL: http://www.greenbuildingadvisor.com

RDH Building Engineering. 2013. *Review of Window Energy Rating Procedure in Canada*. Report for Homeowner Protection Office, Branch of BC Housing. Vancouver, British Columbia.

Renewable Resource Data Center. 2012. *PVWatts, A Performance Calculator for Grid-Connected PV Systems*.

Version 1. [software]. National Renewable Energy Laboratory, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, Golden, Colorado and Washington, D.C.

Siegenthaler, J. and H. Patent. 2012. *Hydronic for Low-Energy & Net-Zero Houses*. Presented at CIPHEX West Plumbing and HVAC Conference, Vancouver, British Columbia.

Solar Radiation Monitoring Laboratory. 2007. Sun Path Chart Program. [database]. Department of Physics, University of Oregon, Eugene, Oregon. [online] URL: http://solardat.uoregon.edu/SunChartProgram.html

Standards Council of Canada. 1986. *Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method*. CAN/CGSB-149.10-M86. Ottawa, Ontario.

Straube, J.F., and E.F.P. Burnett. 2005. *Building Science for Building Enclosures*. Building Science Press, Westford, Maine.

The Sheltair Group. 2006. *Opportunities for Local Government Action on Energy Efficiency in New Buildings*. Vancouver, British Columbia. [online] URL: https://www2.gov.bc.ca

Wang, J. 2014. *Drying Performance of Experimental Wood Roof Assemblies*. Report submitted to Natural Resources Canada. FPInnovations, Vancouver, British Columbia.

Wang, J., P. Symons, and P. Morris. 2010. Time to Initiation of Decay in Plywood, OSB and Solid Wood Under Critical Moisture Conditions. In *Proceedings of International Conference on Building Envelope Systems and Technologies (ICBEST), Vancouver, British Columbia, Volume 2*.

7.2 Other Resources

American Architectural Manufacturers Association (AAMA). Schaumburg, Illinois. http://www.aamanet.org/

APA — The Engineered Wood Association. Tacoma, Washington. http://www.apawood.org/

ASHRAE. Atlanta, Georgia. https://www.ashrae.org/

Athena Sustainable Materials Institute. Ottawa, Ontario. http://www.athenasmi.org/

BC Hydro. Burnaby, British Columbia. www.bchydro.com

Building America program. Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. Washington, U.S. https://www.energy.gov

Building and Safety Standards Branch. Office of Housing and Construction Standards, Ministry of Energy, Mines and Natural Gas, Victoria, British Columbia.

Building Science Corporation. Somerville, Massachusetts. www.buildingscience.com

Canadian Home Builders' Association. Ottawa, Ontario. http://www.chba.ca/

Canada Mortgage and Housing Corporation (CMHC). Ottawa, Ontario. http://www.cmhc-schl.gc.ca

Canada Mortgage and Housing Corporation (CMHC). 2013. Canadian Wood-Frame House Construction. Third combined metric/imperial edition, revised 2013. Canada Mortgage and Housing Corporation, Ottawa, Ontario.
[online] URL: https://www.cmhc-schl.gc.ca

Canada Mortgage and Housing Corporation (CMHC). 2013. Glossary of Housing Terms: The A to Z of Housing Terms. Canadian Wood-Frame House Construction. Revised 2013. Canada Mortgage and Housing Corporation, Ottawa, Ontario.
[online] URL: https:// http://www.cmhc-schl.gc.ca

Canadian Wood Council. Ottawa, Ontario. www.cwc.ca

CanmetENERGY. Natural Resources Canada, Varennes, Québec. http://www.nrcan.gc.ca/energy/offices-labs/canmet/5715

City of Vancouver. Vancouver, British Columbia.

http://www. vancouver.ca/

Colker, R., editor. 2013. *Beyond Green: Guidelines for High-Performance Homes, Meeting the Demand for Low-Energy, Resource-Efficient Homes.* Sixth Edition. National Institute of Building Sciences, Washington, D.C.

Consortium for Energy Efficiency (CEE). Boston, Massachusetts. http://www.cee1.org/

Daylight Dividends research program. Lighting Research Center, Troy, New York. http://www.lrc.rpi.edu/programs/daylighting/

Efficient Windows Collaborative. Center for Sustainable Building Research, University of Minnesota. www.efficientwindows.org

EnerGuide Rating System – New Homes. Natural Resources Canada, Ottawa, Ontario. https://www.nrcan.gc.ca

ENERGYSTAR (in Canada). Natural Resources Canada, Ottawa, Ontario. http://www.nrcan.gc.ca

ENERGYSTAR (in USA). Washington, D.C. https://www.energystar.gov/

Forest Products Laboratory (FPL). Madison, Wisconsin. https://www.fpl.fs.fed.us

FortisBC. Burnaby, British Columbia. www.fortisbc.com

FPInnovations. Point Claire, Quebec and Vancouver, British Columbia. http://www.fpinnovations.ca

Homeowner Protection Office (HPO), Branch of BC Housing. Burnaby, British Columbia. http://www.bchousing.org

Home Ventilating Institute. Phoenix, Arizona. http://www.hvi.org

HOT2000. Ver 10.51. Natural Resources Canada. Ottawa, Ontario, Canada. http://www.nrcan.gc.ca

Johnston, D., and S. Gibson. 2010. *Toward a Zero Energy Home: A Complete Guide to Energy Self-Sufficient at Home*. The Taunton Press, Newtown, Connecticut.

Kadulski, R (Editor-Publisher). Solplan Review (Journal). Vancouver, British Columbia.

National Institute of Building Sciences. Washington, D.C. https://www.nibs.org/

National Research Council Canada (NRC). Ottawa, Ontario. www.nrc.ca

Natural Resources Canada (NRCan). Ottawa, Ontario www.nrcan.gc.ca

Oak Ridge National Laboratory. U.S. Department of Energy. Oak Ridge, Tennessee. www.ornl.gov/sci/ees/etsd/btric/

Renewable Resource Data Center. National Renewable Energy Laboratory, Office of Energy Efficiency and

Renewable Energy, U.S. Department of Energy, Golden, Colorado and Washington, D.C. http://www.nrel.gov/rredc/

Standards Council of Canada. Ottawa, Ontario. http://www.scc.ca/

Structural Insulated Panel Association (SIPA). Tacoma, Washington.
http://www.sips.org/

Thermal Environmental Comfort Association (TECA). Surrey, British Columbia.
http://www.teca.ca/

Appendix A. Sustainable Materials and Products

Another aspect of high-performance housing is the selection and use of effective building products and materials. Where possible, high-performance housing should employ building products and materials that have minimal impacts on the natural environment and which contribute to a healthy indoor environment.

Following is a brief summary of the types of products[29] that should be considered for inclusion in a high-performance housing project:

- Salvaged products and materials – By using recovered building materials, the impacts incurred in the production of new products and materials are avoided. These types of products include framing lumber, hardwood and softwood flooring, millwork, period hardware, etc. Before using salvaged materials they should be thoroughly inspected for rot or damage that may affect their installation or use. Major structural components such as glulam beams will have to be inspected by a structural engineer before being allowed for reuse. Certain salvaged products are not recommended, including plumbing fixtures and windows because of the water and energy savings associated with more efficient new products.
- Products with post-consumer recycled content – By using these products, otherwise useful resources are diverted from landfills and the consumption of virgin materials is reduced. Cellulose fibre insulation is one example of a product that is made primarily from recycled newspapers.
- Products with pre-consumer (post-industrial) recycled content – These products are made from industrial byproducts. Examples include mineral wool board insulation made from blast furnace slag resulting from the processing of iron ore, and concrete made with fly ash produced by coal-burning power plants.
- Products made from agricultural waste material – One example is panel board materials that are produced from straw that is left over from the harvesting of cereal crops.
- Products that are exceptionally durable or have low maintenance requirements – These are environmentally beneficial because they are replaced less frequently and their maintenance has a low environmental impact.
- Products that are resource efficient – Examples of these include engineered wood products, such as parallel strand lumber (PSL), plywood, OSB, wood I-joists, and open web joists, all of which use wood fibre very efficiently.
- Products that sequester carbon dioxide – Products made from wood and plants can lock up or sequester carbon dioxide for the life of the building or perhaps longer, thus

[29] For a complete discussion of sustainable materials and products, and a listing of many of them, refer to http://www.buildinggreen.com.

preventing it from entering the atmosphere. Cross-laminated (CLT) panels, which are used for wall and floor structures, and many other wood-based building products are very effective means of sequestering CO_2.

- Certified wood products – Based on a third-party certification process, these wood products are determined to be sourced from sustainably managed forests. The vast majority of Canada's lumber production fits in this category.
- Rapidly renewable products – These products are typically made from plants that have a harvest rotation of 10 years or less.
- Products and materials that avoid toxic or other pollution emissions during their manufacturing – These include:
    - natural or minimally processed products, such as framing lumber, solid timber, slate, wool insulation, etc.
    - products that avoid or eliminate the need for preservative treatments, or treated products that have minimal environmental impact, such as borate-treated wood products
    - products that reduce stormwater pollution, such as pervious pavers
- Products that save energy and water during the building's operation – These include:
    - insulation materials
    - air-barrier materials
    - high-performance windows, doors, and skylights
    - high-efficiency heating and cooling equipment
    - high-efficiency lighting fixtures, lamps, and controls
    - high-efficiency appliances
    - low-flow, low-flush plumbing fixtures
    - high-efficiency clothes washers and dishwashers
- Interior finish products that do not shed particles and have low chemical off gassing or which are chemically inert – These reduce indoor air pollutant loads, thus enhancing indoor air quality. These include such products as:
    - low- or no-VOC paints
    - water-based sealants
    - water-based coatings
    - hard wax oils
    - MDI-based MDF
    - Exterior-grade plywood and OSB

The total environmental impacts of building assemblies from the cradle to the grave, i.e., covering extraction, processing, transportation, assembly, use, and disposal, is analyzed using a technique called life-cycle assessment. The Athena EcoCalculator is a simplified life-cycle assessment tool that is available online for no charge (Sustainable Materials Institute 2012). Using this tool, or others like it, the designer can get a more complete picture of the environmental impact of building as a whole rather than just of the individual materials, thus allowing for more informed decision making. Individual building materials may have environmental product declarations (EPDs), based on life-cycle assessment data that document their environmental impacts in a similar way to the nutrition labels on foods.

Appendix B. Technologies for Reducing Household Water Consumption

The breakdown of typical household water consumption is shown in Figure B-1.

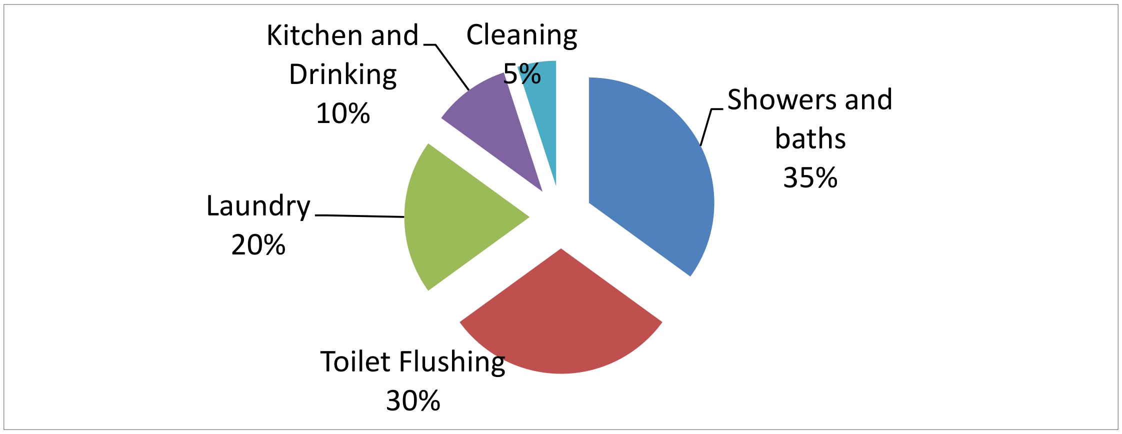

Figure B-1. Breakdown of water consumption in a typical household (source: Environment Canada).

Technologies for reducing household water consumption include:

- Water-efficient plumbing fixtures –In many cases these can be identified as those having the Water Sense label[30]. These will typically consume 20% less water than the average products in their category.
- Low-flush toilets – Pressure-assisted low-flush toilets can reduce water consumption from 6 L/flush to 4 L/flush for solid waste.
- Dual-flush toilets – These allow liquid waste to be removed using 3 L/flush and solid waste at 6 L/flush.
- Composting toilets – Where the local health authority allows them, composting toilets can be used to eliminate water for toilet flushing completely, saving in the range of 30% of the annual consumption of household water.
- Low-flow show heads – Low-flow shower heads with flow rates of 7.5 L/min (1.7 imp gallons/min) or less, and low-flow bathroom sink faucets with flow rates of 5.7 L/min (1.25 imp gallons/min) or less, should be used.
- Water-efficient dishwashers – Water-efficient dishwashers will use water in the range of 6 to 13.25 L/cycle (1.32 to 2.9 imp gallons/cycle). Current listings of dishwashers with their energy-use and water-consumption ratings are available from the Consortium for Energy (CEE).[31]

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30 WaterSense is a program of the U.S. Environmental Protection Agency. It aims to encourage water efficiency in consumers by certifying and labelling products in terms of their water efficiency. See http://www.epa.gov

31 See http://library.cee1.org/content/qualifying-product-lists-residential-dishwashers.

- Water-efficient clothes washers – The water efficiency of clothes washers is rated using a water factor rating. It indicates the number of gallons of water required for each cubic foot of laundry. The lower the water factor the more water efficient the washer. Washers with water factors in the range of 4 to 4.5 will be the most efficient available. The Consortium for Energy Efficiency provides a comprehensive listing of washers, their energy consumption, and their water factor ratings.[32] The most efficient washers will be those rated as Tier 2 or 3.
- Water-efficient landscaping – Water-efficient landscaping, or xeriscaping, utilizes native plant species that have low watering requirements. Turf grass is usually kept to a functional minimum to reduce irrigation requirements. For more information on this topic, the City of Portland, Oregon has some fact sheets and other resources that are pertinent for coastal areas,[33] and the City of Kelowna, British Columbia has some online resources that are pertinent for dryer locations such as the Okanagan Valley and other interior areas of the province.[34]
- Water-efficient irrigation systems – Drip irrigation, also known as trickle irrigation, is an irrigation method that saves water by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters. It is done through narrow tubes that deliver water directly to the base of the plant.
- Rainwater harvesting – Rainwater can be harvested from roofs and stored for later use for non-potable applications such as garden irrigation and toilet flushing. Generally speaking, pre-finished metal roofs are best suited to this application because they are relatively inert and do not shed particles. Rainwater can also be collected and treated for potable applications such as drinking and cooking, but these systems are more complex and costly. The Regional District of Nanaimo's *Rainwater Harvesting Best Practices Guidebook* (Burgess 2012) is a good resource on this topic.

[32] See http://library.cee1.org/content/qualifying-product-lists-residential-clothes-washers.

[33] See http://www.portlandoregon.gov

[34] See http://www.kelowna.ca

Appendix C. Using Sun-Path Charts to Determine the Effects of External Shading on Building Performance

The design of a high-performance home must consider how any external shading will affect passive solar heating of the home, and the use of solar thermal and PV systems. Solar domestic hot water systems and PV systems will utilize solar radiation year round but the most energy will be collected between the beginning of March and the end of October. It is therefore necessary to determine how shading from tall or mass objects might impact the performance of the building. Shading can be caused by permanent or temporary obstructions, such as trees or buildings, or by topographical features such as hills or mountains. The amount of sun shading from objects to the south can be plotted on a sun-path chart (Figure C-1). A sun-path chart shows the path of the sun for the 21^{st} day of every month from December to June according to *altitude* or *solar elevation* in degrees (sun angle above the horizon) and *solar azimuth* (number of degrees east and west of true south).

The further north, the lower the sun will be in the sky during the winter months. Objects in northern latitudes located to the south of a building will cast longer shadows.

The curves on the chart represent the sun's height above the horizon (solar elevation) and its horizontal position (azimuth) on those dates during daylight. On the sun-path chart, 180^{o} is due south. The sun-path chart must be produced for the particular latitude of the building location. The result shows which days (and hours) the site is shaded by the objects plotted.

Some sample sun-path charts for a few locations across British Columbia are included in this appendix. The University of Oregon has developed a free online tool for generating sun-path charts for any location (Solar Radiation Monitoring Laboratory 2007).

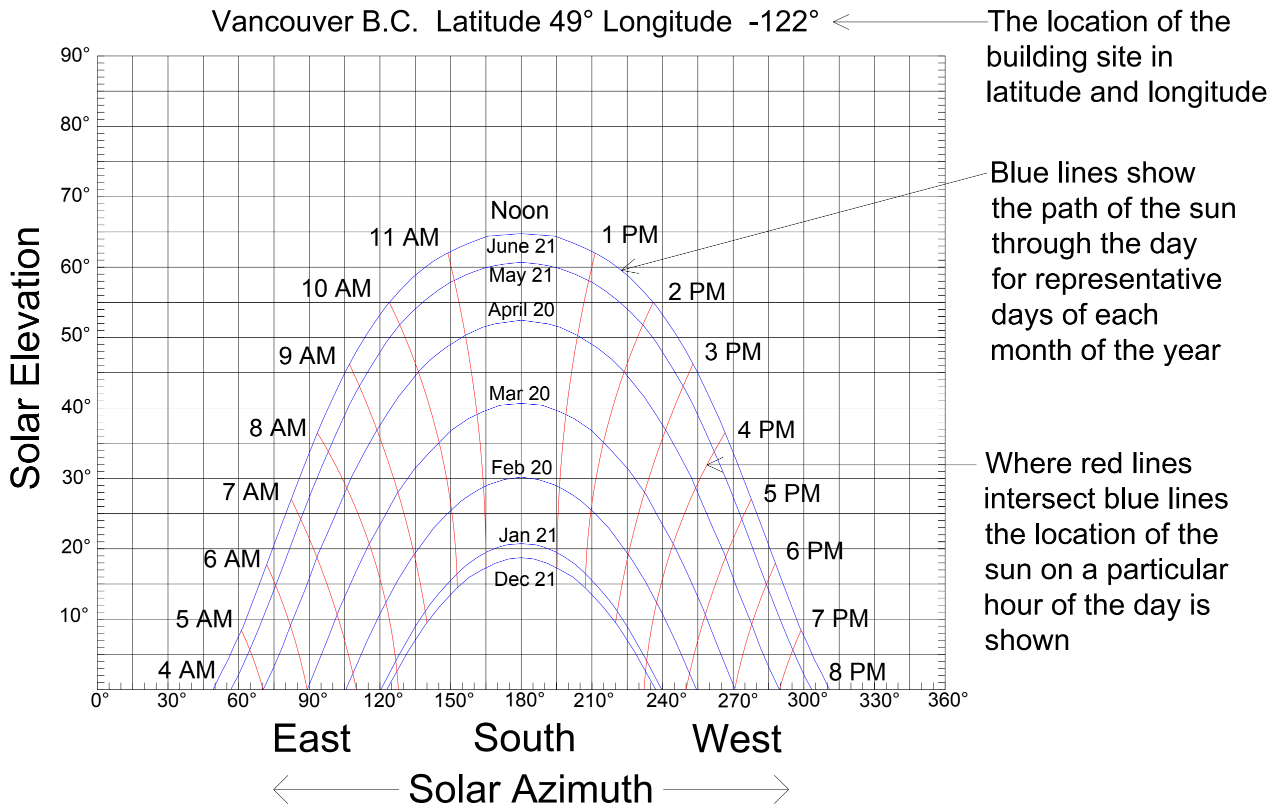

Figure C-1. Sun-path chart: Vancouver, B.C.

Determining True South

Before using a sun-path chart, the direction of true south must be determined. As most people know, a compass does not point to true north (the direct opposite of true south) but to magnetic north. i.e., magnet north is not at the North Pole, rather it is located in the high arctic somewhat east of the pole. The angular difference between true north and magnetic north is called magnetic declination (Figure C-2). The declination will depend on the location from which it is being measured. An online magnetic declination calculator is available from Natural Resources Canada's website.[35]

For a particular location the magnetic declination can be determined from recent maps and navigational charts or through an internet search. A GPS provides the true direction and no magnetic correction is required. For the western half of Canada, it is necessary to add to the

[35] See http://geomag.nrcan.gc.ca/calc/mdcal-eng.php.

compass reading to give true azimuth. For the eastern half of Canada, subtract from the compass reading to give true azimuth.

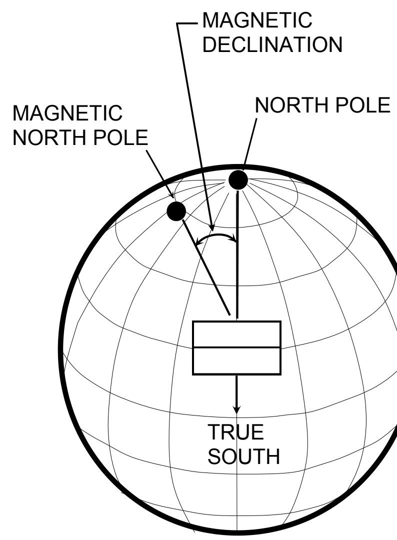

Figure C-2. Magnetic declination is the difference between true north and magnetic north.

How to Use a Sun-Path Chart

With a compass, GPS, or smart phone app in hand, stand on the building site where you anticipate the south side of the building to be located.

Take into account the magnetic declination for your location (Figure C-3). Or set the GPS or smart phone app to locate true south.

While facing south use a transit, hand level, inclinometer, or smart phone app to determine the elevation angle of the objects to the south (Figure C-4). Plot these points on the sun-path chart at its appropriate azimuth position (Figure C-5).

From true east to true west, for every increment of 15 degrees of azimuth along the horizon toward the south, take similar measurements of any tall objects that occur at these degree increments. Plot the points and objects on the sun-path chart. Draw a line connecting these points, which will show the hours of the day and months of the year during which shading will occur (Figure C-5). Ideally, the passive solar heating systems should have potential access to sun for a minimum of 4 hrs per day in the winter.

The sample sun-path chart in Figure C-5 indicates that there is good solar potential, with 5 to 6 hrs available on clear winter days.

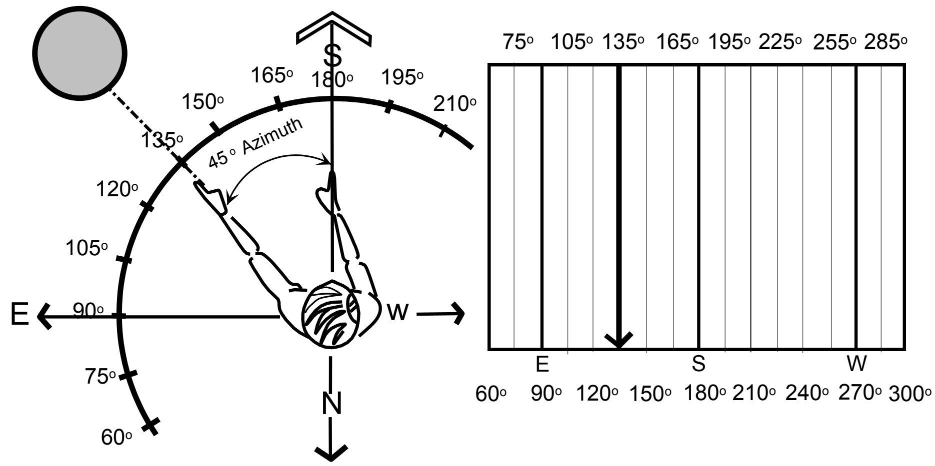

Figure C-3. An example of how to determine the solar azimuth of a tall object on the south-facing side of the building.

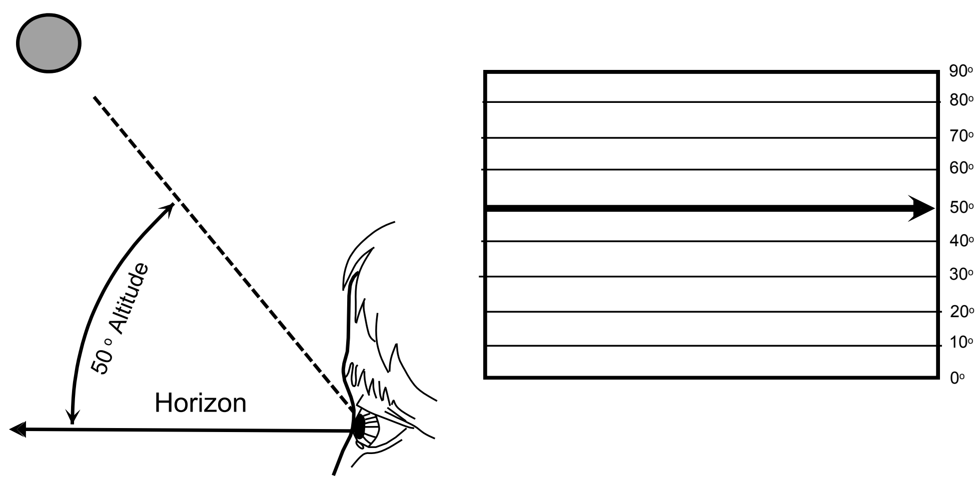

Figure C-4. An example of the altitude and solar elevation of a tall object on the south-facing side of the building.

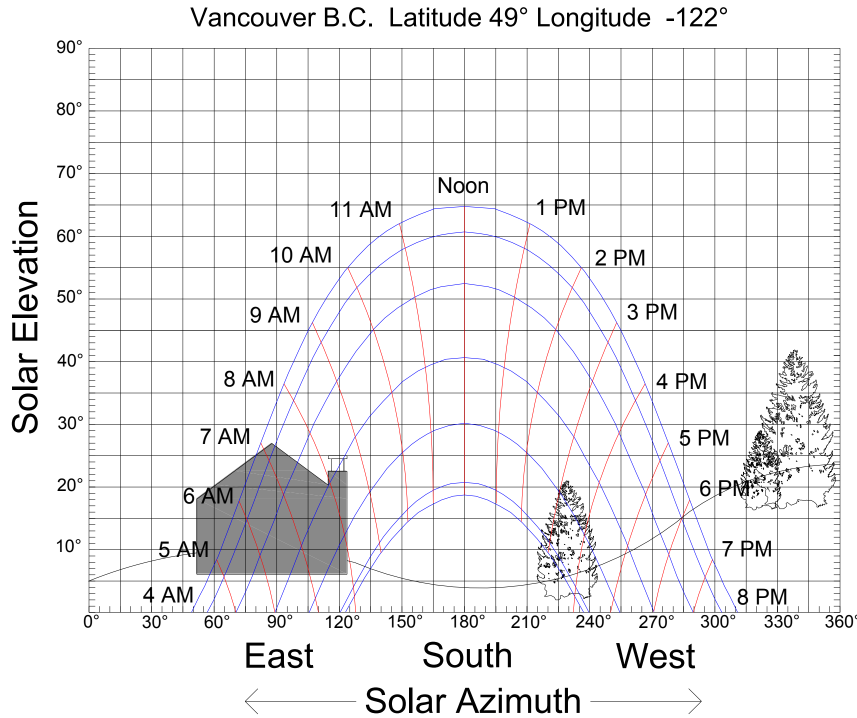

Figure C-5. Trees and tall objects on the south-facing side of the building are plotted according to their altitude and azimuth.

Sample Sun-Path Charts for Some Locations in British Columbia

Figure C-6, Figure C-7, Figure C-8, and Figure C-9 contain sun-path charts for some locations in British Columbia. They were generated using the University of Oregon's free online software (Solar Radiation Monitoring Laboratory 2007).

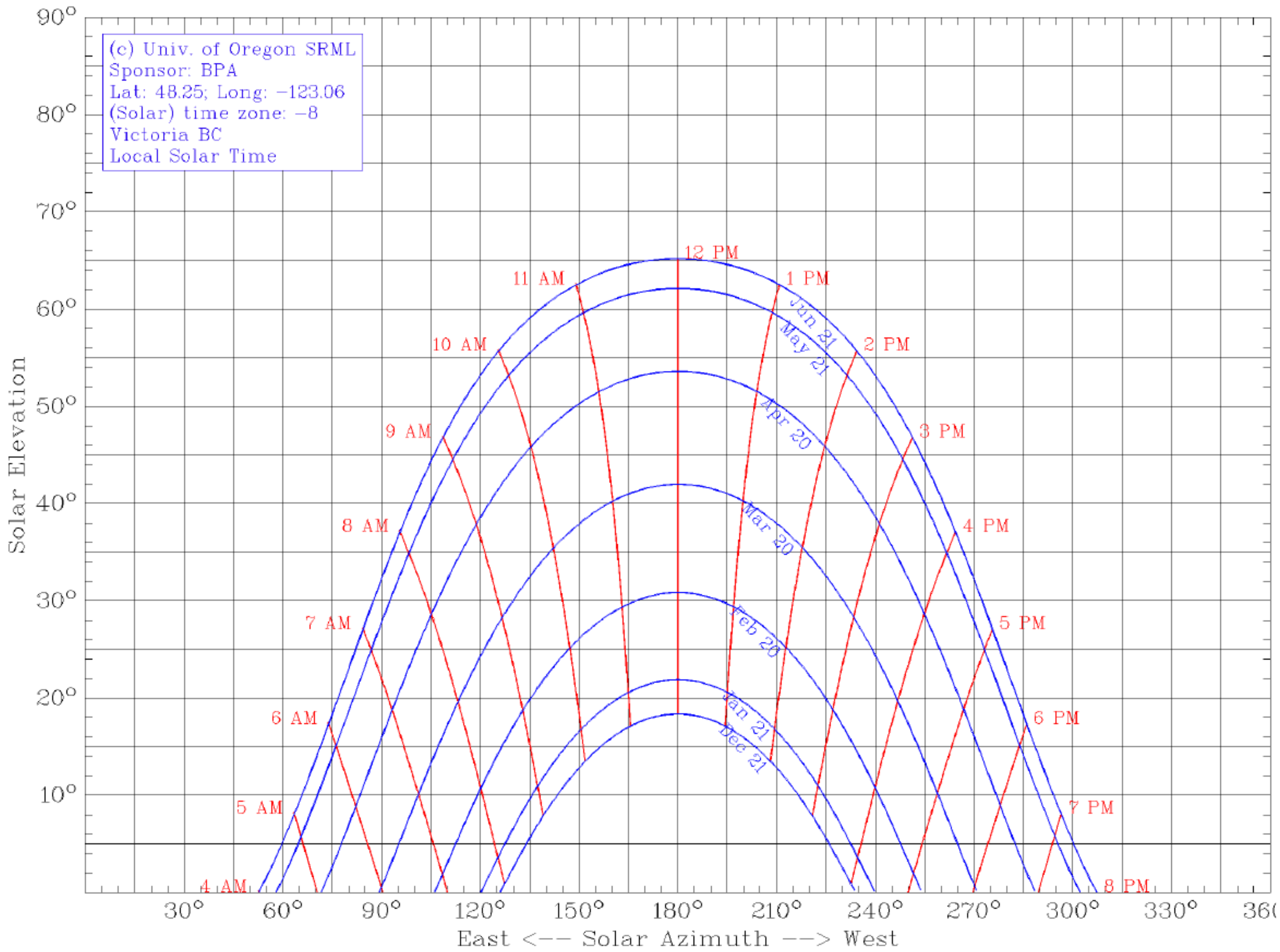

Figure C-6. Sun-path chart: Victoria, B.C.

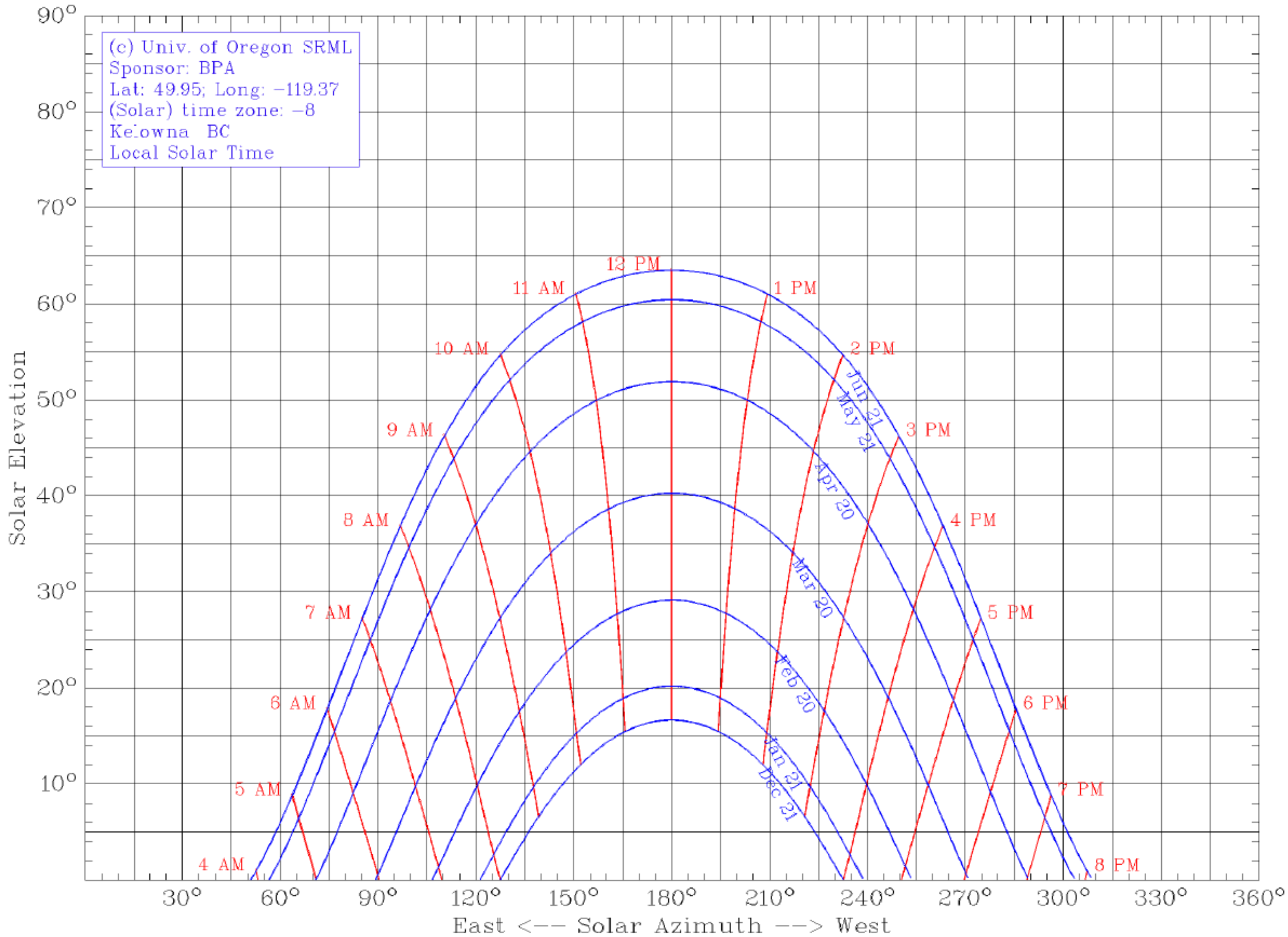

Figure C-7. Sun-path chart: Kelowna, B.C.

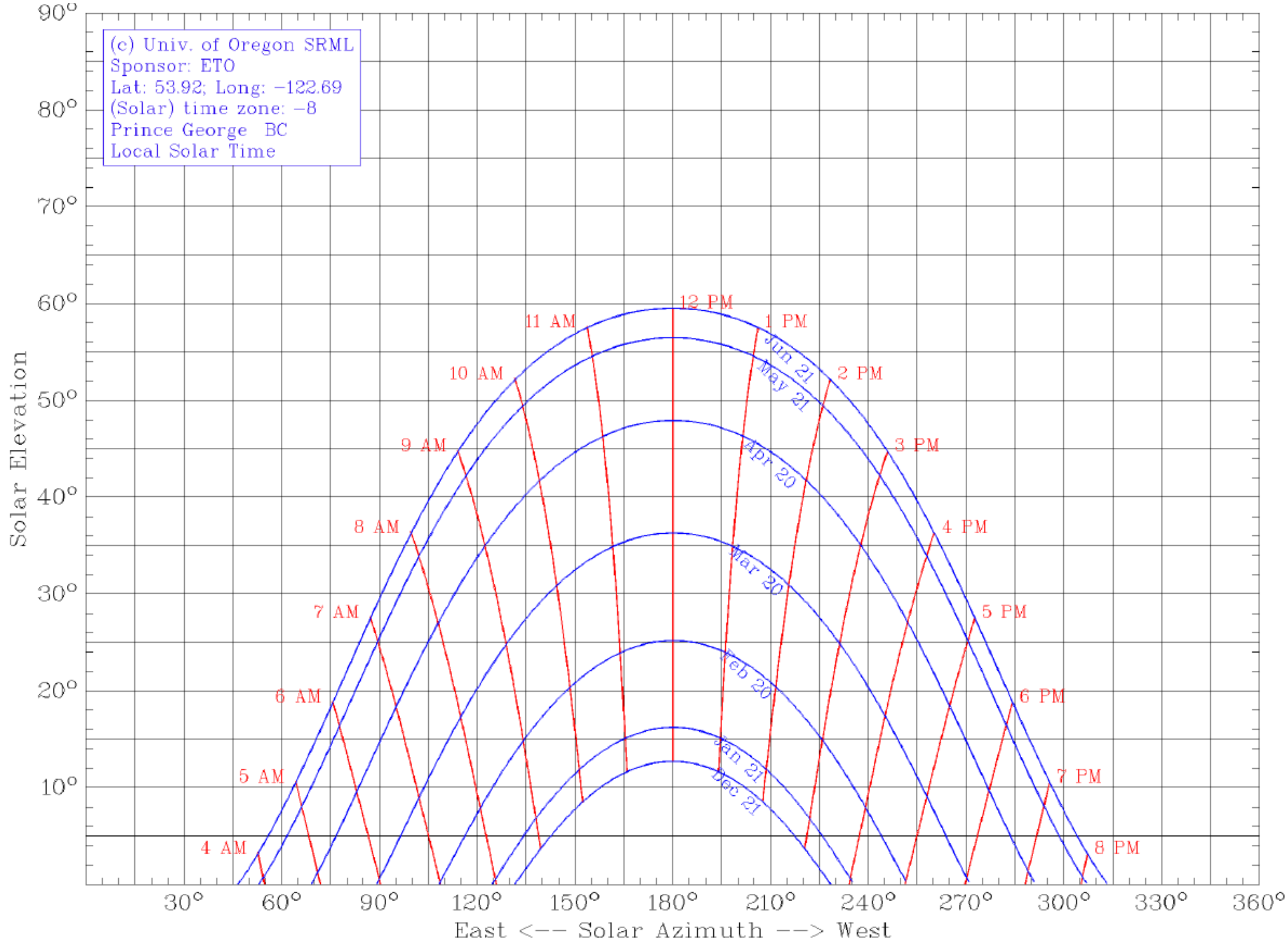

Figure C-8. Sun-path chart: Prince George, B.C.

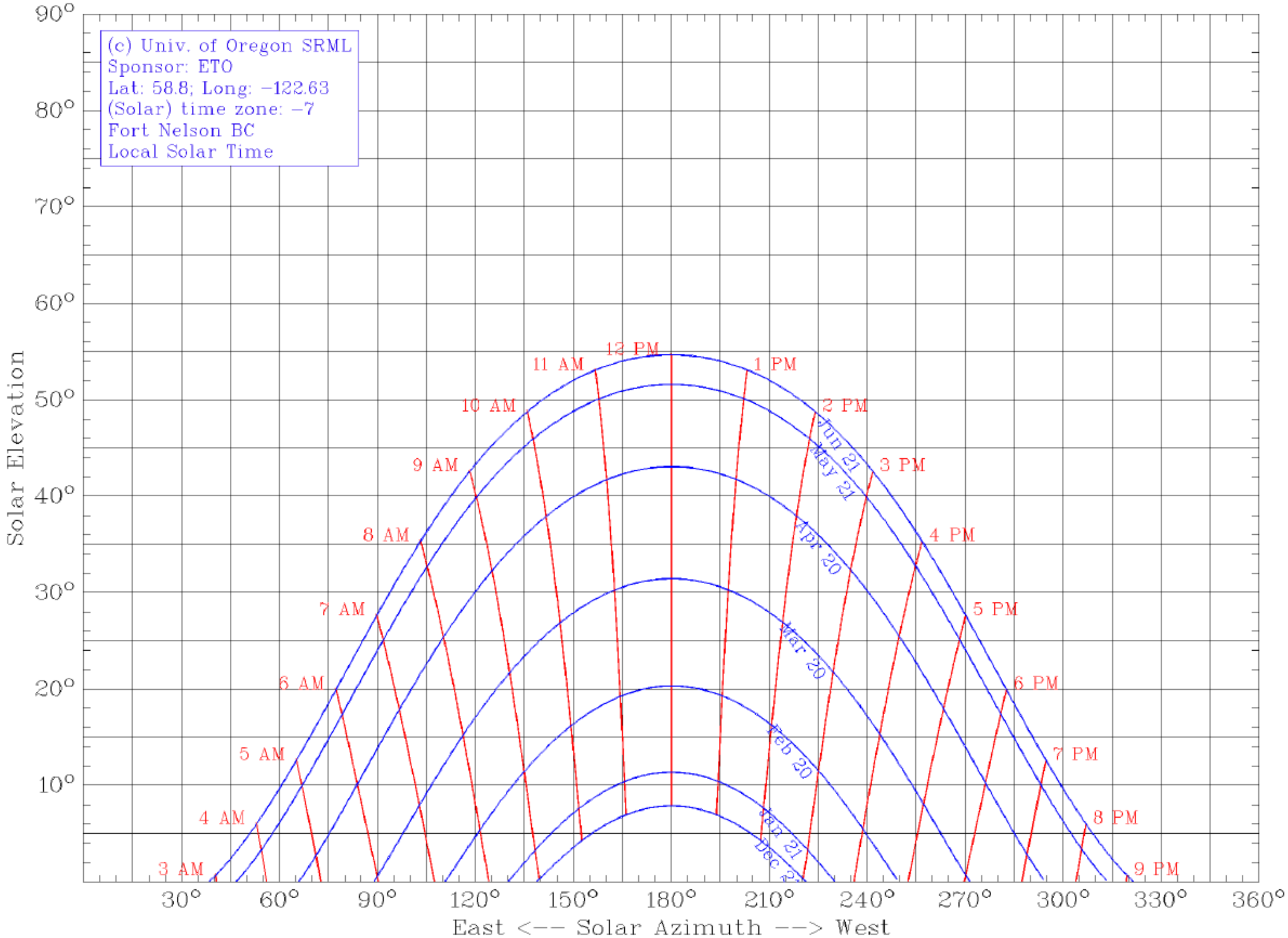

Figure C-9. Sun-path chart: Fort Nelson, B.C.

Appendix D. How to Estimate PV Array Area: Power-Generation Charts for Various Locations in British Columbia

Tables D-1 to D-11 can be used to estimate the PV array area for a particular annual energy use. This is done by dividing the grand total household energy consumption (as calculated in Appendix E) by the value in the tables below that corresponds to the geographic location, slope, and orientation of the PV array.

For example, suppose the total annual energy consumption for a home is 12,000 kilowatt hours per year (kWh/yr) and the home is located in Nelson, British Columbia, and the main south facing roof slope is 30 degrees to the horizontal. Based on the table for Nelson (Table D-7) we see that a PV array of that slope and orientation would produce 254 kW/yr/m^2. Then divide 12,000 kWh/yr by 254 kW/yr/m^2 to get 47.25 m^2. This is the PV array area needed, based on the following assumptions:

- a grid-connected PV system
- unshaded exposure to sunlight over the whole day
- 15.4%-efficient 200-watt solar modules
- 90%-efficient inverter
- 10% miscellaneous losses

The data in the tables below are based on these assumptions. The actual roof area would have to be slightly larger than 47.25 m^2 in order to accommodate the particular PV panel being used and to allow access for servicing. The final PV array area would be determined by the PV supplier or installer.

Alternatively the annual power production of PV arrays and their areas can be calculated using RETscreen 4 software (CanmetENERGY 2011) or PVWatts software (Renewable Resource Data Center 2012).

Table D-1. PV power-generation chart: Victoria, B.C.

Victoria				
	South	30°Southwest / east	45°Southwest / east	East / West
Slope in Degrees	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²
0	201	201	201	201
10	213	211	209	199
20	221	218	214	194
30	225	221	215	189
40	225	220	213	182
45	223	217	211	178
50	220	214	208	173
60	210	205	198	164
70	197	193	187	153
80	180	177	172	141
90	160	158	154	129

Table D-2. PV power-generation chart: Nanaimo, B.C.

Nanaimo				
	South	30°Southwest / east	45°Southwest / east	East / West
Slope in Degrees	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²
0	197	197	197	197
10	208	207	205	195
20	216	213	209	190
30	219	215	210	185
40	218	214	208	178
45	216	211	206	174
50	213	208	202	170
60	204	199	193	161
70	191	187	181	150
80	174	171	167	139
90	154	153	150	127

Table D-3. PV power-generation chart: Vancouver, B.C.

Vancouver	Orientation			
	South	30°Southwest / east	45°Southwest / east	East / West
Slope in Degrees	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²
0	194	194	194	194
10	206	204	202	192
20	213	210	206	188
30	216	212	207	182
40	215	211	205	176
45	213	208	203	172
50	210	205	199	168
60	201	196	190	159
70	188	184	179	148
80	171	169	164	137
90	152	150	148	125

Table D-4. PV power-generation chart: Kamloops, B.C.

Kamloops				
	South	30°Southwest / east	45°Southwest / east	East / West
Slope in Degrees	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²
0	211	211	211	211
10	228	226	223	209
20	241	236	231	205
30	249	243	235	200
40	252	244	236	193
45	251	243	234	190
50	249	241	232	186
60	242	234	224	177
70	229	222	213	167
80	212	206	198	155
90	191	186	180	143

Table D-5. PV power-generation chart: Kelowna, B.C.

Kelowna				
	South	30°Southwest / east	45°Southwest / east	East / West
Slope in Degrees	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²
0	214	214	214	214
10	233	230	227	211
20	248	243	236	207
30	257	250	242	202
40	262	253	243	196
45	262	253	242	192
50	261	251	240	188
60	254	244	232	180
70	242	233	222	169
80	225	217	206	157
90	204	197	188	145

Table D-6. PV power-generation chart: Osoyoos, B.C.

Osyoos				
	South	30°Southwest / east	45°Southwest / east	East / West
Slope in Degrees	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²
0	211	211	211	211
10	229	226	223	209
20	242	237	231	205
30	250	244	236	199
40	253	245	236	193
45	253	244	235	189
50	251	242	232	185
60	243	235	224	175
70	231	223	213	165
80	214	206	197	152
90	192	186	179	140

Table D-7. PV power-generation chart: Nelson, B.C.

Nelson				
	South	30°Southwest / east	45°Southwest / east	East / West
Slope in Degrees	kWh/yr./m^2	kWh/yr./m^2	kWh/yr./m^2	kWh/yr./m^2
0	213	213	213	213
10	231	229	225	210
20	245	240	234	206
30	254	247	239	201
40	258	250	240	194
45	258	249	239	191
50	257	247	237	186
60	250	240	228	177
70	237	228	217	167
80	220	212	202	154
90	199	192	184	142

Table D-8. PV power-generation chart: Cranbrook, B.C.

Cranbrook				
	South	30°Southwest / east	45°Southwest / east	East / West
Slope in Degrees	kWh/yr./m^2	kWh/yr./m^2	kWh/yr./m^2	kWh/yr./m^2
0	219	219	219	219
10	237	234	231	216
20	251	246	240	212
30	260	253	245	207
40	263	255	246	201
45	263	256	245	197
50	262	253	243	193
60	255	246	235	184
70	242	234	224	174
80	225	218	209	163
90	204	198	191	150

Table D-9. PV power-generation chart: Invermere, B.C.

Invermere				
	South	30°Southwest / east	45°Southwest / east	East / West
Slope in Degrees	kWh/yr./m^2	kWh/yr./m^2	kWh/yr./m^2	kWh/yr./m^2
0	212	212	212	212
10	232	229	226	210
20	247	242	236	207
30	258	251	242	202
40	264	255	245	197
45	265	256	245	195
50	265	255	243	191
60	260	250	238	184
70	250	240	229	176
80	236	227	216	166
90	217	209	200	155

Table D-10. PV power-generation chart: Prince George, B.C.

Prince George				
	South	30°Southwest / east	45°Southwest / east	East / West
Slope in Degrees	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²
0	187	187	187	187
10	202	200	197	185
20	213	209	204	182
30	220	215	208	178
40	222	216	209	172
45	222	216	208	170
50	221	214	206	170
60	215	208	199	166
70	204	198	190	159
80	190	185	178	150
90	173	168	162	130

Table D-11. PV power-generation chart: Fort St. John, B.C.

Fort St. John				
	South	30°Southwest / east	45°Southwest / east	East / West
Slope in Degrees	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²	kWh/yr./m²
0	204	204	204	204
10	228	224	220	201
20	248	241	234	199
30	262	254	244	197
40	272	262	249	194
45	275	264	250	192
50	276	264	251	189
60	274	262	247	183
70	266	254	240	176
80	253	241	228	167
90	235	225	212	157

Appendix E. How to Calculate the Total Annual Electrical Energy Consumption

Step 1: Develop a Lighting Plan and Calculate the Total Annual Energy Consumed by Interior and Exterior Lighting

Developing a lighting plan will allow all lighting fixtures and lamps to be identified at the design stage. It will also aid in fully exploiting the daylighting opportunities of the design. To help minimize electrical energy consumption, use only linear fluorescent, compact fluorescent and LED lamps. Look for lamps and fixtures labelled with the ENERGYSTAR logo. Typically most lights are controlled by motion detectors with manual override, and in largely daylit areas daylight sensors are used to dim or switch lights off when daylight levels are high enough. When installing compact fluorescent lamps, ensure that they incorporate dimmable ballasts. In addition, install a central “green switch” by the front door, in the master bedroom, and by the back door to allow all unnecessary circuits and lights to be easily switched off at night and when the occupants leave. Experience has shown that all of these switching functions are most easily met using programmable wireless switches and wireless sensors based on EnOcean protocols.[36]

A spreadsheet, such as that shown in Table E-1, is used to estimate a home’s total annual lighting energy use. The spreadsheet identifies each lamp and its power consumption. Then, for a typical day of each month, the number of hours the lamp will operate is estimated. The estimate is based on the activities that are undertaken in each space, the daylight exposure of the space, and the number of hours of daylight that occur in a typical day for each month. Exterior lighting must also be accounted for. The number of hours of daylight for a typical day in a particular month is derived from the sun-path charts that are discussed in Appendix C.

For each month, the number of hours per day that the lighting operates is multiplied by the number of days in the month; the monthly values are totalled to give the number of hours per year the lighting operates in each room. The hours of operation are then multiplied by the wattage rating of the lights and the total watt hours of energy consumption is calculated. The annual lighting energy consumption for all rooms are then added together to obtain an annual amount for the home; this is then divided by 1000 to get the kWhr/yr of electricity required for lighting.

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[36] See http://www.enocean.com.

Table E-1. Calculation of the total annual electrical energy consumed by interior and exterior lighting: sample spreadsheet.

Lighting Load Calculation							**Hours of Daylight for Typical Day / Month**														
Lighting automatically switched off by							9	10	11	13	15	16	15	13	11	10	9	8			
motion detectors or daylight sensors							Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
							Days / Month														
	Ref	**Light Source**	Ref	**Light Source**	Ref	**Light Source**	31	28	31	30	31	30	31	31	30	31	30	31	Annual Totals	Total / Room	Total
Room / Space		Watts		Watts		Watts	**Estimated Hours of Use Daily Per Month**												Hours	Watts	Watt Hours / Room
Entry Hallway	M1	23	M2	7	M3	16	2	2	2	2	2	2	2	2	2	2	2	2	730	46	33580
Main Floor Bathroom	M4	13	M5	16	M6		1	1	1	1	1	1	1	1	1	1	1	1	365	29	10585
Dining Room	M7	16	M8	16	M9	16	2	2	2	2	2	2	2	2	2	2	2	2	730	48	35040
Kitchen Over Island	M10	23	M11	23			9	8	7	5	3	2	3	5	7	8	9	10	2309	46	106214
Kitchen General Lighting	M12	96					9	8	7	5	3	2	3	5	7	8	9	10	2309	96	221664
Kitchen Under Cabinet	M13	15					2	2	2	2	2	2	2	2	2	2	2	2	730	15	10950
Office	M14	28	M15	28	M16	7	4.5	4	3.5	2.5	1.5	1	1.5	2.5	3.5	4	4.5	5	1154.5	63	72733.5
Family Room	M17	28	M18	36	M19	36	10	10	9	9	8	6	6	6	8	9	10	10	3068	100	306800
Laundry	M20	36	M21	36			4	4	4	4	4	4	4	4	4	4	4	4	1460	72	105120
2nd Floor Bathroom	S1	13		13			2	2	2	2	2	2	2	2	2	2	2	2	730	26	18980
Stairs	M22	39					1	1	1	1	1	1	1	1	1	1	1	1	365	39	14235
2nd Floor Hall	S2	168					1	1	1	1	1	1	1	1	1	1	1	1	365	168	61320
Bedroom	S3	23					3	3	3	3	3	3	3	3	3	3	3	3	1095	23	25185
Bedroom	S4	23					3	3	3	3	3	3	3	3	3	3	3	3	1095	23	25185
Master Bedroom	S5	96					3	3	3	3	3	3	3	3	3	3	3	3	1095	96	105120
MB Ensuite	S6	16	S7	16			2	2	2	2	2	2	2	2	2	2	2	2	730	32	23360
Walk-in Closet	S 8	23	S9	23			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	182.5	46	8395
											Total Lighting Electrical Consumption kWh / yr										**1,184**

Step 2: Calculate the Total Annual Energy Consumed by Major Household Appliances

This involves compiling a list of all the makes and models of major household appliances to be used in the home, along with their annual energy consumption. When selecting appliances for energy efficiency, consider ENERGYSTAR-rated models and models that meet CEE Tier 2 or 3 ratings. Energy consumption information is supplied as part of their EnerGuide rating[37] or it can be obtained online from the Consortium for Energy Efficiency (CEE).[38]

The annual energy consumption values for each major household appliance are then totalled for the year as shown in Table E-2.

Table E-2. Calculation of total annual electrical energy consumed by major household appliances: sample spreadsheet.

Main-floor appliances	Energy consumption		Make/brand	Model	Source of consumption information
	(kWh/yr)	(kWh/day)			
Refrigerator	562		Any	RXX1	EnerGuide Rating
Stove	330		Any	SXX1	EnerGuide Rating
Clothes washer	107		Any	CWXX1	EnerGuide Rating
Dryer	880		Any	DXX1	EnerGuide Rating
Dishwasher	280		Any	DWXX1	EnerGuide Rating
Total	2159	5.92			

Step 3: Compile a List of Other Household Electrical Devices and Calculate their Total Annual Electrical Energy Consumption

Compile a list of household electrical devices other than major household appliances, heating and cooling equipment, and lighting. In some cases the annual electrical energy consumption will be provided by the manufacture and in many cases it will not. Refer to Table E-3 for typical values of various devices.

Using a spreadsheet, such as the one in Table E-4, identify the electrical devices on a room-by-room basis and list their annual power consumption. Total these values to calculate the annual energy consumption.

[37] See http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.welcome-bienvenue&language_langue=en.
[38] See http://library.cee1.org/.

Table E-3. Typical energy-consumption values for various household electronic devices: sample spreadsheet.

Electrical Device	Typical Energy Consumption (kWh/yr		Electrical Device	Typical Energy Consumption (kWh/yr	
General Household			Bathroom		
Sump pump	40		Hair dryer	41.1	
Carbon monoxide detector	17.5		Curling iron	1	
Smoke detectors	3.5		Electric shaver	1	
Doorbell	44		Electric toothbrush charger	11.5	
			Beard trimmer	1	
Home Entertainment					
Digital TV	391.9		Garage and Workshop		
VCR	47.2		Auto block heater	250	
DVD player or recorder/player	30		Lawn mower (electric)	42.9	
DVD/VCR combo	49.8		Heat tape	100	
Video gaming system	20.4		Kiln	50	
Clock radio	14.9		Pipe and gutter heaters	53	
Boombox/portable stereo	16.8		Shop tools	26.4	
Compact stereo	81.3		Cordless power tool chargers	16	
Component/rack stereo	121.4		Garage door opener	35	
Power speakers	24.4				
Subwoofer	68.3		Bedroom		
Radio	9.1		Humidifier	100	
Equalizer	14.7		Waterbed	1095.9	
Satellite dish box	125.9		Electric blanket	120	
Cable box	134.1		Clock	26	
Personal video recorders	236.5		Fan (portable)	11.3	
Home theater (HTIB)	88.7				
			Other		
Kitchen			Small freshwater aquarium (5–20 gal)	105	
Coffee maker	61.2		Medium freshwater aquarium (20–40 gal)	180	
Toaster oven	32.3		Large freshwater aquarium (40-60 gal)	340	
Toaster	45.9		Small marine aquarium (5–20 gal)	245	
Waffle iron	25		Medium marine aquarium (20–40 gal)	615	
Blender	7		Large marine aquarium (40–60 gal)	740	
Can opener	3		Vacuum cleaner (upright)	42.2	
Electric grill	180		Battery charger – camcorder	2.3	
Hand mixer	2		Battery charger – digital camera	7.2	
Electric griddle	6		Battery charger – toy	12.8	
Popcorn popper	5		Battery charger – two-way radio	3.9	
Espresso machine	19		Battery charger – MP3 player	5.6	
Instant hot water dispenser	160		Battery charger – stand-alone	1	
Hot plate	30		Vacuum cleaner (cordless)	41	
Food slicer	1		Heating pads	3	
Electric knife	1		Surge protector/power strip	3.9	
Broiler	80		Timer (lighting)	20.1	
Deep fryer	20		Timer (irrigation)	45.2	
Trash compactor	50		Iron	52.7	
Slow cooker/crock pot	16		Baby monitor	22.8	
Garbage disposal	10		Heat lamp	13	
Home Office			Outdoor		
Laptop PC (Plugged In)	72.1		Pool heater (electric)	2300	
Desktop PC w/Speakers	234		Pool pump (electric)	1102	
PC monitor	85.1		Hot tub/spa (electric heating and pump)	2040.7	
Printer (laser)	92.5		Hot tub/spa pump (electric for gas spa)	460	
Printer (inkjet)	15.5		Well pump (electric)	400	
Dot matrix printer	115				
DSL/cable modem	52.6				
Scanner	49				
Copy machine	25				
Fax machine	326.3				
Multifunction device	58.8				
Cordless phone charger	27.3				
Cell phone charger	3.5				
Answering machine	33.5				
Battery charger – PDA	6.1				

Table E-4. Sample calculation of annual electrical energy consumption from electrical devices: sample spreadsheet.

Electrical Devices Annual Energy Consumption Calculation						
Room	Device	Annual Energy Consumption		Room	Device	Annual Energy Consumption
		kWh/yr				kWh/yr
Entry				2nd Floor Hall		
	Door bell	4.4			Smoke detector	3.5
	Entry Subtotal	4.4			Smoke detector	3.5
					2nd Floor Hall Subtotal	7
Kitchen						
	Radio	9.1		Master Bedroom		
	Coffee maker	61.2			Digital TV	391.9
	Toaster	45.9			VCR	47.2
	Waffle iron	25			Cable box	134.1
	Blender	7			Clock radio	16.8
	Hand mixer	2			Master Bedroom Subtotal	590
	Popcorn popper	5				
	Instant hot water dispenser	160		MB Ensuite		
	Slow cooker	16			Hair dryer	41.1
	Kitchen Subtotal	331.2			Electric shaver	1
					Electric toothbrush charger	11.5
Home Office					MB Ensuite Subtotal	53.6
	Notebook computer	72.1				
	Laser printer	92.5		Bedroom		
	DSL/ cable modem	52.6			Notebook computer	72.1
	Scanner	49			Cel phone charger	3.5
	Cordless phone charger	27.3			Clock radio	16.8
	Cel phone charger	3.5			Bedroom Subtotal	92.4
	Home Office Subtotal	297				
				Bedroom		
Family Room					Notebook computer	72.1
	Digital TV	391.9			Cel phone charger	3.5
	VCR	47.2			Clock radio	16.8
	Cable box	134.1			Bedroom Subtotal	92.4
	Fresh water aquarium	105				
	Family Room Subtotal	678.2		Bathroom		
					Hair dryer	41.1
Laundry					Electric shaver	1
	Vacuum cleaner	42.2			Electric toothbrush charger	11.5
	Iron	52.7			Bathroom Subtotal	53.6
	Laundry Subtotal	94.9				
Grand Total Electrical Device Annual Energy Consumption		**2294.7**		**Grand Total Electrical Device Average Daily Energy Consumption**		**6.29**
		kWh/yr				**kWh/day**

Step 4: Calculate the Total Annual Energy Consumed by HVAC Systems

Using energy analysis software such as HOT2000 (Natural Resources Canada 2010), calculate the annual energy consumption of the space-heating, space cooling, water-heating, and ventilation equipment. This will include energy to operate fans and pumps as well as the energy actually consumed in heating and cooling. Hot2000 requires the entry of information about lighting, appliance, and electrical device loads in order to calculate the heating and cooling requirements. Use the previously calculated values to do this accurately.

Step 5: Calculate the Building's Grand Total Annual Energy Consumption

Draw on the results calculated in the preceding spreadsheets and the energy analysis to calculate the total annual energy consumption of the home. If the project is to be net-zero energy, the size of the renewable energy system can now be calculated (Table E-5, Table E-6).

Table E-5. Calculation of total annual electrical energy loads, for determining the size of the renewable energy system: sample calculation showing total annual electrical consumption, where an air-source heat pump is used for space-heating and water-heating backup. In order for the home to be net-zero energy, the grand total energy consumption will have to be met by the renewable energy system.

Household equipment	Energy consumption (kWhr/yr)	Source of consumption information
Interior and exterior lighting	1,184	Lighting calculation spreadsheet
Household appliances	2,159	Household appliance spreadsheet
Electrical devices	2,295	Electrical devices spreadsheet
Space-heating equipment		
Air-source heat pump	2,465	HOT2000 Energy Analysis
Air-handler fan	247	
Water heating		
Air-source heat pump	1,054	HOT2000 Energy Analysis
Solar water-heater pump	0	PV-powered pump
Ventilation		
HRV + range hood	853	HOT2000 Energy Analysis
Grand Total	10,257	

Table E-6. Calculation of total annual electrical energy loads for determining the size of the renewable energy system. Sample calculation showing total annual equivalent electrical consumption, where a high-efficiency, condensing gas furnace and a high-efficiency, gas, backup water heater are used. In order for the project to be net-zero energy, the grand total energy consumption will have to be met by the renewable energy system.

Household equipment	Energy consumption		Source consumption information
	(MJ/yr)	(kWhr/yr)	
Interior and exterior lighting		1,184	Lighting calculation spreadsheet
Household appliances		2,159	Household appliance spreadsheet
Electrical devices		2,295	Electrical devices spreadsheet
Ventilation			
HRV + range hood		853	HOT2000 Energy Analysis
Space-heating equipment			
Gas/propane-fired furnace (95% AFUE)	28,018	7,783	HOT2000 Energy Analysis
Furnace fan		247	HOT2000 Energy Analysis
Water heating			
Solar water heater		0	PV-powered DC pump
Gas/propane-fired water heater (95% efficient)	5,992	1,664	HOT2000 Energy Analysis
Grand Total		14,521	

Appendix F. Prescriptive Path Tables

Climate Zone >3000 ≤ 4000 Degree Days Below 18 C*

High Efficiency Gas Heating Systems	Above Grade Exterior Walls Effective Thermal Resistance		Ceilings Effective Thermal Resistance		Basement and Conditioned Crawlspace Walls Effective Thermal Resistance		Crawlspace and Basement Floor Slabs Effective Thermal Resistance		Cantilevered Floors or Floors Over Unconditioned Space Effective Thermal Resistance		Exterior Doors		Fixed Windows W/ High SHGC** Effective Minimum Thermal Resistance		Opening Windows and Glazed Doors W/ High SHGC* Effective Thermal Resistance	
Insulation	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI
Prescriptive Effective*** Minimum Insulation Values for Single Family Homes With Up to 15% of the Heated Floor Area in Windows	50	8.81	80	14.09	40	7.04	20	3.52	40	7.04	6	1.06	6	1.06	4.5	0.79

Airtightness	
Maximum Normalized Leakage Area (NLA) of 0.7 cm2/m2 @ 10 Pa or Maximum Air Leakage Rate 0.75 ACH @ 50 Pa When Tested According to CAN/CGSB2-149.10-M86	
Ventilation	
Fully Distributed Heat Recovery Ventilation System with HRV Rated With a Sensible Heat Recovery Efficiency of 80% @ 0C at 55L/s (117 cfm)	
South Window Area and Shading	
South Facing Window Area Maximum 5% of Heated Floor Area	
South Facing Window Overhang Depth Equal to 1/3 Window Height	
Electrical Loads	
Minimum Appliance Energy Ratings	
Range	Energy Star
Dishwasher	CEE**** Tier 1
Clothes Washer / Dryer	CEE Tier 3
Refrigerator	CEE Tier 3
Freezer	Energy Star
Minimum Electrical Device Energy Ratings	
Desk Top Computers	Energy Star
Computer Monitors	Energy Star
Notebook Computers	Energy Star
All Lamps	Linear Fluorescent, Compact Florescent or LED
All Room and Hallway Lighting	Controlled by Motion Detector Switch or Combined Daylighting and Motion Detector Switch With Manual Override
Maximum total average daily electrical energy consumption for all lighting, appliances and electrical devices (not including heating equipment) 16 kWh	
Heating Systems	
Space Heating	
	High Efficiency Condensing Gas Furnace with AFUE of 95% and an Electrically Commutated (ECM) Fan Motor
Air Distribution Systems	
	All ductwork joints and seams to be air tight sealed with a water based liquid sealer or aluminum foil tape
	Where possible ductwork to be run in conditioned spaces, when located in unconditioned spaces to insulated to a minimum of RSI 1.14 (R6.5)
	Air handler and furnace fans to be powered by electrically commutated motors (ECMs)
	HRV fans to be powered by electrically commutated motors (ECMs)
Domestic Water Heating	
	Condensing Gas Water Heater and CSA Rated Solar Water Heater With a Minimum CSIA Rating of 9940 MJ/yr. or
	CSA Rated Solar Water Heater With a Minimum CSIA Rating of 9940 MJ/yr. and a High Efficiency Electric Hot Water Tank
PV Array Area Allocation	Assuming a Due South Facing Array at 40 Degrees to the Horizontal 200 Peak Watt Rated Panels With Conversion Efficiency of 15.4%, 90% Efficient Inverter and 10% Misc. Losses PV area can be estimated at 0.34 X Floor Area for interior regions, for the north coast PV area can be estimated at 0.53 X Floor Area
	Final PV Array Area Will be Determined by System Designer/ Supplier

* Degree Days below 18 C for many locations in British Columbia can be found Table C-2 Division B - Appendix C of the 2012 BC Building Code
** Solar Heat Gain Coefficient of the Triple Glazed Insulated Glass Unit to be a Minimum of 0.55
*** Effective Insulation Values Account for Thermal Bridging and Represent the Thermal Resistance of the Entire Assembly See Appendices J, K, M & N
**** Consortium for Energy Efficiency Appliance Ratings Available at http://www.cee1.org/content/cee-program-resources

Climate Zone >4000 ≤ 5000 Degree Days Below 18 C*

Air Source or Ground Source Heat Pump Heating Systems	Above Grade Exterior Walls Effective Thermal Resistance		Ceilings Effective Thermal Resistance		Basement and Conditioned Crawlspace Walls Effective Thermal Resistance		Crawlspace and Basement Floor Slabs Effective Thermal Resistance		Cantilevered Floors or Floors Over Unconditioned Space Effective Thermal Resistance		Exterior Doors		Fixed Windows W/ High SHGC** Effective Minimum Thermal Resistance		Opening Windows and Glazed Doors W/ High SHGC* Effective Thermal Resistance	
Insulation	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI
Prescriptive Effective*** Minimum Insulation Values for Single Family Homes With Up to 12% of the Heated Floor Area in Windows	40	7.04	80	14.09	40	7.04	20	3.52	40	7.04	6	1.06	6	1.06	4.5	0.79
Airtightness																
Maximum Normalized Leakage Area (NLA) of 0.35cm2/m2 @ 10 Pa or Maximum Air Leakage Rate 0.75 ACH @ 50 Pa When Tested According to CAN/CGSB2-149.10-M86																
Ventilation																
Fully Distributed Heat Recovery Ventilation System with HRV Rated With a Sensible Heat Recovery Efficiency of 80% @ 0C at 55L/s (117 cfm)																
South Window Area and Shading																
South Facing Window Area Maximum 5% of Heated Floor Area																
South Facing Window Overhang Depth Equal to 1/3 Window Height																
Electrical Loads																
Minimum Appliance Energy Ratings																
Range	Energy Star															
Dishwasher	CEE**** Tier 1															
Clothes Washer / Dryer	CEE Tier 3															
Refrigerator	CEE Tier 3															
Freezer	Energy Star															
Minimum Electrical Device Energy Ratings																
Desk Top Computers	Energy Star															
Computer Monitors	Energy Star															
Notebook Computers	Energy Star															
All Lamps	Linear Fluorescent, Compact Florescent or LED															
All Room and Hallway Lighting	Controlled by Motion Detector Switch or Combined Daylighting and Motion Detector Switch With Manual Override															
Maximum total average daily electrical energy consumption for all lighting, appliances and electrical devices (not including heating equipment) 16 kWh																
Heating Systems																
Space Heating																
	High Efficiency Cold Climate Air Source Heat Pump With Minimum COP of 1.9 @ -9C															
	Ground Source Heat Pump With Minimum COP of 3.0															
Air Distribution Systems																
	All ductwork joints and seams to be air tight sealed with a water based liquid sealer or aluminum foil tape															
	Where possible ductwork to be run in conditioned spaces, when located in unconditioned spaces to insulated to a minimum of RSI 1.14 (R6.5)															
	Air handler and furnace fans to be powered by electrically commutated motors (ECMs)															
	HRV fans to be powered by electrically commutated motors (ECMs)															
Domestic Water Heating																
	Exterior Air Source Heat Pump Water Heater With Minimum Annual COP of 2.0 or															
	Water Heating Provided by Ground Source Heat Pump Desuper Heater or															
	CSA Rated Solar Water Heater With a Minimum CSIA Rating of 9940 MJ/yr. and a High Efficiency Electric Hot Water Tank															
PV Array Area Allocation	Assuming a Due South Facing Array at 45 Degrees to the Horizontal 200 Peak Watt Rated Panels With Conversion															
	Efficiency of 15.4%, 90% Efficient Inverter and 10% Misc. Losses PV area can be estimated at 0.4 X Floor Area,															
	Final PV Array Area Will be Determined by System Designer/ Supplier															

* Degree Days below 18 C for many locations in British Columbia can be found Table C-2 Division B - Appendix C of the 2012 BC Building Code

** Solar Heat Gain Coefficient of the Triple Glazed Insulated Glass Unit to be a Minimum of 0.55

*** Effective Insulation Values Account for Thermal Bridging and Represent the Thermal Resistance of the Entire Assembly See Appendices J, K, M & N

**** Consortium for Energy Efficiency Appliance Ratings Available at http://www.cee1.org/content/cee-program-resources

Climate Zone >4000 ≤ 5000 Degree Days Below 18 C*																
High Efficiency Gas Heating Systems	Above Grade Exterior Walls Effective Thermal Resistance		Ceilings Effective Thermal Resistance		Basement and Conditioned Crawlspace Walls Effective Thermal Resistance		Crawlspace and Basement Floor Slabs Effective Thermal Resistance		Cantilevered Floors or Floors Over Unconditioned Space Effective Thermal Resistance		Exterior Doors		Fixed Windows W/ High SHGC** Effective Minimum Thermal Resistance		Opening Windows and Glazed Doors W/ High SHGC* Effective Thermal Resistance	
Insulation	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI
Prescriptive Effective*** Minimum Insulation Values for Single Family Homes With Up to 10% of the Heated Floor Area in Windows	60	10.57	80	14.09	40	7.04	20	3.52	60	10.57	6	1.06	6	1.06	4.5	0.79
Airtightness																
Maximum Normalized Leakage Area (NLA) of 0.35cm2/m2 @ 10 Pa or Maximum Air Leakage Rate 0.75 ACH @ 50 Pa When Tested According to CAN/CGSB2-149.10-M86																
Ventilation																
Fully Distributed Heat Recovery Ventilation System with HRV Rated With a Sensible Heat Recovery Efficiency of 80% @ 0C at 55L/s (117 cfm)																
South Window Area and Shading																
South Facing Window Area Maximum 5% of Heated Floor Area																
South Facing Window Overhang Depth Equal to 1/3 Window Height																
Electrical Loads																
Minimum Appliance Energy Ratings																
Range	Energy Star															
Dishwasher	CEE**** Tier 1															
Clothes Washer / Dryer	CEE Tier 3															
Refrigerator	CEE Tier 3															
Freezer	Energy Star															
Minimum Electrical Device Energy Ratings																
Desk Top Computers	Energy Star															
Computer Monitors	Energy Star															
Notebook Computers	Energy Star															
All Lamps	Linear Fluorescent, Compact Florescent or LED															
All Room and Hallway Lighting	Controlled by Motion Detector Switch or Combined Daylighting and Motion Detector Switch With Manual Override															
Maximum total average daily electrical energy consumption for all lighting, appliances and electrical devices (not including heating equipment) 16 kWh																
Heating Systems																
Space Heating																
	High Efficiency Condensing Gas Furnace with AFUE of 95% and an Electrically Commutated (ECM) Fan Motor															
Air Distribution Systems																
	All ductwork joints and seams to be air tight sealed with a water based liquid sealer or aluminum foil tape															
	Where possible ductwork to be run in conditioned spaces, when located in unconditioned spaces to insulated to a minimum of RSI 1.14 (R6.5)															
	Air handler and furnace fans to be powered by electrically commutated motors (ECMs)															
	HRV fans to be powered by electrically commutated motors (ECMs)															
Domestic Water Heating																
	Condensing Gas Water Heater and CSA Rated Solar Water Heater With a Minimum CSIA Rating of 9940 MJ/yr. or															
	CSA Rated Solar Water Heater With a Minimum CSIA Rating of 9940 MJ/yr. and a High Efficiency Electric Hot Water Tank															
PV Array Area Allocation	Assuming a Due South Facing Array at 45 Degrees to the Horizontal 200 Peak Watt Rated Panels With Conversion Efficiency of 15.4%, 90% Efficient Inverter and 10% Misc. Losses PV area can be estimated at 0.45 X Floor Area, Final PV Array Area Will be Determined by System Designer/ Supplier															

* Degree Days below 18 C for many locations in British Columbia can be found Table C-2 Division B - Appendix C of the 2012 BC Building Code

** Solar Heat Gain Coefficient of the Triple Glazed Insulated Glass Unit to be a Minimum of 0.55

*** Effective Insulation Values Account for Thermal Bridging and Represent the Thermal Resistance of the Entire Assembly See Appendices J, K, M & N

**** Consortium for Energy Efficiency Appliance Ratings Available at http://www.cee1.org/content/cee-program-resources

Climate Zone >5000 ≤ 6000 Degree Days Below 18 C*

Air Source or Ground Source Heat Pump Heating Systems	Above Grade Exterior Walls Effective Thermal Resistance		Ceilings Effective Thermal Resistance		Basement and Conditioned Crawlspace Walls Effective Thermal Resistance		Crawlspace and Basement Floor Slabs Effective Thermal Resistance		Cantilevered Floors or Floors Over Unconditioned Space Effective Thermal Resistance		Exterior Doors		Fixed Windows W/ High SHGC** Effective Minimum Thermal Resistance		Opening Windows and Glazed Doors W/ High SHGC* Effective Thermal Resistance	
Insulation	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI		
Prescriptive Effective*** Minimum Insulation Values for Single Family Homes With Up to 10% of the Heated Floor Area in Windows	50	8.81	80	14.09	40	7.04	20	3.52	50	8.81	6	1.06	6	1.06	4.5	0.79		
Airtightness																		
Maximum Normalized Leakage Area (NLA) of 0.35cm2/m2 @ 10 Pa or Maximum Air Leakage Rate 0.75 ACH @ 50 Pa When Tested According to CAN/CGSB2-149.10-M86																		
Ventilation																		
Fully Distributed Heat Recovery Ventilation System with HRV Rated With a Sensible Heat Recovery Efficiency of 80% @ 0C at 55L/s (117 cfm)																		
South Window Area and Shading																		
South Facing Window Area Maximum 5% of Heated Floor Area																		
South Facing Window Overhang Depth Equal to 1/3 Window Height																		
Electrical Loads																		
Minimum Appliance Energy Ratings																		
Range	Energy Star																	
Dishwasher	CEE**** Tier 1																	
Clothes Washer / Dryer	CEE Tier 3																	
Refrigerator	CEE Tier 3																	
Freezer	Energy Star																	
Minimum Electrical Device Energy Ratings																		
Desk Top Computers	Energy Star																	
Computer Monitors	Energy Star																	
Notebook Computers	Energy Star																	
All Lamps	Linear Fluorescent, Compact Florescent or LED																	
All Room and Hallway Lighting	Controlled by Motion Detector Switch or Combined Daylighting and Motion Detector Switch With Manual Override																	
Maximum total average daily electrical energy consumption for all lighting, appliances and electrical devices (not including heating equipment) 16 kWh																		
Heating Systems																		
Space Heating																		
	High Efficiency Cold Climate Air Source Heat Pump With Minimum COP of 1.8 @ -15°C																	
	Ground Source Heat Pump With Minimum COP of 3.0																	
Air Distribution Systems																		
	All ductwork joints and seams to be air tight sealed with a water based liquid sealer or aluminum foil tape																	
	Where possible ductwork to be run in conditioned spaces, when located in unconditioned spaces to insulated to a minimum of RSI 1.14 (R6.5)																	
	Air handler and furnace fans to be powered by electrically commutated motors (ECMs)																	
	HRV fans to be powered by electrically commutated motors (ECMs)																	
Domestic Water Heating																		
	Water Heating Provided by Ground Source Heat Pump Desuper Heater or CSA Rated Solar Water Heater With a Minimum CSIA Rating of 9940 MJ/yr. and a High Efficiency Electric Hot Water Tank																	
PV Array Area Allocation	Assuming a Due South Facing Array at 50 Degrees to the Horizontal 200 Peak Watt Rated Panels With Conversion Efficiency of 15.4%, 90% Efficient Inverter and 10% Misc. Losses PV area can be estimated at 0.36 X Floor Area, Final PV Array Area Will be Determined by System Designer/ Supplier																	

* Degree Days below 18 C for many locations in British Columbia can be found Table C-2 Division B - Appendix C of the 2012 BC Building Code

** Solar Heat Gain Coefficient of the Triple Glazed Insulated Glass Unit to be a Minimum of 0.55

*** Effective Insulation Values Account for Thermal Bridging and Represent the Thermal Resistance of the Entire Assembly See Appendices J, K, M & N

**** Consortium for Energy Efficiency Appliance Ratings Available at http://www.cee1.org/content/cee-program-resources

Climate Zone >5000 ≤ 6000 Degree Days Below 18 C*

High Efficiency Gas Heating Systems	Above Grade Exterior Walls Effective Thermal Resistance		Ceilings Effective Thermal Resistance		Basement and Conditioned Crawlspace Walls Effective Thermal Resistance		Crawlspace and Basement Floor Slabs Effective Thermal Resistance		Cantilevered Floors or Floors Over Unconditioned Space Effective Thermal Resistance		Exterior Doors		Fixed Windows W/ High SHGC** Effective Minimum Thermal Resistance		Windows and Glazed Doors W/ High SHGC* Effective Minimum Thermal Resistance	
Insulation	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI
Prescriptive Effective*** Minimum Insulation Values for Single Family Homes With Up to 10% of the Heated Floor Area in Windows	60	10.57	80	14.09	40	7.04	20	3.52	60	10.57	6	1.06	6	1.06	4.5	0.79
Airtightness																
Maximum Normalized Leakage Area (NLA) of 0.35cm2/m2 @ 10 Pa or Maximum Air Leakage Rate 0.75 ACH @ 50 Pa When Tested According to CAN/CGSB2-149.10-M86																
Ventilation																
Fully Distributed Heat Recovery Ventilation System with HRV Rated With a Sensible Heat Recovery Efficiency of 80% @ 0C at 55L/s (117 cfm)																
South Window Area and Shading																
South Facing Window Area Maximum 5% of Heated Floor Area																
South Facing Window Overhang Depth Equal to 1/3 Window Height																
Electrical Loads																
Minimum Appliance Energy Ratings																
Range	Energy Star															
Dishwasher	CEE**** Tier 1															
Clothes Washer / Dryer	CEE Tier 3															
Refrigerator	CEE Tier 3															
Freezer	Energy Star															
Minimum Electrical Device Energy Ratings																
Desk Top Computers	Energy Star															
Computer Monitors	Energy Star															
Notebook Computers	Energy Star															
All Lamps	Linear Fluorescent, Compact Florescent or LED															
All Room and Hallway Lighting	Controlled by Motion Detector Switch or Combined Daylighting and Motion Detector Switch With Manual Override															
Maximum total average daily electrical energy consumption for all lighting, appliances and electrical devices (not including heating equipment) 16 kWh																
Heating Systems																
Space Heating																
	High Efficiency Condensing Gas Furnace with AFUE of 95% and an Electrically Commutated (ECM) Fan Motor															
Air Distribution Systems																
	All ductwork joints and seams to be air tight sealed with a water based liquid sealer or aluminum foil tape															
	Where possible ductwork to be run in conditioned spaces, when located in unconditioned spaces to															
	insulated to a minimum of RSI 1.14 (R6.5)															
	Air handler and furnace fans to be powered by electrically commutated motors (ECMs)															
	HRV fans to be powered by electrically commutated motors (ECMs)															
Domestic Water Heating																
	Condensing Gas Water Heater and CSA Rated Solar Water Heater With a Minimum CSIA Rating of 9940 MJ/yr. or															
	CSA Rated Solar Water Heater With a Minimum CSIA Rating of 9940 MJ/yr. and a High Efficiency Electric Hot Water Tank															
PV Array Area Allocation	Assuming a Due South Facing Array at 50 Degrees to the Horizontal 200 Peak Watt Rated Panels With Conversion															
	Efficiency of 15.4%, 90% Efficient Inverter and 10% Misc. Losses PV area can be estimated at 0.39 X Floor Area,															
	Final PV Array Area Will be Determined by System Designer/ Supplier															

* Degree Days below 18 C for many locations in British Columbia can be found Table C-2 Division B - Appendix C of the 2012 BC Building Code
** Solar Heat Gain Coefficient of the Triple Glazed Insulated Glass Unit to be a Minimum of 0.55
*** Effective Insulation Values Account for Thermal Bridging and Represent the Thermal Resistance of the Entire Assembly See Appendices J, K, M & N
**** Consortium for Energy Efficiency Appliance Ratings Available at http://www.cee1.org/content/cee-program-resources

Climate Zone > 6000 ≤ 7000 Degree Days Below 18 C*

Air Source or Ground Source Heat Pump Heating Systems	Above Grade Exterior Walls Effective Thermal Resistance		Ceilings Effective Thermal Resistance		Basement and Conditioned Crawlspace Walls Effective Thermal Resistance		Crawlspace and Basement Floor Slabs Effective Thermal Resistance		Cantilevered Floors or Floors Over Unconditioned Space Effective Thermal Resistance		Exterior Doors		Fixed Windows W/ High SHGC** Effective Minimum Thermal Resistance		Opening Windows and Glazed Doors W/ High SHGC* Effective Thermal Resistance	
Insulation	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI
Prescriptive Effective*** Minimum Insulation Values for Single Family Homes With Up to 10% of the Heated Floor Area in Windows	60	10.57	100	17.61	60	10.57	20	3.52	60	10.57	6	1.06	6	1.06	4.5	0.79

Airtightness	
Maximum Normalized Leakage Area (NLA) of 0.35cm2/m2 @ 10 Pa or Maximum Air Leakage Rate 0.75 ACH @ 50 Pa When Tested According to CAN/CGSB2-149.10-M86	
Ventilation	
Fully Distributed Heat Recovery Ventilation System with HRV Rated With a Sensible Heat Recovery Efficiency of 80% @ 0C at 55L/s (117 cfm)	
South Window Area and Shading	
South Facing Window Area Maximum 5% of Heated Floor Area	
South Facing Window Overhang Depth Equal to 1/3 Window Height	
Electrical Loads	
Minimum Appliance Energy Ratings	
Range	Energy Star
Dishwasher	CEE**** Tier 1
Clothes Washer / Dryer	CEE Tier 3
Refrigerator	CEE Tier 3
Freezer	Energy Star
Minimum Electrical Device Energy Ratings	
Desk Top Computers	Energy Star
Computer Monitors	Energy Star
Notebook Computers	Energy Star
All Lamps	Linear Fluorescent, Compact Florescent or LED
All Room and Hallway Lighting	Controlled by Motion Detector Switch or Combined Daylighting and Motion Detector Switch With Manual Override
Maximum total average daily electrical energy consumption for all lighting, appliances and electrical devices (not including heating equipment) 16 kWh	
Heating Systems	
Space Heating	
	High Efficiency Cold Climate Air Source Heat Pump With Minimum COP of 1.6 @ -20 °C
	Ground Source Heat Pump With Minimum COP of 3.0
Air Distribution Systems	
	All ductwork joints and seams to be air tight sealed with a water based liquid sealer or aluminum foil tape
	Where possible ductwork to be run in conditioned spaces, when located in unconditioned spaces to insulated to a minimum of RSI 1.14 (R6.5)
	Air handler and furnace fans to be powered by electrically commutated motors (ECMs)
	HRV fans to be powered by electrically commutated motors (ECMs)
Domestic Water Heating	
	Water Heating Provided by Ground Source Heat Pump Desuper Heater or
	CSA Rated Solar Water Heater With a Minimum CSIA Rating of 9940 MJ/yr. and a High Efficiency Electric Hot Water Tank
PV Array Area Allocation	Assuming a Due South Facing Array at 50 Degrees to the Horizontal 200 Peak Watt Rated Panels With Conversion Efficiency of 15.4%, 90% Efficient Inverter and 10% Misc. Losses PV area can be estimated at 0.38 X Floor Area, Final PV Array Area Will be Determined by System Designer/ Supplier

* Degree Days below 18 C for many locations in British Columbia can be found Table C-2 Division B - Appendix C of the 2012 BC Building Code

** Solar Heat Gain Coefficient of the Triple Glazed Insulated Glass Unit to be a Minimum of 0.55

*** Effective Insulation Values Account for Thermal Bridging and Represent the Thermal Resistance of the Entire Assembly See Appendices J, K, M & N

**** Consortium for Energy Efficiency Appliance Ratings Available at http://www.cee1.org/content/cee-program-resources

Climate Zone > 6000 ≤ 7000 Degree Days Below 18 C*

High Efficiency Gas Heating Systems	Above Grade Exterior Walls Effective Thermal Resistance		Ceilings Effective Thermal Resistance		Basement and Conditioned Crawlspace Walls Effective Thermal Resistance		Crawlspace and Basement Floor Slabs Effective Thermal Resistance		Cantilevered Floors or Floors Over Unconditioned Space Effective Thermal Resistance		Exterior Doors		Fixed Windows W/ High SHGC** Effective Minimum Thermal Resistance		Windows and Glazed Doors W/ High SHGC* Effective Minimum Thermal Resistance	
Insulation	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI	R	RSI
Prescriptive Effective*** Minimum Insulation Values for Single Family Homes With Up to 10% of the Heated Floor Area in Windows	60	10.57	100	17.61	60	10.57	20	3.52	60	10.57	6	1.06	6	1.06	4.5	0.79

Airtightness	
Maximum Normalized Leakage Area (NLA) of 0.35cm2/m2 @ 10 Pa or Maximum Air Leakage Rate 0.75 ACH @ 50 Pa When Tested According to CAN/CGSB2-149.10-M86	
Ventilation	
Fully Distributed Heat Recovery Ventilation System with HRV Rated With a Sensible Heat Recovery Efficiency of 80% @ 0C at 55L/s (117 cfm)	
South Window Area and Shading	
South Facing Window Area Maximum 5% of Heated Floor Area	
South Facing Window Overhang Depth Equal to 1/3 Window Height	
Electrical Loads	
Minimum Appliance Energy Ratings	
Range	Energy Star
Dishwasher	CEE**** Tier 1
Clothes Washer / Dryer	CEE Tier 3
Refrigerator	CEE Tier 3
Freezer	Energy Star
Minimum Electrical Device Energy Ratings	
Desk Top Computers	Energy Star
Computer Monitors	Energy Star
Notebook Computers	Energy Star
All Lamps	Linear Fluorescent, Compact Florescent or LED
All Room and Hallway Lighting	Controlled by Motion Detector Switch or Combined Daylighting and Motion Detector Switch With Manual Override
Maximum total average daily electrical energy consumption for all lighting, appliances and electrical devices (not including heating equipment) 16 kWh	
Heating Systems	
Space Heating	
	High Efficiency Condensing Gas Furnace with AFUE of 95% and an Electrically Commutated (ECM) Fan Motor
Air Distribution Systems	
	All ductwork joints and seams to be air tight sealed with a water based liquid sealer or aluminum foil tape
	Where possible ductwork to be run in conditioned spaces, when located in unconditioned spaces to insulated to a minimum of RSI 1.14 (R6.5)
	Air handler and furnace fans to be powered by electrically commutated motors (ECMs)
	HRV fans to be powered by electrically commutated motors (ECMs)
Domestic Water Heating	
	Condensing Gas Water Heater and CSA Rated Solar Water Heater With a Minimum CSIA Rating of 9940 MJ/yr. or
	CSA Rated Solar Water Heater With a Minimum CSIA Rating of 9940 MJ/yr. and a High Efficiency Electric Hot Water Tank
PV Array Area Allocation	Assuming a Due South Facing Array at 50 Degrees to the Horizontal 200 Peak Watt Rated Panels With Conversion Efficiency of 15.4%, 90% Efficient Inverter and 10% Misc. Losses PV area can be estimated at 0.42 X Floor Area, Final PV Array Area Will be Determined by System Designer/ Supplier

* Degree Days below 18 C for many locations in British Columbia can be found Table C-2 Division B - Appendix C of the 2012 BC Building Code

** Solar Heat Gain Coefficient of the Triple Glazed Insulated Glass Unit to be a Minimum of 0.55

*** Effective Insulation Values Account for Thermal Bridging and Represent the Thermal Resistance of the Entire Assembly See Appendices J, K, M & N

**** Consortium for Energy Efficiency Appliance Ratings Available at http://www.cee1.org/content/cee-program-resources

Appendix G. Table of Default Values to Use in HOT2000

In the HOT2000 software (Natural Resources Canada 2010), use the values in Table G-1 as default values when calculating an "envelope-only" EnerGuide Scores, i.e., to keep all of the parts of the home that affect energy use, other than the building envelope, at minimum.

Table G-1. HOT2000 default values, for standard operating conditions in a high-performance home.

Hot 2000 Defaults (Standard Operating Conditions)	
Main floor Heating set point	21.0 °C
Basement heated	Yes
Basement cooled	No
Basement set point	19.0 °C
Basement separate thermostat	No
Allowable daily temperature rise	Medium (2.8 °C = 5 °F)
Interior loads, lighting	3.0 kWh/day
Interior loads, appliances	9.0 kWh/day
Average exterior use	4.0 kWh/day
Hot water load	225.0 L/day
Hot water temperature	55.0 °C
Fraction of internal gains in basement	0.15
Adult occupants	2 at home 50% of time
Child occupants	2 at home 50% of time
Terrain, building site	Suburban, Forest
Local shielding, walls	Very heavy
Local shielding, flue	Light local shielding
Ventilation modeling	0.3 ac/h (natural plus mechanical)
Ventilation sizing including HRV	as per CSA Standard F326
To establish "envelope only" Energuide Score of 82 the following mechanical equipment must be used	
Space heating	natural gas furnace with 80% AFUE
Water heating	natural gas water heater with 0.57 energy factor
Ventilation	HRV with 55% heat recovery and other typical performance inputs as per HOT2000 defaults

Appendix H. Properties of Insulation Materials: Comparison

Table H-1. Properties of insulation materials: comparison.

Selected insulation materials	RSI/mm[1]	R/inch	Vapour permeance	Air permeance	Moisture tolerance
Batt insulations					
Fibreglass batt	0.0250	3.6	High	High	Low
High-density	0.0300	4.36	High	High	Low
High-density mineral wool batt	0.0300	4.36	High	High	High
Board insulations					
Foil-faced isocyanurate	0.0374	5.44	Low	Low	High
Polystyrene					
Extruded (XPS)	0.0336	4.88	Low	Low	High
Expanded (EPS)					
Type 1	0.0260	3.78	Medium	High	High
Type 2	0.0280	4.07	Medium	High	High
Type 3	0.0300	4.36	Medium	High	High
Fibreglass board (48 kg/m^3)	0.0298	4.33	High	High	High
Mineral wool board (56 kg/m^3)	0.0277	4.03	High	High	High
Vacuum insulation panels	0.208 – 0.417	30 – 60	Low	Low	High
Wood-fibre insulation boards (50 – 180 kg/m^3)	0.023 – 0.027	3.30 – 3.90	High	High	Low
Spray-applied insulations					
Polyurethane spray foam					
Closed-cell (2 pcf)	0.036	5.23	Low	Low	High
Open-cell (1/2 pcf)	0.026	3.78	High	Low	Low
Blown insulations					
Cellulose fibre	0.024	3.49	High	Medium	Low
Fibreglass	0.025	3.63	High	High	Low

[1] Most values were drawn from Table A-9.36.2.4.(1) D in the *National Building Code of Canada 2010* (National Research Council Canada 2010). Actual values for particular products may vary.

Appendix I. Air-Barrier Systems

A wide range of air-barrier systems have been developed and used in residential construction. An air barrier must be economical and straightforward to construct. In many cases this involves using existing components of the building assembly, ensuring the assembly is systematically sealed at all joints and penetrations. The air barrier can comprise such components as the interior finish drywall, the interior polyethylene vapour barrier, spray-foam or board insulation, the structural sheathing, or the weather-resistant barrier.

When constructing an air barrier, it is critical to ensure good performance, that the air barrier not only be visually inspected but also physically tested using fan-door depressurization. In a fan-door depressurization test all exterior doors and windows are closed and interior doors are opened. A large, variable-speed fan is installed in the front or back door and the home is depressurized, a series of readings are taken to measure the pressure on the building envelope and the quantity of air passing through the fan. These data, along with information on the volume and surface area of the home and about the weather conditions, are fed into the computer software. From this the airtightness of the home is calculated. High-performance housing should have a measured airtightness of 0.5 or less to 1.5 air changes at 50 Pa.

Alternatively the home's airtightness can be expressed as the normalized leakage area (NLA). The normalized leakage area is the summation of the cracks and holes in the building, known as the equivalent leakage area (ELA), divided by the surface area of the building. This gives the average square centimetres of cracks and holes per square metre of exterior skin. The maximum normalized leakage area should be $0.7 cm^2/m^2$ or less when measured at 10 Pa. The advantage of using the normalized leakage area measure instead of the air changes per hour at 50 Pa measure is that all building sizes are treated equally. The air changes per hour at 50 Pa measure favours larger homes over small ones because the bigger the building the smaller the surface area is relative to the building's volume. The test must follow a standard protocol as laid out in CAN/CGSB-149.10 M-86 (Standards Council of Canada 1986). Another benefit of a fan-door depressurization test is that it can cause the air-leakage locations to be exaggerated, thus they can be easily identified and fixed.

Following are descriptions and illustrations of common air-barrier systems (Figure I-1, Figure I-2, Figure I-3, and Figure I-4). Figure I-5 and Table I -1 list many air barriers and their relevant characteristics. Appendix G shows a series of typical air-barrier penetration and connection details.

For more information about the typical details for air barriers refer to the *Building Envelope Details Guide: Part 9 Residential Constructio*n (Homeowner Protection Office 2007), the *Guide* *for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America* (FPInnovations 2013), or the *Canadian Home Builders' Association Builders' Manual* (Canadian Homebuilders' Association 2013).

Types of Systems

Sealed 6-mil (150-micrometre) polyethylene

This method, which is widely used in residential construction, involves systematically sealing a polyethylene vapour barrier to the inside face of the framing with a butyl sealant and staples, or with durable sheathing tape, thereby creating a combined air–vapour barrier. The details are illustrated in Figure I-1. Due to its limited ability to withstand wind loads, this type of air barrier should be used in buildings up to 2-storeys high in wind-shaded locations, such as in a forested area or where surrounded by buildings of similar height.

Pros:

- An existing component of the wall assembly also serves as the air barrier.
- It is used and understood by the building industry.
- Materials are commonly available.
- Prefabricated polyethylene hats are available for sealing electrical boxes and recessed lights.
- Because the barrier is located on the interior, it is protected from large temperature fluctuations.

Cons:

- It is unable to withstand high wind pressures; should be limited to 2-storey buildings in wind-shaded locations.
- It can be damaged when interior finish installed.
- It is difficult to transition between floors and past interior partition walls.
- It will not allow drying to the interior.
- It can conceal evidence of water accumulation in a wall and in ceiling assemblies.
- It is not readily accessible for maintenance over the life of the building

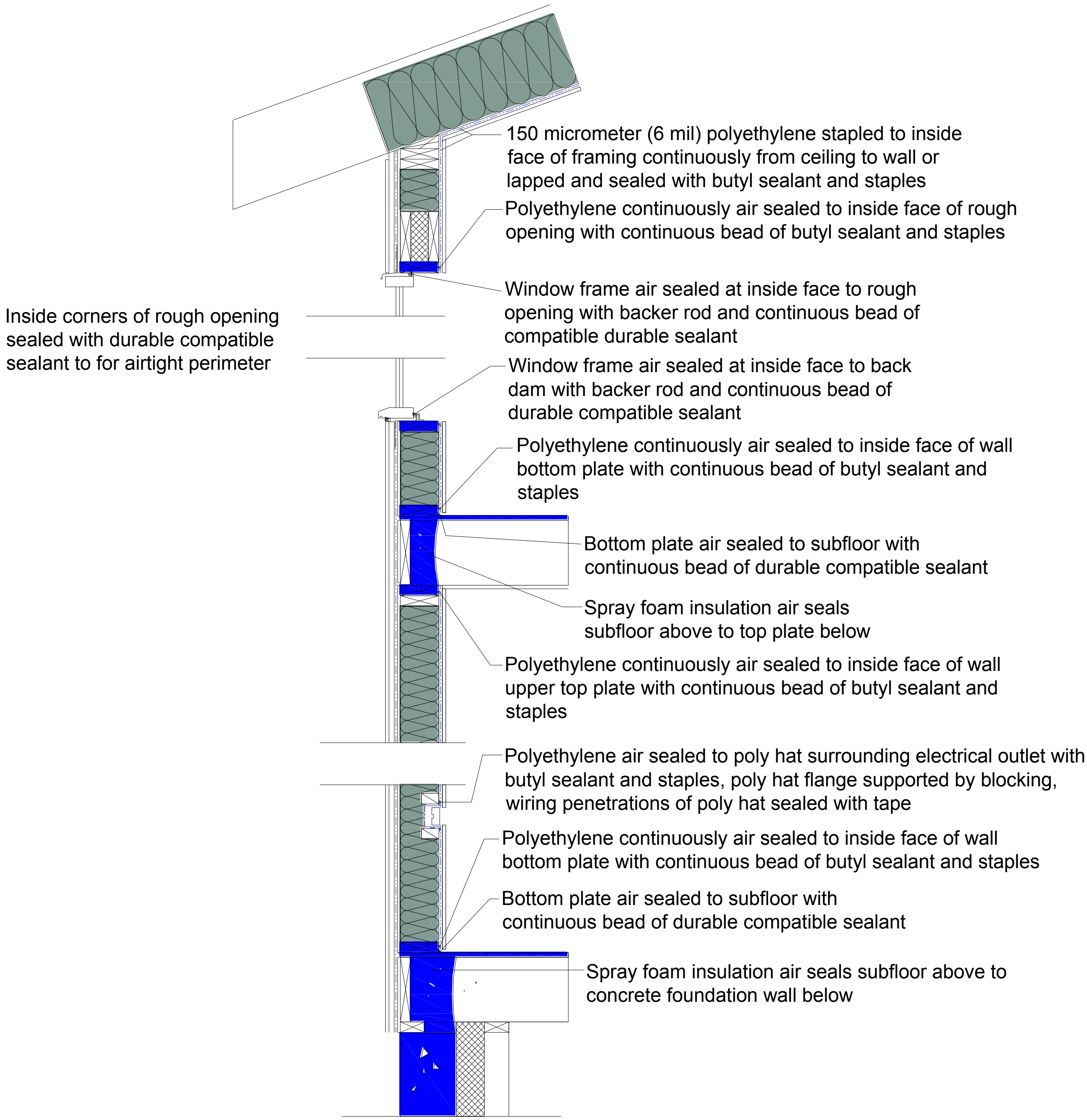


Figure I-1. Sealed 6-mil (150-micrometer) polyethylene applied to the interior functions as a combined air–vapour barrier.

Airtight drywall

In this method the interior finish drywall is systematically sealed to wall top and bottom plates, at partition wall end studs, and around window and skylight rough openings, with low-density, closed-cell foam gaskets and drywall screws or drywall adhesive. Framing components are sealed to each other with construction adhesive, sealants, and/or spray foam. The details are illustrated in Figure I-2. Typically a low-vapour-permeance paint or primer is used as vapour barrier with airtight drywall.

Pros:

- An existing component of the wall assembly also serves as the air barrier.
- A structural air barrier able to withstand wind loads is formed.
- Will allow drying to the interior when used in combination with a vapour barrier paint or primer.
- Being located on the interior, it is protected from outdoor temperature fluctuations.
- It can be repaired over the life of the building.
- It will not conceal evidence of water in wall or ceiling assemblies.
- Normal taping of drywall joints forms an airtight seal.
- It is relatively cost effective.

Cons:

- Installation may initially require more supervision because it is not understood by all building trades.
- Transition detailing where drywall is not used, such as at partition wall/exterior wall connections and ceiling drops, can be difficult to make airtight unless pre-planned.

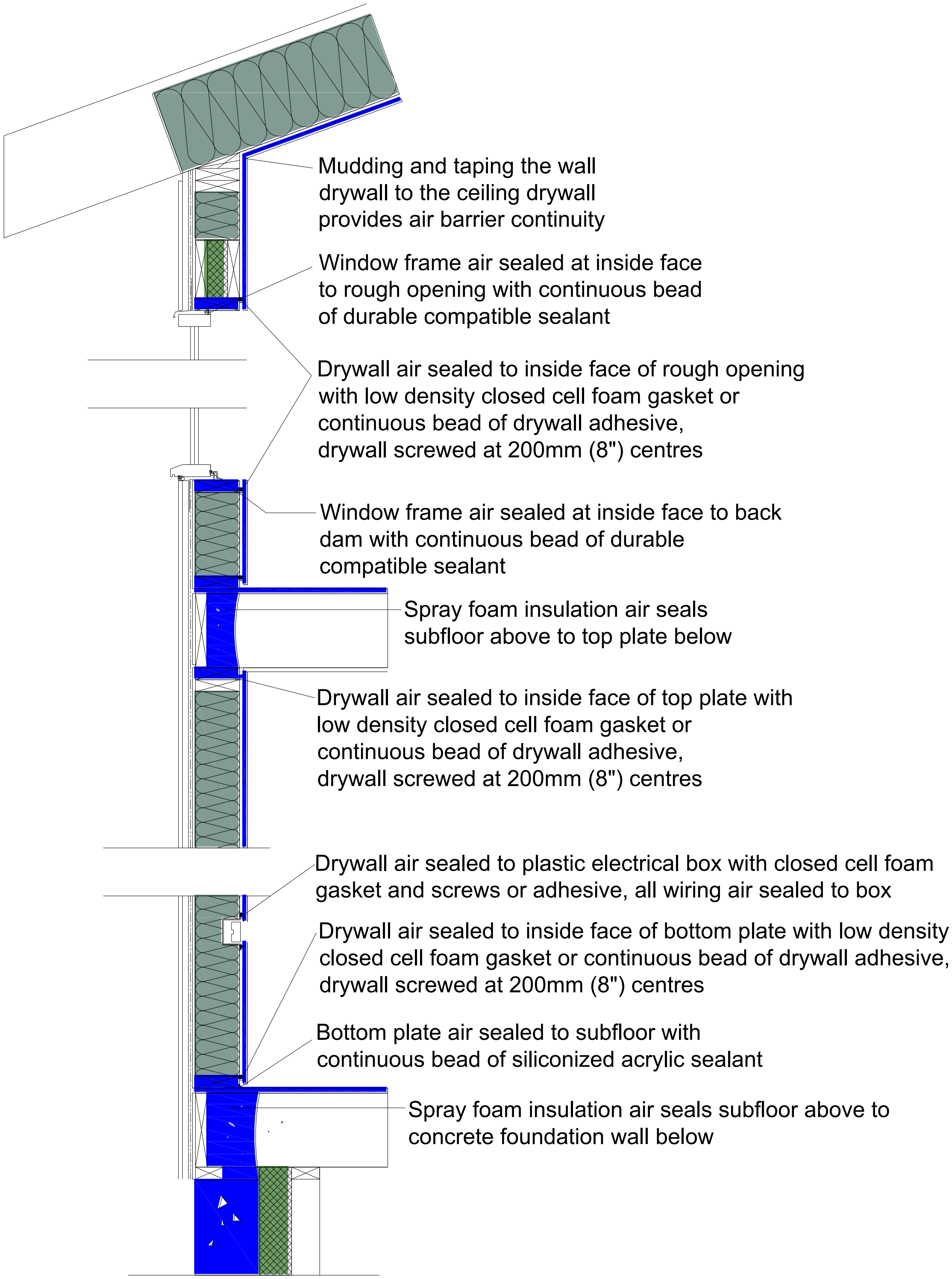


Figure I-2. The creation of an airtight drywall air barrier involves systematic sealing of the interior finish drywall. (Major air-barrier components shaded in blue.)

Structural sheathing covered with vapour-permeable self-adhering membrane

In this approach the OSB or plywood structural wall sheathing on the exterior is covered with a vapour-permeable peel-and-stick membrane. The structural sheathing is also sealed to the inside to wall top and bottom plates and at window and door rough-opening framing, with continuous beads of construction adhesive. Care must be taken to ensure that the wall cavities are completely filled with insulation to prevent air circulation within the cavity by natural convection, which could transport moisture to the back side of the sheathing. A vapour-barrier paint or primer can be used on the interior drywall in combination with this air barrier. An exterior layer of vapour-permeable insulation such as mineral wool board can be used over the vapour-permeable peel-and-stick to enhance wall thermal performance.

Pros:

- It is strong enough to withstand higher wind loads.
- Interior electrical receptacles and plumbing penetrations are located within the air barrier and do not require individual air sealing.
- It utilizes standard construction materials.
- It can produce a very tight air barrier.
- Air-barrier components are protected from exterior temperature extremes if exterior rigid insulation is used.

Cons:

- Installation will initially require more supervision because it is not widely understood by building trades.
- It is not accessible for maintenance over the life of the building.

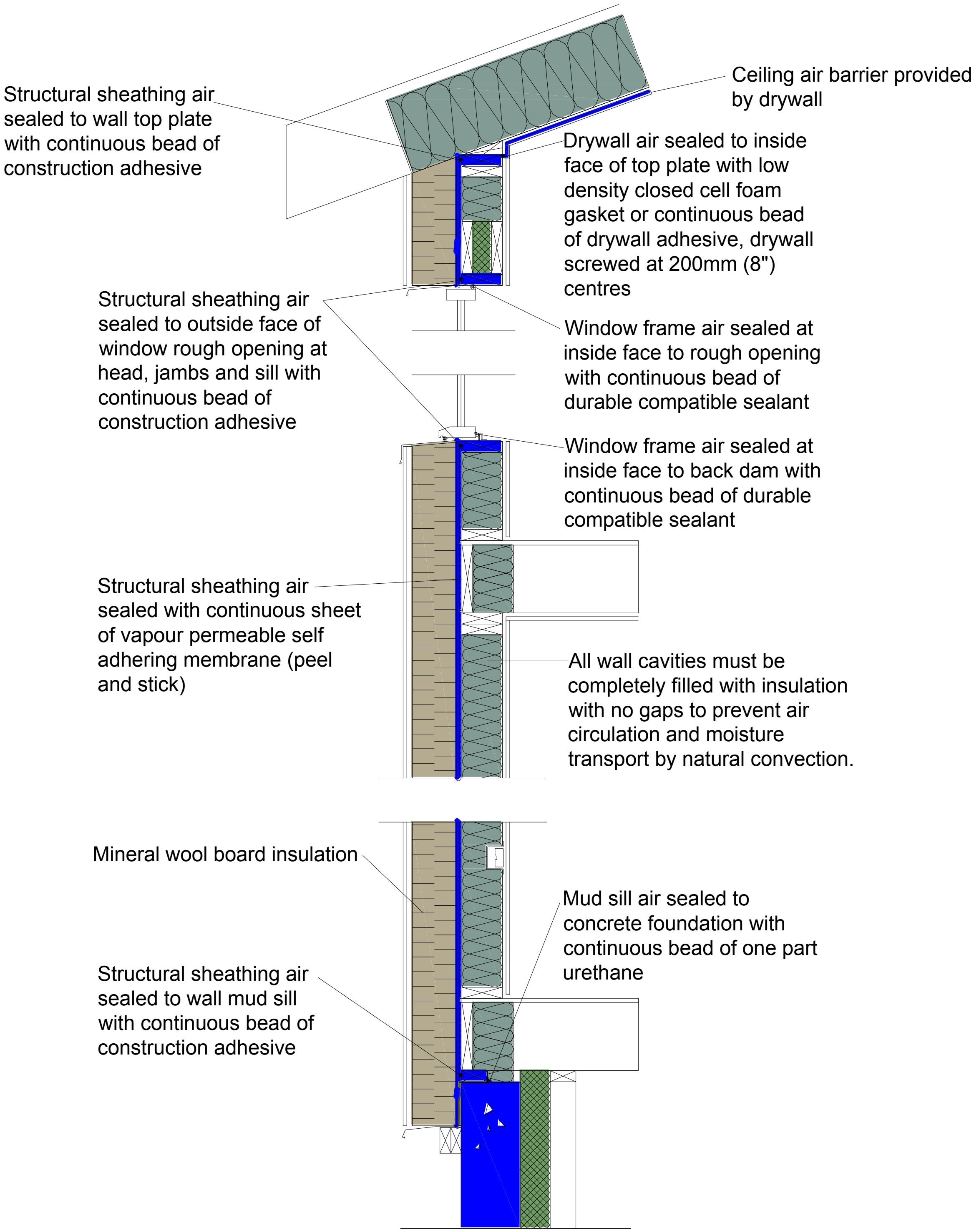


Figure I-3. An air barrier is created by applying a vapour-permeable peel-and-stick membrane to the structural sheathing on the outside, and by sealing it on the inside. (Major air-barrier components shaded in blue.)

Building wrap

In this approach, a material, such as a spun-bonded polyolefin building wrap, that functions as a weather-resistant barrier is used as the primary air-barrier component. The air barrier can be effectively achieved only when the weather-resistant barrier consists of a spun-bonded polyolefin building wrap with taped seams. The building wrap is systematically air sealed to the inside of window and door rough openings and service penetrations using compatible durable sealants and tapes. Due to the fact that building wraps are membranes, they must be fully structurally supported under both positive and negative wind loads. Structural support initially consists of using capped staples when applying the building wrap. Further support is provided by vertical strapping that is used to form the rainscreen cavity and support the exterior cladding. The strapping should be located at a maximum spacing of 200 mm (8 inches) o.c. Better structural support can be provided by placing the building-wrap air barrier between the structural sheathing and an exterior rigid insulated sheathing, which in turn is supported by vertical strapping. Attention has to be paid to the transition between the wall air barrier and the foundation or floor air barrier and the ceiling air barrier, which typically function as interior air-barrier systems. Care must be taken to ensure that the wall cavities are completely filled with insulation to prevent air circulation within the cavity by natural convection, which could transport moisture to the back side of the sheathing. Typically a 6-mil (150 micrometre) polyethylene or a low-vapour-permeance paint or primer on the drywall serves as the interior vapour control layer.

Pros:

- An existing component of the wall assembly also serves as the air barrier.
- Interior electrical receptacles and plumbing penetrations are located within the air barrier and do not require individual air sealing.

Cons:

- Except where the building wrap is placed behind a rigid insulated sheathing, the air barrier, and the tapes and sealants used to join it, are exposed to exterior conditions.
    - The air barrier is not accessible for maintenance over the life of the building.
    - Confusion over detailing can occur on site because this element serves the dual functions of air barrier and weather-resistant barrier.

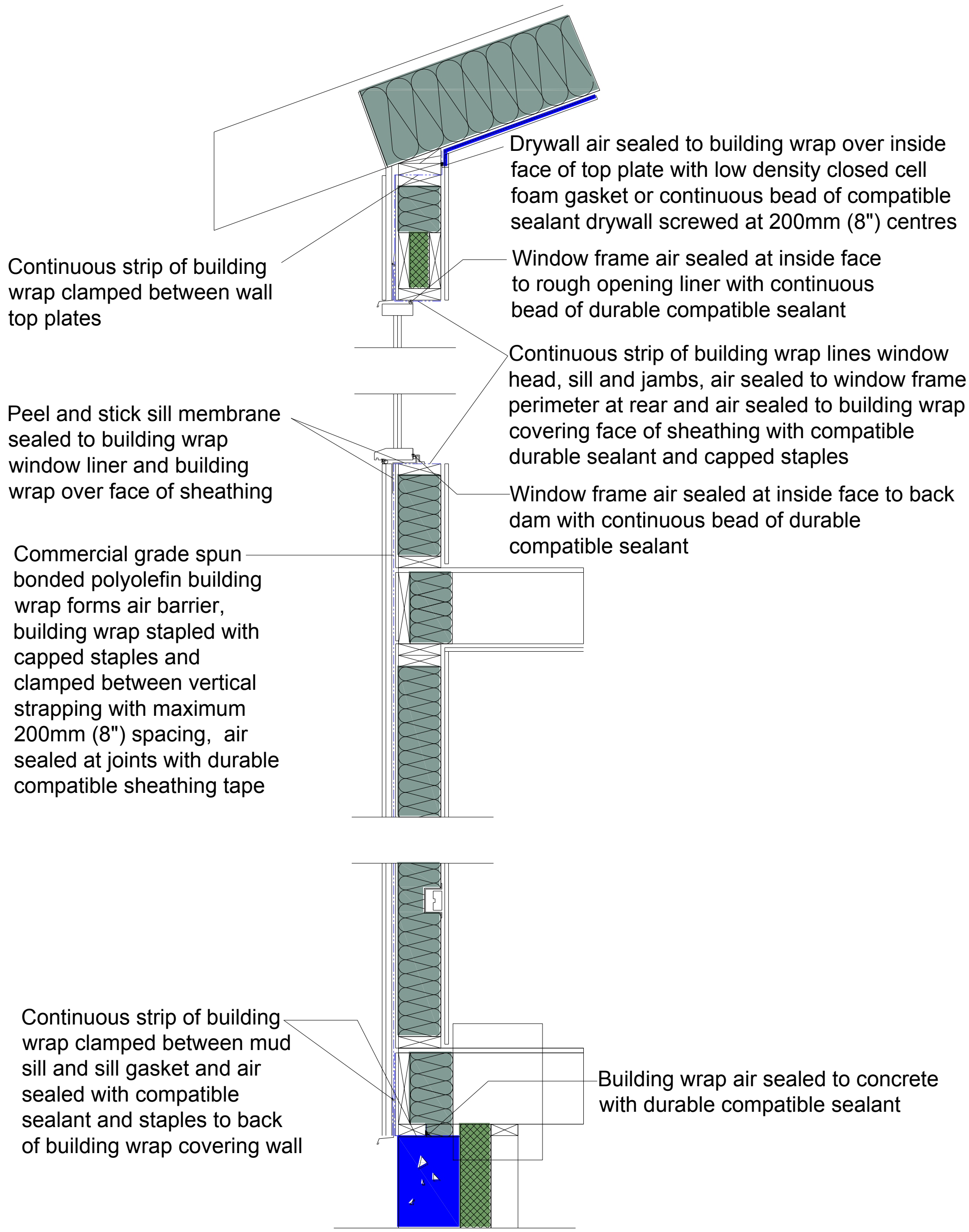


Figure I-4. In a building-wrap air barrier a weather-resistant barrier, such as spun-bonded polyolefin, is systematically air sealed to the inside of window and door rough openings and service penetrations. (Major air-barrier components shaded in blue.)

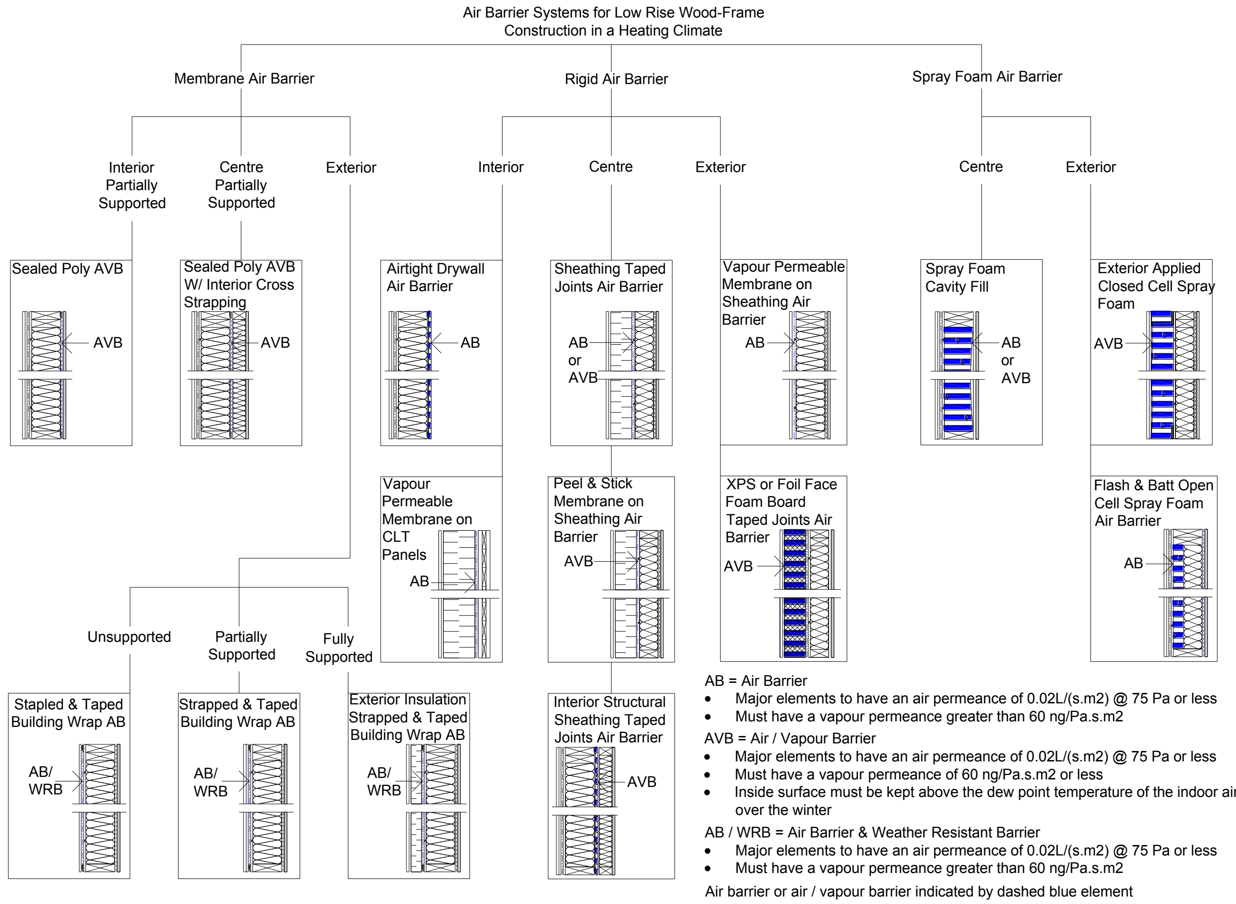


Figure I-5. Common types of air-barrier systems for low-rise, wood-frame construction in a heating climate.

Table I -1. Characteristics of air-barrier systems: comparison (see Figure I-5).

Types, by location within the wall assembly	Protection from exterior temperature variations	Accessible for repair	Ability to withstand wind pressures	No. of penetrations	Vapour barrier	Weather-resistant barrier	Drying to interior [1]	Drying to exterior
Interior membrane								
Sealed 6-mil (150-micrometre) polyethylene air–vapour barrier (Figure I-1)	High	No	Low	High	Yes	No	No	Yes
Centre membrane								
Sealed 6-mil (150-micrometre) polyethylene air–vapour barrier with interior 38x64-mm (2x3-inch) or 38x89-mm (2x4-inch) cross strapping and insulation	High	No	Low	Low	Yes	No	No	Yes
Exterior membrane								
Building wrap: taped, sealed, and stapled (Figure I-3)	Low	No	Low	Low	No	Yes	Yes/No	Yes
Building wrap: taped, sealed, stapled, and strapped (Figure I-4)	Low	No	Medium	Low	No	Yes	Yes/No	Yes
Exterior membrane, beneath exterior rigid insulation								
Building wrap: taped, stapled, and covered with vapour-permeable exterior rigid insulation that is anchored to framing with vertical strapping	High	No	High	Low	No	Yes	Yes/No	Yes
Interior rigid								
Airtight drywall (Figure I-2)	High	Yes	High	High	No	No	Yes/No	Yes

Types, by location within the wall assembly	Protection from exterior temperature variations	Accessible for repair	Ability to withstand wind pressures	No. of penetrations	Vapour barrier	Weather-resistant barrier	Drying to interior [1]	Drying to exterior
Cross-laminated timber (CLT) panels with a vapour-permeable, self-adhering, air-barrier membrane beneath vapour-permeable, rigid insulation fastened to the CLT with vertical strapping and screws	High	No	High	Medium	No	Yes	Yes	Yes
Below-grade concrete wall with a peel-and-stick exterior membrane and exterior insulation	High	No	High	Low	Yes	Yes	Yes	No
Centre flexible								
Open-cell spray foam in framing cavity	High	No	High	Low	No	No	Yes/No	Yes
Centre rigid								
Below-grade insulated concrete forms	High	No	High	Low	No	No	Yes/No	Yes
Interior structural sheathing joints taped with interior strapping or 2x4 stud wall for services and insulation	High	No	High	Low	Yes	No	Yes	Yes
Exterior structural sheathing covered with a vapour-permeable, self-adhering, air-barrier membrane covered with vapour-permeable, exterior rigid insulation	High	No	High	Low	Yes	Yes	Yes	Yes

Types, by location within the wall assembly	Protection from exterior temperature variations	Accessible for repair	Ability to withstand wind pressures	No. of penetrations	Vapour barrier	Weather-resistant barrier	Drying to interior [1]	Drying to exterior
Exterior structural sheathing covered with a peel-and-stick air–vapour barrier membrane and vapour-permeable exterior rigid insulation	High	No	High	Low	Yes	No	Yes	Yes
Exterior spray-foam								
Closed-cell spray foam applied to exterior of structural sheathing; standoff supports hold up cladding and provide rainscreen. All lumber and sheathing must have moisture content of 19% or less	High	No	High	Low	Yes	Yes	Yes	No
Flash and batt, 50 mm (2inches) of open-cell spray foam applied to inside face of structural sheathing; rest of cavity filled with batt insulation	Low	No	High	Low	No	No	Yes/No	Yes
Exterior rigid								
Structural sheathing covered with a vapour-permeable. self-adhering membrane	Low	No	High	Low	No	Yes	Yes/No	Yes

[1] Yes: if vapour barrier paint of primer used. No: if polyethylene or aluminum foil vapour barrier used.

Appendix J. Advanced Framing

Advanced framing refers to a range of techniques that have been developed over the past 30 years aimed at using lumber more efficiently in wood-frame construction (Figure J-1). In addition to reducing the cost of framing materials by using less of it, advanced framing also has the benefit of making wood-frame assemblies more energy efficient by allowing a portion of the framing lumber to be replaced with insulation. Conventional framing results in 23% or more of the wall area being taken up with framing lumber. In the case of advanced framing, the amount this is typically reduced to 16% and in some cases as low as 9%. Typically, advanced framing will reduce heat losses through the building envelope by about 10%. Advanced framing is recognized by the *British Columbia Building Code 2012* (Building and Safety Standards Branch 2012), but local authorities may require a structural engineering review be conducted before it can be used.

Advanced framing techniques include:

- Studs, floor joists, and rafters – These are spaced at 610 mm (24 inches) o.c.
- Single wall top plates – The use of single wall top plates requires that all vertical loads carried by the walls, roofs, and floor assemblies are lined up.
- Modified three stud corners or two stud corners – These are used with drywall clips rather than the conventional three-stud corners (Figure J-2). This technique reduces the amount of lumber in the corner and allows full insulation in the corner. Where drywall clips are used, both sheets of drywall in a corner are tied to one stud, to minimize the potential for cracking at the joint.
- Use of ladder blocking to connect interior partition walls to exterior walls – This reduces the number of studs in the exterior wall and allows a continuous layer of insulation to run past the end of the partition wall.
- Single studs on either side of windows and doors – These are used in conjunction with let-in headers.
- Headers beneath gable end trusses – These are eliminated.

For a more in-depth discussion of advanced framing refer to the *Advanced Framing Construction Guide* (APA — The Engineered Wood Association 2012).

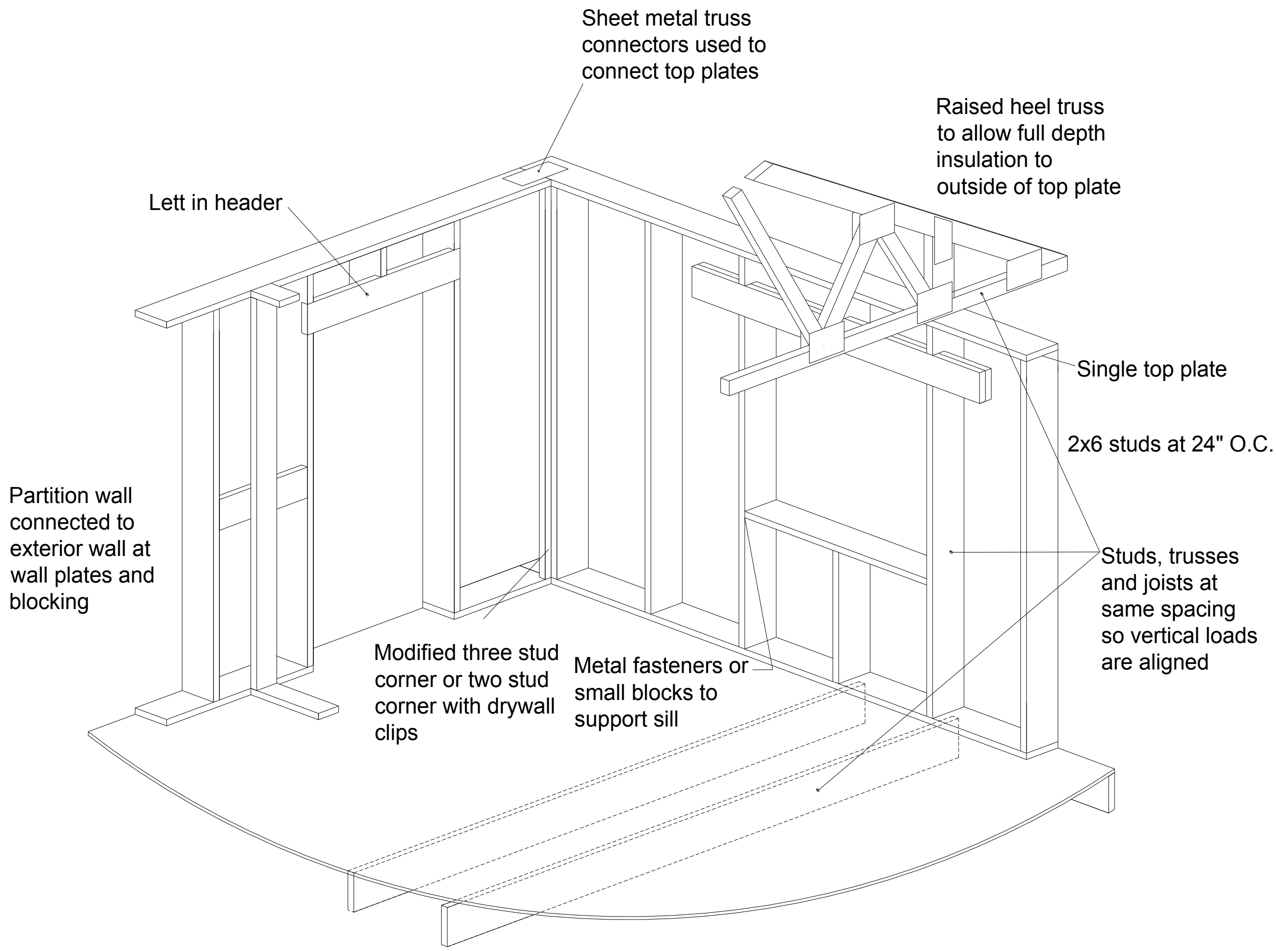


Figure J-1. Overview of some advanced framing techniques.

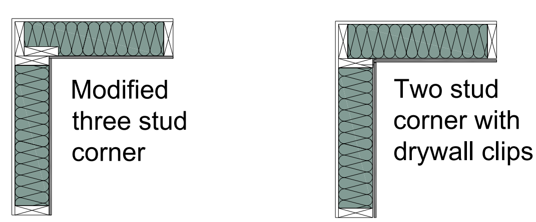


Figure J-2. Advanced framing of exterior corners.

Appendix K. Effective Insulation Values for Foundation Assemblies

Table K-1,Table K-2, and Table K-3 list the effective RSI-values (R-values) associated with the various basement and heated crawl space wall assemblies used in high-performance housing (Figure K-1, Figure K-2, Figure K-3). These values are calculated based on methods and tables presented in the *National Building Code of Canada 2010* section A-9.36.2.8.(1) as well as materials properties listed in Table A-9.36.2.4.(1)D (National Research Council Canada 2010).

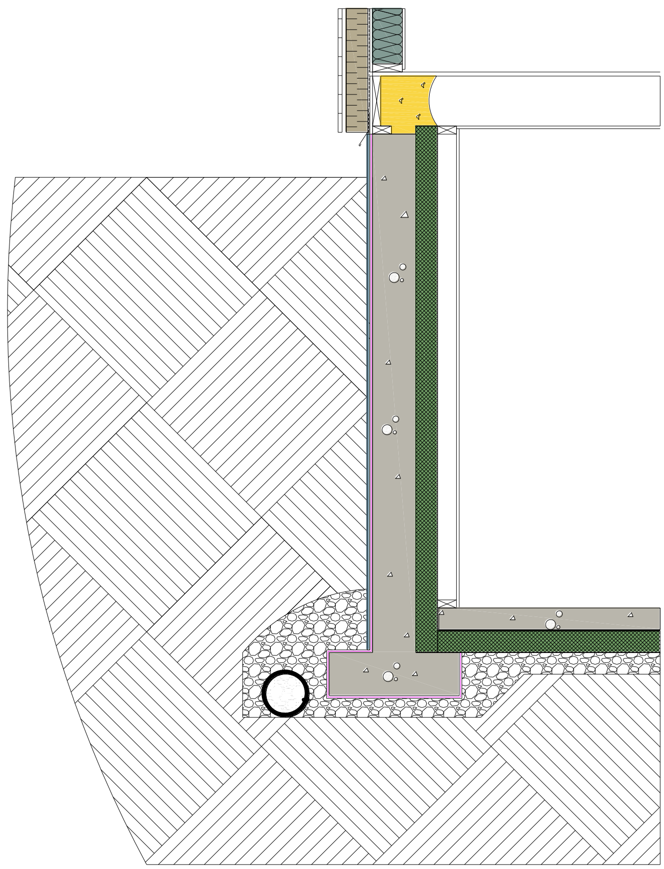


Figure K-1. Foundation wall assembly with interior-applied, XPS foam-board insulation.

Table K-1. Effective insulation values for foundation wall assemblies with interior-applied XPS or foil-faced isocyanurate foam-board insulation.

Foundation wall assemblies with interior applied XPS or foil faced isocyanurate foam board insulation														
#	Exterior Continuous Insulation Layer Adjacent to Structural Wall	Foundation Structural Wall	Interior Continuous Insulation Layer Adjacent to Structural Wall	Insulation Value		Framing Supporting Interior Finish	Insulation in Framing	Insulation Value		Effective Insulation of Framed Wall		Total Effective Insulation of Foundation Wall Assembly	
				R	RSI			R	RSI	R	RSI	R	RSI
1	None	200mm (8") cast in place concrete wall	50 mm (2") layer XPS	10.0	1.76	38x89 @ 610 (2x4 @ 24)	None	0	0	2.7	0.48	13.2	2.32
2	None	200mm (8") cast in place concrete wall	75 mm (3") layer XPS	15.0	2.64	38x89 @ 610 (2x4 @ 24)	None	0	0	2.7	0.48	18.2	3.20
3	None	200mm (8") cast in place concrete wall	100 mm (4") layer XPS	20.0	3.52	38x89 @ 610 (2x4 @ 24)	None	0	0	2.7	0.48	23.2	4.08
4	None	200mm (8") cast in place concrete wall	100 mm (4") layer XPS	20.0	3.52	38x89 @ 610 (2x4 @ 24)	F'glass or MW	12	2.1	10.7	1.88	31.1	5.48
5	None	200mm (8") cast in place concrete wall	100 mm (4") layer XPS	20.0	3.52	38x89 @ 610 (2x4 @ 24)	F'glass or MW	14	2.5	11.7	2.06	32.2	5.66
6	None	200mm (8") cast in place concrete wall	50 mm (2") Iso Board	10.6	1.87	38x89 @ 610 (2x4 @ 24)	None	0	0	2.7	0.48	13.8	2.43
7	None	200mm (8") cast in place concrete wall	75mm (3") Iso Board	15.9	2.81	38x89 @ 610 (2x4 @ 24)	None	0	0	2.7	0.48	19.1	3.37
8	None	200mm (8") cast in place concrete wall	100mm (4") Iso Board	21.3	3.75	38x89 @ 610 (2x4 @ 24)	None	0	0	2.7	0.48	24.5	4.30
9	None	200mm (8") cast in place concrete wall	100mm (4") Iso Board	21.3	3.74	38x89 @ 610 (2x4 @ 24)	F'glass or MW	12	2.1	10.7	1.88	32.4	5.70
10	None	200mm (8") cast in place concrete wall	100mm (4") Iso Board	21.3	3.74	38x89 @ 610 (2x4 @ 24)	F'glass or MW	14	2.5	11.7	2.06	33.4	5.88

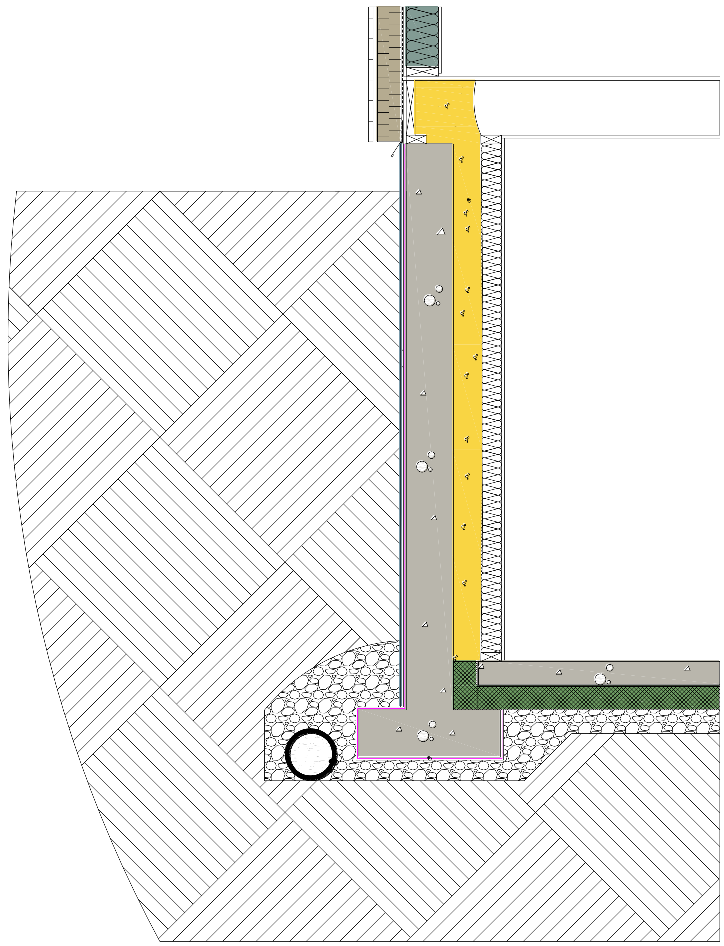


Figure K-2. Foundation wall assembly with interior-applied, closed-cell, polyurethane foam insulation.

Table K-2. Effective insulation values for foundation wall assemblies with interior-applied, closed-cell, polyurethane foam insulation.

Foundation wall with interior applied closed cell polyurethane foam insulation													
11	None	200mm (8") cast in place concrete wall	50 mm (2") closed cell spray polyurethane	10.2	1.80	38x89 @ 610 (2x4 @ 24)	None	0.0	0.00	2.7	0.48	13.4	2.36
12	None	200mm (8") cast in place concrete wall	75mm (3") closed cell spray polyurethane	15.3	2.70	38x89 @ 610 (2x4 @ 24)	None	0.0	0.00	2.7	0.48	18.5	3.26
13	None	200mm (8") cast in place concrete wall	100mm (4") closed cell spray polyurethane	20.4	3.60	38x89 @ 610 (2x4 @ 24)	None	0.0	0.00	2.7	0.48	23.7	4.16
14	None	200mm (8") cast in place concrete wall	100mm (4") closed cell spray polyurethane	20.4	3.60	38x89 @ 610 (2x4 @ 24)	F'glass or MW	12.0	2.11	10.7	1.88	31.6	5.56
15	None	200mm (8") cast in place concrete wall	100mm (4") closed cell spray polyurethane	20.4	3.60	38x89 @ 610 (2x4 @ 24)	F'glass or MW	14.0	2.47	11.7	2.06	32.6	5.74

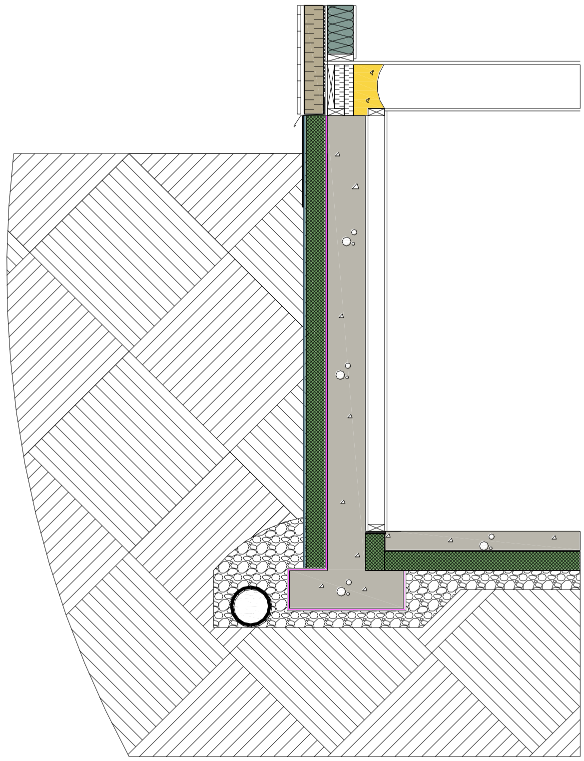


Figure K-3. Foundation wall assembly with exterior-applied, XPS foam-board insulation.

Table K-3. Effective insulation values for foundation wall assemblies with exterior-applied, XPS foam-board insulation.

Foundation wall with exterior applied XPS foam board insulation													
#	Exterior Continuous Insulation Layer Adjacent to Structural Wall	Foundation Structural Wall	Interior Continuous Insulation Layer Adjacent to Structural Wall	Insulation Value		Framing Supporting Interior Finish	Insulation in Framing	Insulation Value		Effective Insulation of Framed Wall		Total Effective Insulation of Foundation Wall Assembly	
				R	RSI			R	RSI	R	RSI	R	RSI
16	50 mm (2") layer XP	200mm (8") cast in place concrete wall	None	10.0	1.76	38x89 @ 610 (2x4 @ 24)	None	0.0	0.00	2.7	0.48	13.2	2.32
17	75 mm (3") layer XP	200mm (8") cast in place concrete wall	None	15.0	2.64	38x89 @ 610 (2x4 @ 24)	None	0.0	0.00	2.7	0.48	18.2	3.20
18	100 mm (4") layer X	200mm (8") cast in place concrete wall	None	20.0	3.52	38x89 @ 610 (2x4 @ 24)	None	0.0	0.00	2.7	0.48	23.2	4.08
19	100 mm (4") layer X	200mm (8") cast in place concrete wall	None	20.0	3.52	38x89 @ 610 (2x4 @ 24)	F'glass or MW	12.0	2.11	0.0	0.00	31.1	5.48
20	100 mm (4") layer X	200mm (8") cast in place concrete wall	None	20.0	3.52	38x89 @ 610 (2x4 @ 24)	F'glass or MW	14.0	2.47	0.0	0.00	32.2	5.66

Appendix L. Effective Insulation Values for Exterior Above-Grade Wall Assemblies

All effective RSI-values (R-values) of exterior wall assemblies (Tables L-1 to L-13) are calculated according to the Isothermal-Planes Method or the Parallel-Path Flow Method, as presented in A-9.36.24.(1) of the *National Building Code of Canada 2010* (National Research Council Canada 2010). Compared to the thermal resistance values provided in Table A-9.36.2.4(1)D of the Code, the manufacturers' actual tested values may vary. All wall assemblies utilize 12.7-mm (1/2-inch) gypsum interior finish; 12.7-mm (1/2-inch) plywood structural sheathing; building wrap; 9.5-mm (3/8-inch) vertical plywood strapping; and 8-mm (5/16-inch), wood-fibre, reinforced, cement panel cladding. Framing and cavity percentages are based on A-9.36.24.(1)A 2010 of the Code, at 23% for conventional framing and 16% for advanced framing.

Another reference for effective thermal resistance of wood-frame wall assemblies is the Canadian Wood Council's Wall Thermal Design Calculator (Canadian Wood Council 2013).

Table L-1. Effective insulation values for an exterior above-grade wall assembly: single stud.

Single Stud

Wall #	Framing Type: Conventional						
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	R Value	RSI Value
1	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	20.0	3.5	16.9	3.0
2	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22.0	3.9	17.8	3.1
3	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24.0	4.2	18.6	3.3
4	2x6 @ 16	38 x 140 @ 406	140mm (5.5") open cell spray foam	20.7	3.6	17.2	3.0
5	2x6 @ 16	38 x 140 @ 406	50mm (2") open cell spray foam w/ RSI 2.46 (R14) batt	21.4	3.8	17.2	3.0

	Framing Type: Advanced						
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	R Value	RSI Value
6	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	20.0	3.5	18.2	3.2
7	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22.0	3.9	19.3	3.4
8	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24.0	4.2	20.4	3.6
9	2x6 @ 24	38 x 140 @ 610	140mm (5.5") open cell spray foam	20.7	3.6	18.6	3.3
10	2x6 @ 24	38 x 140 @ 610	50mm (2") open cell spray foam w/ RSI 2.46 (R14) batt	21.4	3.8	18.6	3.3

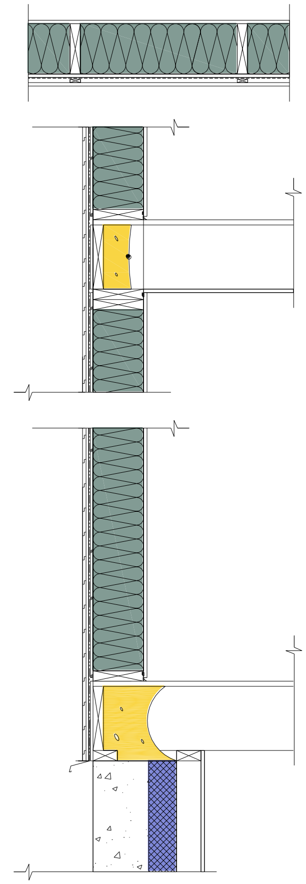


Table L-2. Effective insulation values for an exterior above-grade wall assembly: double stud.

Wall #	Framing Type:	Conventional					
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	R Value	RSI Value
23	2x4 @16 walls spaced 3 1/2 " apart	38 x 89mm @ 406 walls spaced 89mm apart	RSI 2.1 (R12) in stud cavities RSI 2.1 (R12) between	36.0	6.3	33.2	5.8
24	2x4 @16 walls spaced 3 1/2 " apart	38 x 89mm @ 406 walls spaced 89mm apart	RSI 2.46 (R14) in stud cavities RSI 2.46 (R14) between	42.0	7.4	37.6	6.6
25	2x4 @16 walls spaced 3 1/2 " apart	38 x 89mm @ 406 walls spaced 89mm apart	267mm (10.5 ") blown cellulose fiber	37.9	6.7	34.7	6.1

	Framing Type:	Advanced					
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	R Value	RSI Value
26	2x4 @24 walls spaced 3 1/2 " apart	38 x 89 @ 610 walls spaced 89mm apart	RSI 2.1 (R12) in stud cavities RSI 2.1 (R12) between	36.0	6.3	34.5	6.1
27	2x4 @24 walls spaced 3 1/2 " apart	38 x 89 @ 610 walls spaced 89mm apart	RSI 2.46 (R14) in stud cavities RSI 2.46 (R14) between	42.0	7.4	39.3	6.9
28	2x4 @24 walls spaced 3 1/2 " apart	38 x 89 @ 610 walls spaced 89mm apart	267mm (10.5 ") blown cellulose fiber	37.9	6.7	36.1	6.4

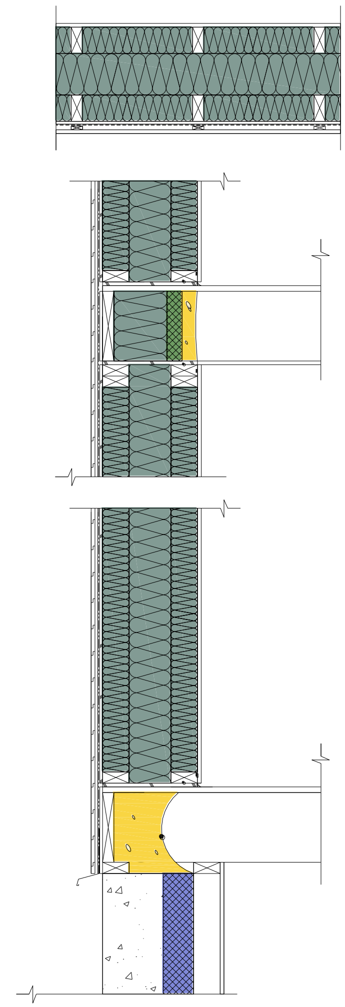


Table L-3. Effective insulation values for an exterior above-grade wall assembly: double stud—*continued*.

Wall #	Framing Type:	Conventional					
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	R Value	RSI Value
29	2x4 @16 walls spaced 5 1/2 " apart	38 x 89 @ 406 walls spaced 140mm apart	RSI 2.1 (R12) in stud cavities RSI 3.5 (R20) between	44.0	7.7	41.5	7.3
30	2x4 @16 walls spaced 5 1/2 " apart	38 x 89 @ 406 walls spaced 140mm apart	RSI 2.46 (R14) in stud cavities RSI 4.23 (R24) between	62.0	10.9	48.2	8.5
31	2x4 @16 walls spaced 5 1/2 " apart	38 x 89 @ 406 walls spaced 140mm apart	318mm (12.5 ") blown cellulose fiber	45.0	8.0	42.2	7.4

	Framing Type:	Advanced					
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	R Value	RSI Value
32	2x4 @24 walls spaced 5 1/2 " apart	38 x 89 @ 610 walls spaced 140mm apart	RSI 2.1 (R12) in stud cavities RSI 3.5 (R20) between	44.0	7.7	42.8	7.5
33	2x4 @24 walls spaced 5 1/2 " apart	38 x 89 @ 610 walls spaced 140mm apart	RSI 2.46 (R14) in stud cavities RSI 4.23 (R24) between	62.0	10.9	49.8	8.8
34	2x4 @24 walls spaced 5 1/2 " apart	38 x 89 @ 610 walls spaced 140mm apart	318mm (12.5 ") blown cellulose fiber	45.0	8.0	43.6	7.7

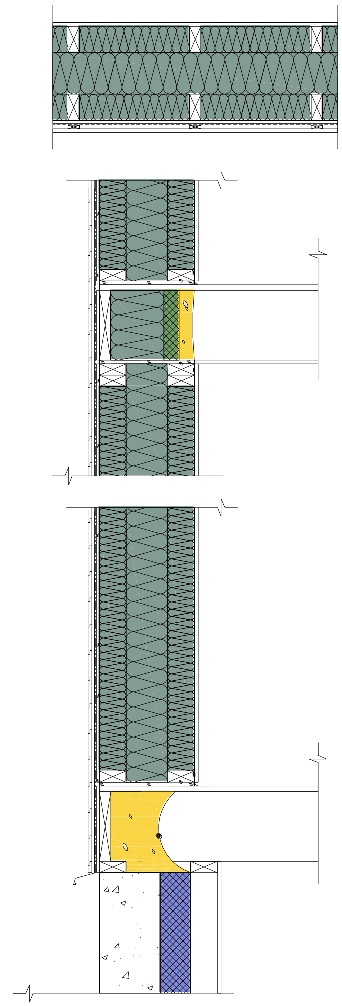
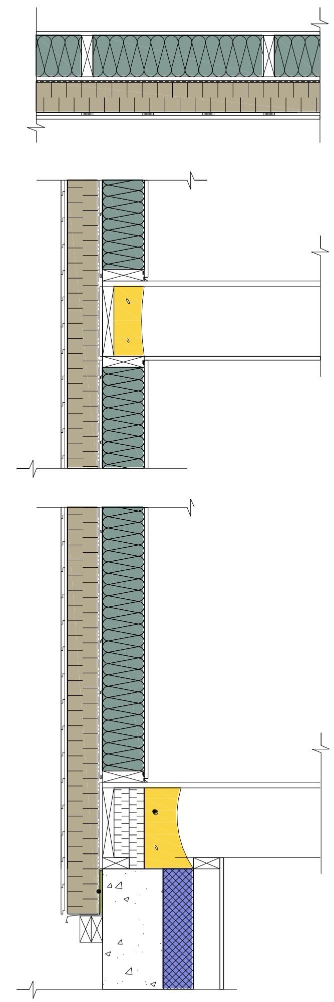


Table L-4. Effective insulation values for an exterior above-grade wall assembly: single-stud with insulated sheathing.[a]

Wall #	Framing Type: Conventional									
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	Type	R Value	RSI Value	R Value	RSI Value
41	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	20.0	3.5	1" MWB	4	0.70	21.4	3.8
42	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	20.0	3.5	1.5" MWB	6	1.06	23.6	4.2
43	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	20.0	3.5	2" MWB	8	1.41	25.8	4.6
44	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	20.0	3.5	3" MWB	12	2.11	30.0	5.3
45	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	20.0	3.5	4" MWB	16	2.82	34.2	6.0

	Framing Type: Advanced									
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	Type	R Value	RSI Value	R Value	RSI Value
46	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	20.0	3.5	1" MWB	4	0.70	22.6	4.0
47	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	20.0	3.5	1.5" MWB	6	1.06	24.8	4.4
48	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	20.0	3.5	2" MWB	8	1.41	27.0	4.8
49	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	20.0	3.5	3" MWB	12	2.11	31.1	5.5
50	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	20.0	3.5	4" MWB	16	2.82	35.3	6.2

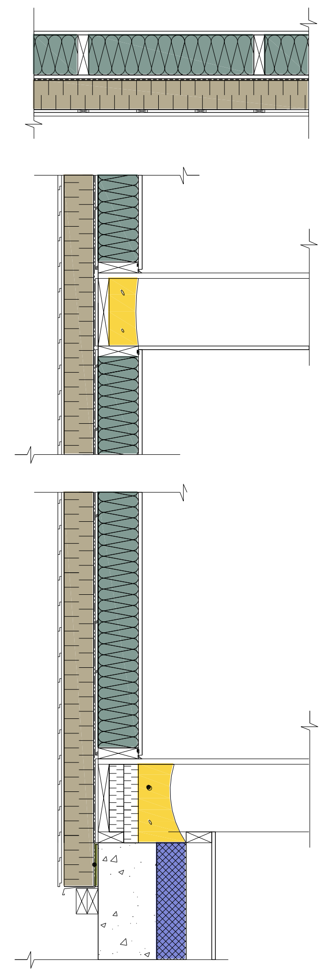


[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table L-5. Effective insulation values for an exterior above-grade wall assembly: single stud with insulated sheathing—*continued*.[a]

Wall #	Framing Type: Conventional									
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	Type	R Value	RSI Value	R Value	RSI Value
51	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22.0	3.9	1" MWB	4	0.70	22.4	4.0
52	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22.0	3.9	1.5" MWB	6	1.06	24.7	4.4
53	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22.0	3.9	2" MWB	8	1.41	26.9	4.7
54	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22.0	3.9	3" MWB	12	2.11	31.2	5.5
55	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22.0	3.9	4" MWB	16	2.82	35.5	6.3

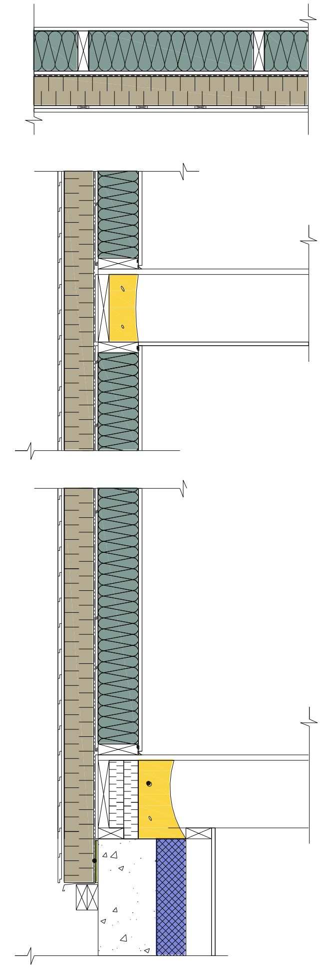
	Framing Type: Advanced									
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	Type	R Value	RSI Value	R Value	RSI Value
56	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22.0	3.9	1" MWB	4	0.70	23.8	4.2
57	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22.0	3.9	1.5" MWB	6	1.06	26.1	4.6
58	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22.0	3.9	2" MWB	8	1.41	28.3	5.0
59	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22.0	3.9	3" MWB	12	2.11	32.5	5.7
60	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22.0	3.9	4" MWB	16	2.82	36.7	6.5



[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table L-6. Effective insulation values for an exterior above-grade wall assembly: single stud with insulated sheathing—*continued*.[a]

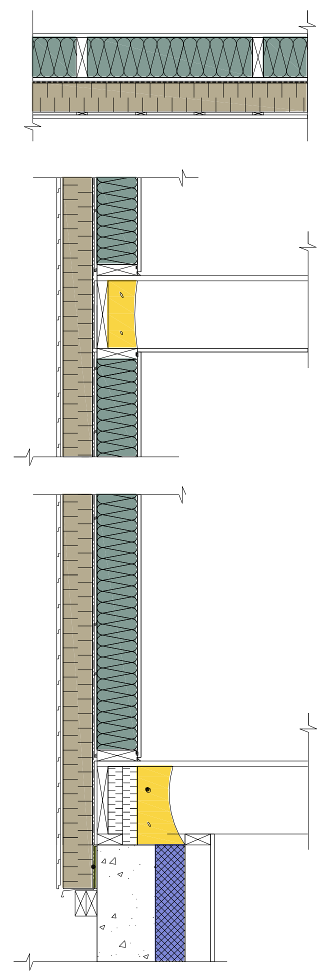
Wall #	Framing Type: Conventional									
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	Type	R Value	RSI Value	R Value	RSI Value
61	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24.0	4.2	1" MWB	4	0.70	23.4	4.1
62	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24.0	4.2	1.5" MWB	6	1.06	25.7	4.5
63	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24.0	4.2	2" MWB	8	1.41	28.0	4.9
64	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24.0	4.2	3" MWB	12	2.11	32.3	5.7
65	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24.0	4.2	4" MWB	16	2.82	36.7	6.5
	Framing Type: Advanced									
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	Type	R Value	RSI Value	R Value	RSI Value
66	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24.0	4.2	1" MWB	4	0.70	25.1	4.4
67	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24.0	4.2	1.5" MWB	6	1.06	27.4	4.8
68	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24.0	4.2	2" MWB	8	1.41	29.6	5.2
69	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24.0	4.2	3" MWB	12	2.11	33.9	6.0
70	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24.0	4.2	4" MWB	16	2.82	38.2	6.7



[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m³ (8 lb/ft³).

Table L-7. Effective insulation values for an exterior above-grade wall assembly: single stud with insulated sheathing—*continued*.[a]

Wall #	Framing Type: Conventional									
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	Type	R Value	RSI Value	R Value	RSI Value
71	2x6 @ 16	38 x 140 @ 406	140mm (5.5") open cell spray foam	20.7	3.6	1" MWB	4	0.70	21.7	3.8
72	2x6 @ 16	38 x 140 @ 406	140mm (5.5") open cell spray foam	20.7	3.6	1.5" MWB	6	1.06	24.0	4.2
73	2x6 @ 16	38 x 140 @ 406	140mm (5.5") open cell spray foam	20.7	3.6	2" MWB	8	1.41	26.2	4.6
74	2x6 @ 16	38 x 140 @ 406	140mm (5.5") open cell spray foam	20.7	3.6	3" MWB	12	2.11	30.4	5.4
75	2x6 @ 16	38 x 140 @ 406	140mm (5.5") open cell spray foam	20.7	3.6	4" MWB	16	2.82	34.7	6.1
	Framing Type: Advanced									
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	Type	R Value	RSI Value	R Value	RSI Value
76	2x6 @ 24	38 x 140 @ 610	140mm (5.5") open cell spray foam	20.7	3.6	1" MWB	4	0.70	23.1	4.1
77	2x6 @ 24	38 x 140 @ 610	140mm (5.5") open cell spray foam	20.7	3.6	1.5" MWB	6	1.06	25.3	4.5
78	2x6 @ 24	38 x 140 @ 610	140mm (5.5") open cell spray foam	20.7	3.6	2" MWB	8	1.41	27.5	4.8
79	2x6 @ 24	38 x 140 @ 610	140mm (5.5") open cell spray foam	20.7	3.6	3" MWB	12	2.11	31.6	5.6
80	2x6 @ 24	38 x 140 @ 610	140mm (5.5") open cell spray foam	20.7	3.6	4" MWB	16	2.82	35.8	6.3

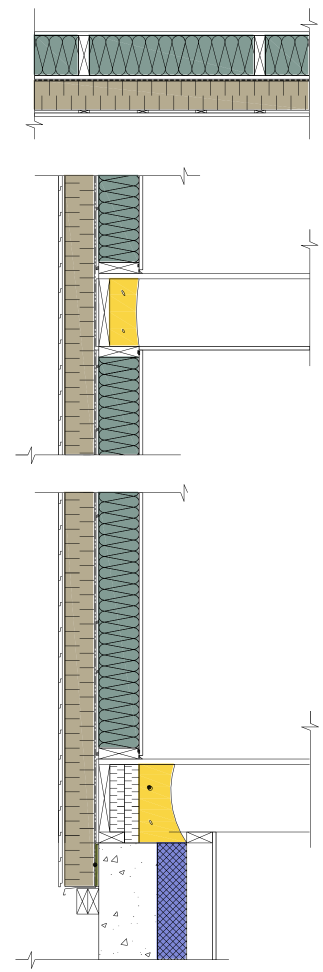


[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table L-8. Effective insulation values for an exterior above-grade wall assembly: single stud with insulated sheathing—*continued*.[a]

Wall #	Framing Type: Conventional									
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	Type	R Value	RSI Value	R Value	RSI Value
81	2x6 @ 16	38 x 140 @ 406	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	1" MWB	4	0.70	22.2	3.9
82	2x6 @ 16	38 x 140 @ 406	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	1.5" MWB	6	1.06	24.5	4.3
83	2x6 @ 16	38 x 140 @ 406	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	2" MWB	8	1.41	26.7	4.7
84	2x6 @ 16	38 x 140 @ 406	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	3" MWB	12	2.11	30.9	5.4
85	2x6 @ 16	38 x 140 @ 406	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	4" MWB	16	2.82	35.0	6.2

	Framing Type: Advanced									
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value	Type	R Value	RSI Value	R Value	RSI Value
86	2x6 @ 24	38 x 140 @ 610	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	1" MWB	4	0.70	23.6	4.2
87	2x6 @ 24	38 x 140 @ 610	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	1.5" MWB	6	1.06	25.8	4.6
88	2x6 @ 24	38 x 140 @ 610	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	2" MWB	8	1.41	28.0	4.9
89	2x6 @ 24	38 x 140 @ 610	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	3" MWB	12	2.11	32.1	5.7
90	2x6 @ 24	38 x 140 @ 610	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	4" MWB	16	2.82	36.3	6.4

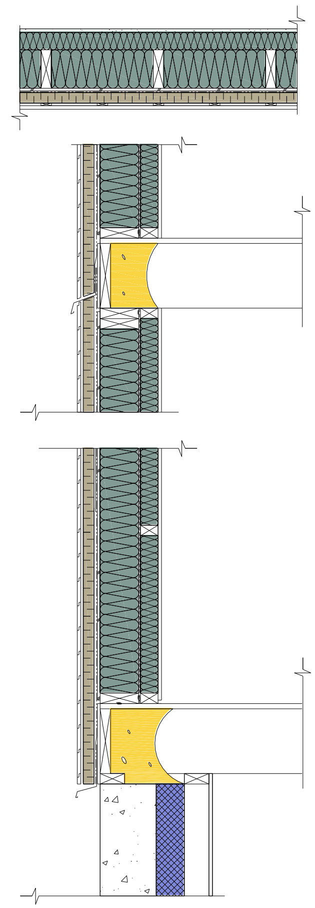


[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table L-9. Effective insulation values for an exterior above-grade wall assembly: wrap and strap.[a]

Wall #	Framing Type: Conventional										
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Interior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value		Description	R Value	RSI Value	R Value	RSI Value
101	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22.0	3.9	1" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	32.1	5.7
102	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22.0	3.9	1.5" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	34.3	6.0
103	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22.0	3.9	2" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	36.4	6.4
104	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22.0	3.9	3" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	40.5	7.1
105	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22.0	3.9	4" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	44.7	7.9

Wall #	Framing Type: Advanced										
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Interior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value		Description	R Value	RSI Value	R Value	RSI Value
106	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22.0	3.9	1" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	33.4	5.9
107	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22.0	3.9	1.5" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	35.6	6.3
108	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22.0	3.9	2" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	37.7	6.6
109	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22.0	3.9	3" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	41.7	7.4
110	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22.0	3.9	4" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	45.9	8.1

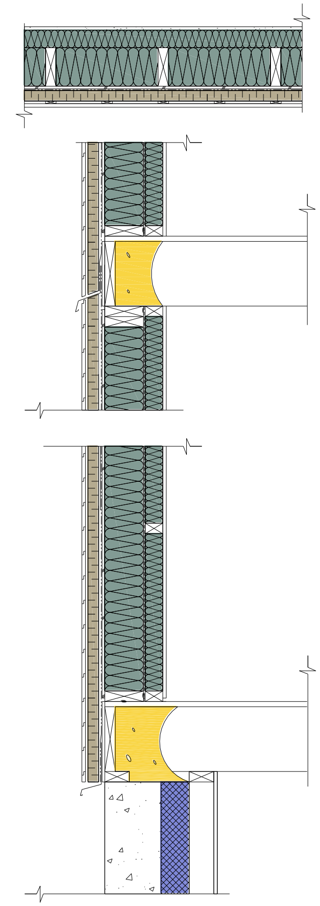


[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table L-10. Effective insulation values for an exterior above-grade wall assembly: wrap and strap—*continued*.[a]

Wall #	Framing Type: Conventional										
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Interior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value		Description	R Value	RSI Value	R Value	RSI Value
111	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24.0	4.2	1" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	33.3	5.9
112	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24.0	4.2	1.5" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	35.5	6.2
113	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24.0	4.2	2" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	37.6	6.6
114	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24.0	4.2	3" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	41.7	7.4
115	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24.0	4.2	4" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	46.0	8.1

Wall #	Framing Type: Advanced										
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Interior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value		Description	R Value	RSI Value	R Value	RSI Value
116	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24.0	4.2	1" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	34.8	6.1
117	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24.0	4.2	1.5" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	37.0	6.5
118	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24.0	4.2	2" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	39.1	6.9
119	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24.0	4.2	3" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	43.2	7.6
120	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24.0	4.2	4" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	47.4	8.4

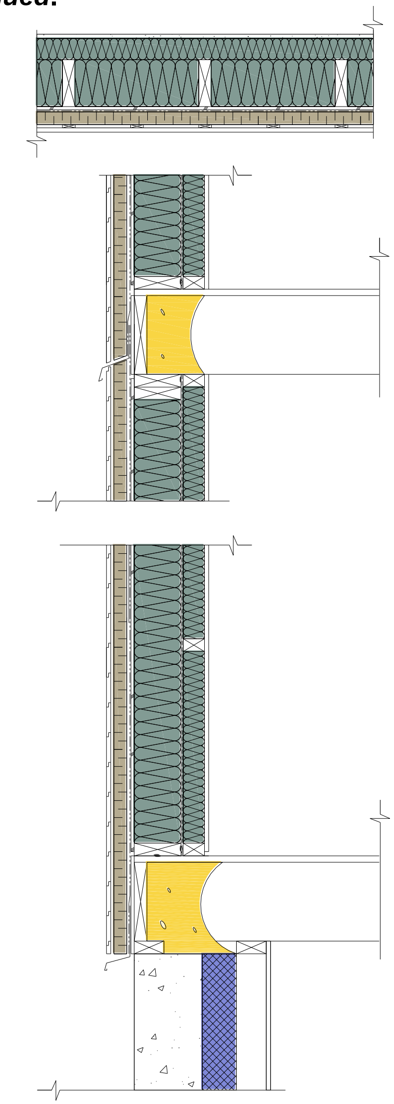


[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table L-11. Effective insulation values for an exterior above-grade wall assembly: wrap and strap—*continued*.[a]

Wall #	Framing Type: Conventional										
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Interior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value		Description	R Value	RSI Value	R Value	RSI Value
121	2x6 @ 16	38 x 140 @ 406	140mm (5.5") open cell spray foam	20.7	3.6	1" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	31.3	5.5
122	2x6 @ 16	38 x 140 @ 406	140mm (5.5") open cell spray foam	20.7	3.6	1.5" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	33.5	5.9
123	2x6 @ 16	38 x 140 @ 406	140mm (5.5") open cell spray foam	20.7	3.6	2" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	35.6	6.3
124	2x6 @ 16	38 x 140 @ 406	140mm (5.5") open cell spray foam	20.7	3.6	3" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	39.7	7.0
125	2x6 @ 16	38 x 140 @ 406	140mm (5.5") open cell spray foam	20.7	3.6	4" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	43.9	7.7

Wall #	Framing Type: Advanced										
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Interior Insulation			Wall Assembly Effective Thermal Resistance	
126	inches	mm		R Value	RSI Value		Description	R Value	RSI Value	R Value	RSI Value
127	2x6 @ 24	38 x 140 @ 610	140mm (5.5") open cell spray foam	20.7	3.6	1" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	32.5	5.7
128	2x6 @ 24	38 x 140 @ 610	140mm (5.5") open cell spray foam	20.7	3.6	1.5" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	34.7	6.1
129	2x6 @ 24	38 x 140 @ 610	140mm (5.5") open cell spray foam	20.7	3.6	2" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	36.8	6.5
130	2x6 @ 24	38 x 140 @ 610	140mm (5.5") open cell spray foam	20.7	3.6	3" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	40.8	7.2
131	2x6 @ 24	38 x 140 @ 610	140mm (5.5") open cell spray foam	20.7	3.6	4" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	45.0	7.9

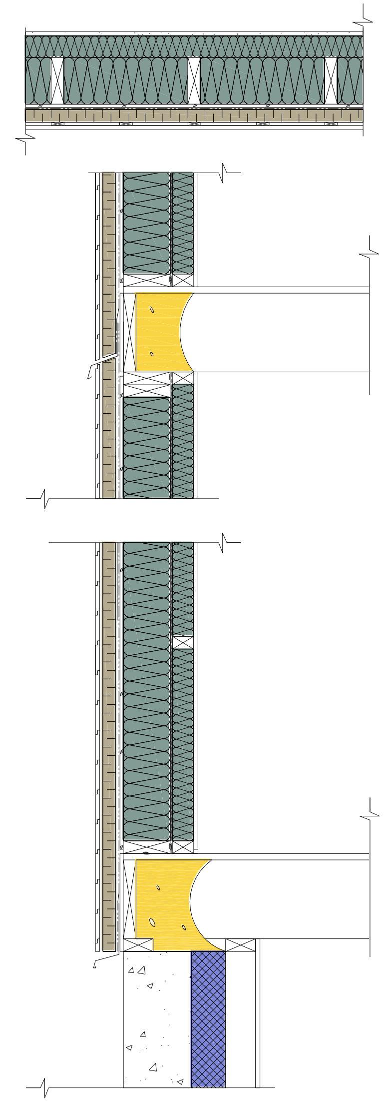


[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table L-12. Effective insulation values for an exterior above-grade wall assembly: wrap and strap—*continued*.[a]

Wall #	Framing Type: Conventional										
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Interior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value		Description	R Value	RSI Value	R Value	RSI Value
132	2x6 @ 16	38 x 140 @ 406	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	1" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	31.8	5.6
133	2x6 @ 16	38 x 140 @ 406	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	1.5" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	34.0	6.0
134	2x6 @ 16	38 x 140 @ 406	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	2" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	36.1	6.4
135	2x6 @ 16	38 x 140 @ 406	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	3" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	40.2	7.1
136	2x6 @ 16	38 x 140 @ 406	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	4" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	44.4	7.8

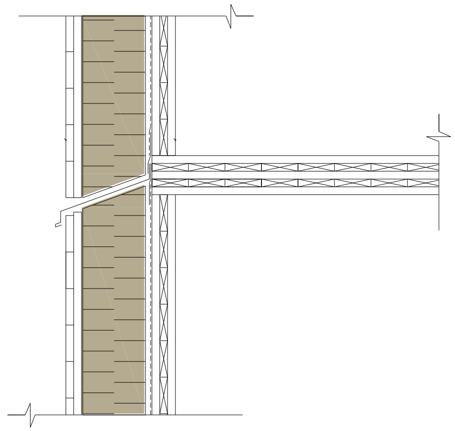
Wall #	Framing Type: Advanced										
	Stud Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Interior Insulation			Wall Assembly Effective Thermal Resistance	
	inches	mm		R Value	RSI Value		Description	R Value	RSI Value	R Value	RSI Value
137	2x6 @ 24	38 x 140 @ 610	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	1" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	33.1	5.8
138	2x6 @ 24	38 x 140 @ 610	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	1.5" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	35.2	6.2
139	2x6 @ 24	38 x 140 @ 610	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	2" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	37.4	6.6
140	2x6 @ 24	38 x 140 @ 610	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	3" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	41.4	7.3
141	2x6 @ 24	38 x 140 @ 610	50mm (2") open cell w/ RSI 2.46 (R14) batt	21.5	3.8	4" MWB	2x3 on flat withRSI 2.1 (R 12) batt between	8.9	1.6	45.6	8.0



[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m³ (8 lb/ft³).

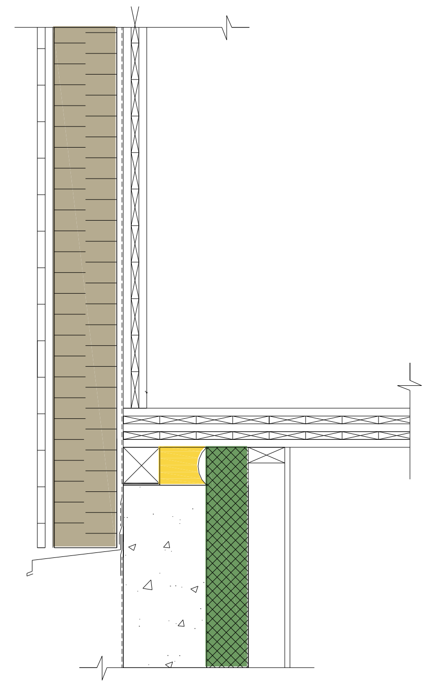
Table L-13. Effective insulation values for an exterior above-grade wall assembly: cross-laminated timber (CLT) panel walls with mineral wool board semi-rigid exterior insulation.[a,b]

CLT Panel Thickness		Exterior Insulation Thickness		Insulation Thermal Resistance		Wall Effective Thermal Resistance	
in	mm	in	mm	R	RSI	R	RSI
3.5	89	3	76	12	2.1	17.2	3
3.5	89	4	102	16	2.8	20.9	3.7
3.5	89	5	127	20	3.5	24.4	4.3
3.5	89	6	152	24	4.2	27.9	4.9
3.5	89	7	178	28	4.9	31.6	5.6
3.5	89	8	203	32	5.6	35	6.2



[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m3 (8 lb/ft3). Screw fastened with #12 screws and vertical strapping at 300x406 mm (12x16 inches. (Based on Table 4.3.1 in the Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America (FPInnovations 2013)).

CLT Panel Thickness		Exterior Insulation Thickness		Insulation Thermal Resistance		Wall Effective Thermal Resistance	
in	mm	in	mm	R	RSI	R	RSI
3.5	89	3.5	76	14	2.5	16.4	2.9
3.5	89	4	102	16	2.8	18	3.2
3.5	89	5	127	20	3.5	21.1	3.7
3.5	89	6	152	24	4.2	24.2	4.3



[b] Cross-laminated timber (CLT) panels with MWB semi-rigid exterior insulation rated at 0.029 RSI/mm (R 4.2/inch) held in place with pultruded fibreglass girt spacers at 610x406 mm (24x16 inches) by spacer depth. (Based on Table 4.3.2 in the Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America (FPInnovations 2013)).

Appendix M. Effective Insulation Values for Roof Assemblies

All RSI-values (R-values) for roof assemblies (Tables M-3 to M-13) are calculated according to the Isothermal-Planes Method or the Parallel-Path Flow Method, as presented in A-9.36.24.(1) of the *National Building Code of Canada 2010* (National Research Council Canada 2010). Compared to the thermal resistance values provided in Table A-9.36.2.4(1)D of the Code, the manufacturers' actual tested values may vary. All wall assemblies utilize 12.7-mm (1/2-inch) gypsum interior finish; 12.7-mm (1/2-inch) plywood structural sheathing; building wrap; 9.5-mm (3/8-inch) vertical plywood strapping; and 8-mm (5/16-inch), wood-fibre, reinforced, cement panel cladding. Framing and cavity percentages are based on A-9.36.24.(1)A of the Code, at 23% for conventional framing and 16% for advanced framing.

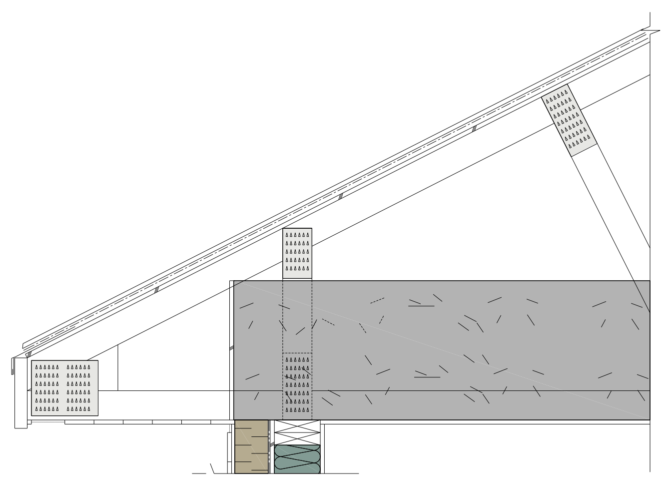


Figure M-1. Raised-heel attic truss with insulation placed on the ceiling.

Table M-1. Effective insulation values: raised-heel attic truss with insulation placed on ceiling.

Raised Heel Attic Truss With Insulation Placed on Ceiling											
	Truss Spacing		Top Cord		Bottom Cord		Insulation Type	Cavity Insulation		Effective Thermal Resistance	
Roof #	inches	mm	inches	mm	inches	mm		R Value	RSI Value	R Value	RSI Value
1	16	406	2x4	38x89	2x6	38x140	Blown Cellulose Fibre	60	10.6	60.1	10.6
2	16	406	2x4	38x89	2x6	38x140	Blown Cellulose Fibre	80	14.1	79.3	14.0
3	16	406	2x4	38x89	2x6	38x140	Blown Cellulose Fibre	100	17.6	98.5	17.4
4	24	610	2x4	38x89	2x6	38x140	Blown Cellulose Fibre	60	10.6	60.3	10.6
5	24	610	2x4	38x89	2x6	38x140	Blown Cellulose Fibre	80	14.1	79.6	14.0
6	24	610	2x4	38x89	2x6	38x140	Blown Cellulose Fibre	100	17.6	98.8	17.4

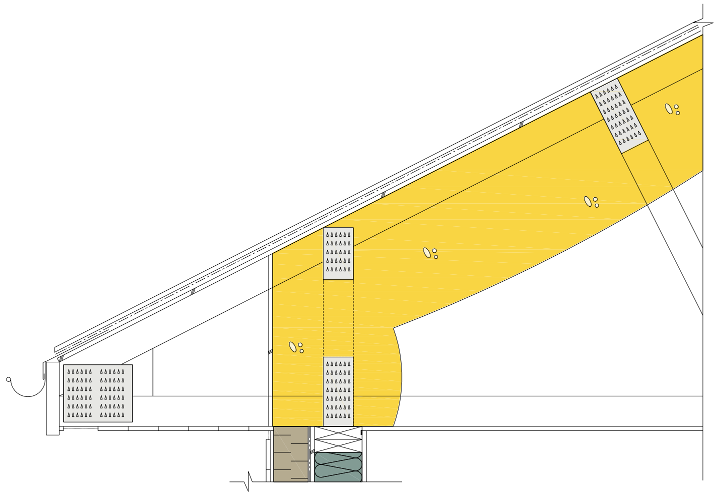


Figure M-2. Raised-heel attic truss with open-cell spray-foam insulation applied to the underside of the roof sheathing.

Table M-2. Effective insulation values: raised-heel attic truss with open-cell spray foam applied to underside of roof sheathing.

Raised Heel Attic Truss With Open Cell Spray Foam Applied to Underside of Roof Sheathing											
	Truss Spacing		Top Cord		Bottom Cord		Insulation Type	Cavity Insulation		Effective Thermal Resistance	
Roof #	inches	mm	inches	mm	inches	mm		R Value	RSI Value	R Value	RSI Value
7	16	406	2x4	38x89	2x6	38x140	Open Cell Spray Foam Applied to Underside of Roof Sheathing	60	10.6	63.3	11.2
8	16	406	2x4	38x89	2x6	38x140	Open Cell Spray Foam Applied to Underside of Roof Sheathing	80	14.1	83.3	14.7
9	16	406	2x4	38x89	2x6	38x140	Open Cell Spray Foam Applied to Underside of Roof Sheathing	100	17.6	103.6	18.3
10	24	610	2x4	38x89	2x6	38x140	Open Cell Spray Foam Applied to Underside of Roof Sheathing	60	10.6	63.4	11.2
11	24	610	2x4	38x89	2x6	38x140	Open Cell Spray Foam Applied to Underside of Roof Sheathing	80	14.1	83.3	14.7
12	24	610	2x4	38x89	2x6	38x140	Open Cell Spray Foam Applied to Underside of Roof Sheathing	100	17.6	103.7	18.3

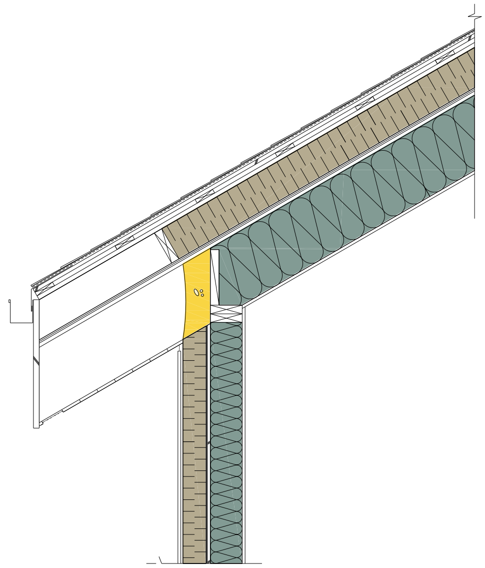


Figure M-3. Dimension-lumber sloped ceiling joists with cavity and exterior insulation.

Table M-3. Effective insulation values: dimension-lumber, sloped ceiling joists with cavity insulation and exterior insulation.

Dimension Lumber Sloped Ceiling Joists With Cavity Insulation and Exterior Insulation												
Roof #	Joist Spacing		Joist Dimensions		Cavity Insulation	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm	inches	mm		R	RSI		R	RSI	R	RSI
13	16	406	2x12	38 x 286	F'glass or MW	40	7.0	102mm (4")MWB	16	2.8	53.4	9.4
14	16	406	2x12	38 x 286	Open Cell Spray Foam	42.3	7.4	102mm (4")MWB	16	2.8	55.1	9.7
15	24	610	2x12	38 x 286	F'glass or MW	40	7.0	102mm (4")MWB	16	2.8	53.9	9.5
16	24	610	2x12	38 x 286	Open Cell Spray Foam	42.3	7.4	102mm (4")MWB	16	2.8	56.2	9.9
17	16	406	2x12	38 x 286	F'glass or MW	40	7.0	152mm (6")MWB	24	4.2	61.3	10.8
18	16	406	2x12	38 x 286	Open Cell Spray Foam	42.3	7.4	152mm (6")MWB	24	4.2	63.0	11.1
19	24	610	2x12	38 x 286	F'glass or MW	40	7.0	102mm (4")MWB	16	2.8	53.9	9.5
20	24	610	2x12	38 x 286	Open Cell Spray Foam	42.3	7.4	102mm (4")MWB	16	2.8	56.2	9.9
21	24	610	2x12	38 x 286	F'glass or MW	40	7.0	152mm (6")MWB	24	4.2	61.9	10.9
22	24	610	2x12	38 x 286	Open Cell Spray Foam	42.3	7.4	152mm (6")MWB	24	4.2	64.2	11.3
23	24	610	2x12	38 x 286	F'glass or MW	40	7.0	203mm (8") MWB	32	5.6	70.4	12.4
24	24	610	2x12	38 x 286	Open Cell Spray Foam	42.3	7.4	203mm (8") MWB	32	5.6	72.7	12.8

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

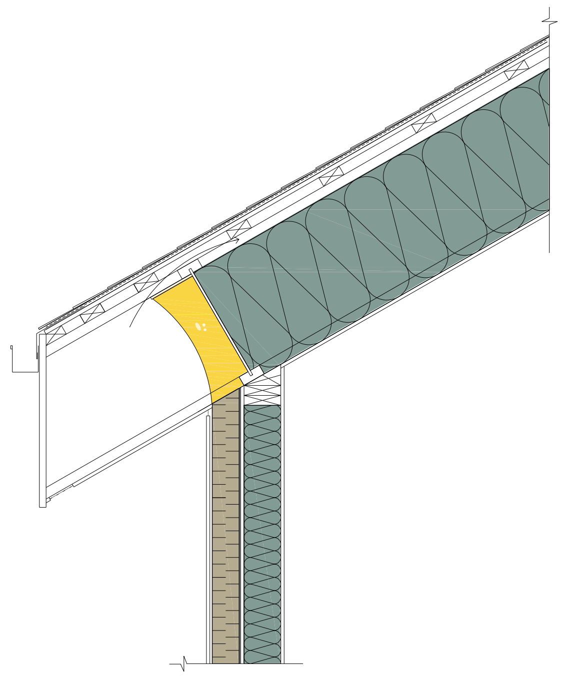


Figure M-4. Wood I-joist and sloped ceiling joist with cavity insulation.

Table M-4. Effective insulation values: wood I-joist and sloped ceiling joists with cavity insulation.[a]

Wood I Joist Sloped Ceiling Joists With Cavity Insulation									
Roof #	Joist Spacing		Wood I Joist Depth		Cavity Insulation	Cavity Insulation		Effective Thermal Resistance	
	inches	mm	inches	mm		R	RSI	R	RSI
25	16	406	20	508	F'glass or MW	71.6	12.6	64.7	11.4
26	16	406	20	508	Open Cell Spray Foam	69.5	12.2	63.3	11.1
27	16	406	20	508	Cellulose Fibre	64.1	11.3	59.3	10.5
28	24	610	20	508	F'glass or MW	71.6	12.6	67.3	11.8
29	24	610	20	508	Open Cell Spray Foam	69.5	12.2	65.6	11.5
30	24	610	20	508	Cellulose Fibre	64.1	11.3	61.2	10.8

[a] MW = mineral wool.

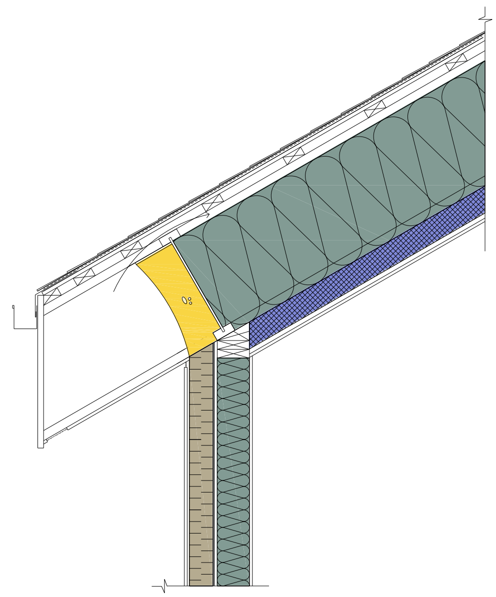


Figure M-5. Wood I-joist and sloped ceiling joist with cavity insulation and interior-applied rigid insulation.

Table M-5. Effective insulation values: 406-mm (16-inch) wood I-joist and sloped ceiling joists with cavity insulation and interior-applied rigid insulation.[a]

406mm (16")Wood I Joist Sloped Ceiling Joists With Cavity Insulation and Interior Applied Rigid Insulation												
Roof #	Joist Spacing		Wood I Joist Depth		Cavity Insulation	Cavity Insulation		Interior Insulation	Interior Insulation		Effective Thermal Resistance	
	inches	mm	inches	mm		R	RSI		R	RSI	R	RSI
31	16	406	16	406	F'glass or MW	56.2	9.9	50mm (2") XPS	9.6	1.7	61.6	10.9
32	16	406	16	406	Open Cell Spray Foam	54.5	9.6	50mm (2") XPS	9.6	1.7	60.3	10.6
33	16	406	16	406	Cellulose Fibre	50.0	8.8	50mm (2") XPS	9.6	1.7	57.0	10.0
34	16	406	16	406	F'glass or MW	56.2	9.9	100mm (4") XPS	19.1	3.4	71.6	12.6
35	16	406	16	406	Open Cell Spray Foam	54.5	9.6	100mm (4") XPS	19.1	3.4	69.9	12.3
36	16	406	16	406	Cellulose Fibre	50.0	8.8	100mm (4") XPS	19.1	3.4	66.9	11.8
37	16	406	16	406	F'glass or MW	56.2	9.9	50mm (2") Foil Faced Iso Board	10.6	1.9	62.8	11.1
38	16	406	16	406	Open Cell Spray Foam	54.5	9.6	50mm (2") Foil Faced Iso Board	10.6	1.9	61.5	10.8
39	16	406	16	406	Cellulose Fibre	50.0	8.8	50mm (2") Foil Faced Iso Board	10.6	1.9	58.2	10.2
40	16	406	16	406	F'glass or MW	56.2	9.9	100mm (4") Foil Faced Iso Board	21.2	3.7	73.9	13.0
41	16	406	16	406	Open Cell Spray Foam	54.5	9.6	100mm (4") Foil Faced Iso Board	21.2	3.7	73.7	13.0
42	16	406	16	406	Cellulose Fibre	50.0	8.8	100mm (4") Foil Faced Iso Board	21.2	3.7	69.1	12.2

[a] MW = mineral wool.

Table M-6. Effective insulation values: 406-mm (16-inch) wood I-joist and sloped ceiling joists with cavity insulation and interior-applied rigid insulation—*continued*.[a]

406mm (16")Wood I Joist Sloped Ceiling Joists With Cavity Insulation and Interior Applied Rigid Insulation												
Roof #	Joist Spacing		Wood I Joist Depth		Cavity Insulation	Cavity Insulation		Interior Insulation	Interior Insulation		Effective Thermal Resistance	
	inches	mm	inches	mm		R	RSI		R	RSI	R	RSI
43	24	610	16	406	F'glass or MW	56.2	9.9	50mm (2") XPS	9.7	1.7	63.3	11.1
44	24	610	16	406	Open Cell Spray Foam	54.5	9.6	50mm (2") XPS	9.7	1.7	61.9	10.9
45	24	610	16	406	Cellulose Fibre	50.0	8.8	50mm (2") XPS	9.7	1.7	58.3	10.3
46	24	610	16	406	F'glass or MW	56.2	9.9	100mm (4") XPS	19.1	3.4	73.1	12.9
47	24	610	16	406	Open Cell Spray Foam	54.5	9.6	100mm (4") XPS	19.1	3.4	71.7	12.6
48	24	610	16	406	Cellulose Fibre	50.0	8.8	100mm (4") XPS	19.1	3.4	68.0	12.0
49	24	610	16	406	F'glass or MW	56.2	9.9	50mm (2") Foil Faced Iso Board	10.6	1.9	64.4	11.3
50	24	610	16	406	Open Cell Spray Foam	54.5	9.6	50mm (2") Foil Faced Iso Board	10.6	1.9	63.0	11.1
51	24	610	16	406	Cellulose Fibre	50.0	8.8	50mm (2") Foil Faced Iso Board	10.6	1.9	59.4	10.5
52	24	610	16	406	F'glass or MW	56.2	9.9	100mm (4") Foil Faced Iso Board	21.2	3.7	75.3	13.3
53	24	610	16	406	Open Cell Spray Foam	54.5	9.6	100mm (4") Foil Faced Iso Board	21.2	3.7	73.9	13.0
54	24	610	16	406	Cellulose Fibre	50.0	8.8	100mm (4") Foil Faced Iso Board	21.2	3.7	70.2	12.4
55	24	610	16	406	F'glass or MW	56.2	9.9	50mm (2") XPS	9.7	1.7	63.3	11.1
56	24	610	16	406	Open Cell Spray Foam	54.5	9.6	50mm (2") XPS	9.7	1.7	61.9	10.9
57	24	610	16	406	Cellulose Fibre	50.0	8.8	50mm (2") XPS	9.7	1.7	58.3	10.3
58	24	610	16	406	F'glass or MW	56.2	9.9	100mm (4") XPS	19.1	3.4	73.1	12.9
59	24	610	16	406	Open Cell Spray Foam	54.5	9.6	100mm (4") XPS	19.1	3.4	71.7	12.6
60	24	610	16	406	Cellulose Fibre	50.0	8.8	100mm (4") XPS	19.1	3.4	68.0	12.0
61	24	610	16	406	F'glass or MW	56.2	9.9	50mm (2") Foil Faced Iso Board	10.6	1.9	64.4	11.3
62	24	610	16	406	Open Cell Spray Foam	54.5	9.6	50mm (2") Foil Faced Iso Board	10.6	1.9	63.0	11.1
63	24	610	16	406	Cellulose Fibre	50.0	8.8	50mm (2") Foil Faced Iso Board	10.6	1.9	59.4	10.5
64	24	610	16	406	F'glass or MW	56.2	9.9	100mm (4") Foil Faced Iso Board	21.2	3.7	75.3	13.3
65	24	610	16	406	Open Cell Spray Foam	54.5	9.6	100mm (4") Foil Faced Iso Board	21.2	3.7	73.9	13.0
66	24	610	16	406	Cellulose Fibre	50.0	8.8	100mm (4") Foil Faced Iso Board	21.2	3.7	70.2	12.4

[a] MW = mineral wool.

Table M-7. Effective insulation values: 508-mm (20-inch) wood I-joist and sloped ceiling joists with cavity insulation and interior-applied rigid insulation.[a]

508mm (20")Wood I Joist Sloped Ceiling Joists With Cavity Insulation and Interior Applied Rigid Insulation												
Roof #	Joist Spacing		Wood I Joist Depth		Cavity Insulation	Cavity Insulation		Interior Insulation	Interior Insulation		Effective Thermal Resistance	
	inches	mm	inches	mm		R	RSI		R	RSI	R	RSI
67	16	406	20	508	F'glass or MW	71.6	12.6	50mm (2") XPS	9.6	1.7	75.3	13.3
68	16	406	20	508	Open Cell Spray Foam	69.5	12.2	50mm (2") XPS	9.6	1.7	73.6	13.0
69	16	406	20	508	Cellulose Fibre	64.1	11.3	50mm (2") XPS	9.6	1.7	69.5	12.2
70	16	406	20	508	F'glass or MW	71.6	12.6	100mm (4") XPS	19.1	3.4	85.4	15.0
71	16	406	20	508	Open Cell Spray Foam	69.5	12.2	100mm (4") XPS	19.1	3.4	83.7	14.7
72	16	406	20	508	Cellulose Fibre	64.1	11.3	100mm (4") XPS	19.1	3.4	79.4	14.0
73	16	406	20	508	F'glass or MW	71.6	12.6	50mm (2") Foil Faced Iso Board	10.6	1.9	76.4	13.5
74	16	406	20	508	Open Cell Spray Foam	69.5	12.2	50mm (2") Foil Faced Iso Board	10.6	1.9	74.8	13.2
75	16	406	20	508	Cellulose Fibre	64.1	11.3	50mm (2") Foil Faced Iso Board	10.6	1.9	70.6	12.4
76	16	406	20	508	F'glass or MW	71.6	12.6	100mm (4") Foil Faced Iso Board	21.2	3.7	87.6	15.4
77	16	406	20	508	Open Cell Spray Foam	69.5	12.2	100mm (4") Foil Faced Iso Board	21.2	3.7	86.0	15.1
78	16	406	20	508	Cellulose Fibre	64.1	11.3	100mm (4") Foil Faced Iso Board	21.2	3.7	81.7	14.4
79	24	610	20	508	F'glass or MW	71.6	12.6	50mm (2") XPS	9.7	1.7	77.5	13.6
80	24	610	20	508	Open Cell Spray Foam	69.5	12.2	50mm (2") XPS	9.7	1.7	75.7	13.3
81	24	610	20	508	Cellulose Fibre	64.1	11.3	50mm (2") XPS	9.7	1.7	71.2	12.5
82	24	610	20	508	F'glass or MW	71.6	12.6	100mm (4") XPS	19.1	3.4	87.4	15.4
83	24	610	20	508	Open Cell Spray Foam	69.5	12.2	100mm (4") XPS	19.1	3.4	85.6	15.1
84	24	610	20	508	Cellulose Fibre	64.1	11.3	100mm (4") XPS	19.1	3.4	81.0	14.3
85	24	610	20	508	F'glass or MW	71.6	12.6	50mm (2") Foil Faced Iso Board	10.6	1.9	78.6	13.8
86	24	610	20	508	Open Cell Spray Foam	69.5	12.2	50mm (2") Foil Faced Iso Board	10.6	1.9	76.8	13.5
87	24	610	20	508	Cellulose Fibre	64.1	11.3	50mm (2") Foil Faced Iso Board	10.6	1.9	72.3	12.7
88	24	610	20	508	F'glass or MW	71.6	12.6	100mm (4") Foil Faced Iso Board	21.2	3.7	89.7	15.8
89	24	610	20	508	Open Cell Spray Foam	69.5	12.2	100mm (4") Foil Faced Iso Board	21.2	3.7	87.8	15.5
90	24	610	20	508	Cellulose Fibre	64.1	11.3	100mm (4") Foil Faced Iso Board	21.2	3.7	83.2	14.7

[a] MW = mineral wool.

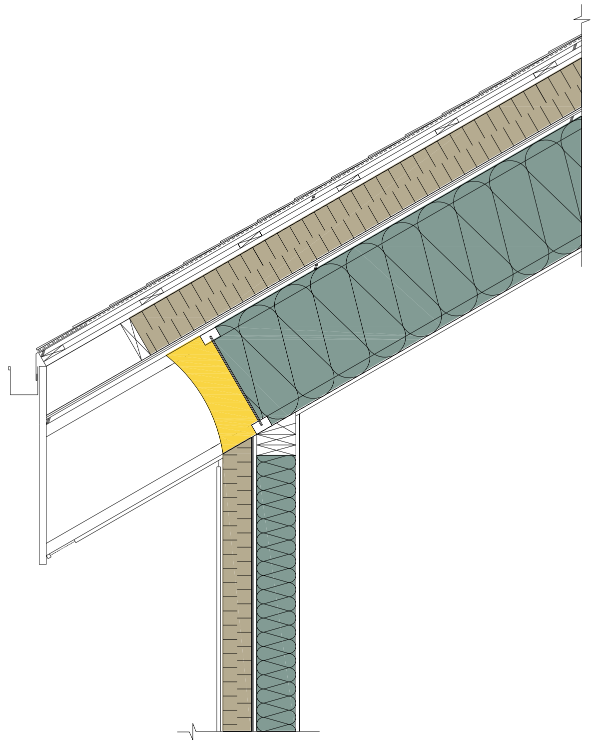


Figure M-6. Wood I-joist and sloped ceiling joist with cavity insulation and exterior mineral wool board sheathing.

Table M-8. Effective insulation values: 302-mm (11 7/8-inch) wood I-joist and sloped ceiling joists with cavity insulation and exterior-applied mineral wool board insulation.[a]

302mm (11 7/8")Wood I Joist Sloped Ceiling Joists With Cavity Insulation and Exterior Applied Mineral Wool Board												
Roof #	Joist Spacing		Wood I Joist Depth		Cavity Insulation	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm	inches	mm		R	RSI		R	RSI	R	RSI
91	16	406	14	302	F'glass or MW	45.9	8.1	50mm (2") MWB	7.9	1.4	51.5	9.1
92	16	406	14	302	Open Cell Spray Foam	44.6	7.9	50mm (2") MWB	7.9	1.4	50.4	8.9
93	16	406	14	302	Cellulose Fibre	41.2	7.2	50mm (2") MWB	7.9	1.4	47.7	8.4
94	16	406	14	302	F'glass or MW	45.9	8.1	100mm (4") MWB	15.7	2.8	59.7	10.5
95	16	406	14	302	Open Cell Spray Foam	44.6	7.9	100mm (4") MWB	15.7	2.8	58.6	10.3
96	16	406	14	302	Cellulose Fibre	41.2	7.2	100mm (4") MWB	15.7	2.8	55.9	9.8
97	16	406	14	302	F'glass or MW	45.9	8.1	150mm (6") MWB	23.6	4.2	67.8	11.9
98	16	406	14	302	Open Cell Spray Foam	44.6	7.9	150mm (6") MWB	23.6	4.2	66.7	11.8
99	16	406	14	302	Cellulose Fibre	41.2	7.2	150mm (6") MWB	23.6	4.2	63.9	11.3
100	16	406	14	302	F'glass or MW	45.9	8.1	200mm (8") MWB	31.5	5.5	75.9	13.4
101	16	406	14	302	Open Cell Spray Foam	44.6	7.9	200mm (8") MWB	31.5	5.5	74.8	13.2
102	16	406	14	302	Cellulose Fibre	41.2	7.2	200mm (8") MWB	31.5	5.5	71.9	12.7

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table M-9. Effective insulation values: 302-mm (11 7/8-inch) wood I-joist and sloped ceiling joists with cavity insulation and exterior-applied mineral wool board insulation—*continued*.[a]

302mm (11 7/8")Wood I Joist Sloped Ceiling Joists With Cavity Insulation and Exterior Applied Mineral Wool Board												
Roof #	Joist Spacing		Wood I Joist Depth		Cavity Insulation	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm	inches	mm		R	RSI		R	RSI	R	RSI
103	24	610	14	302	F'glass or MW	45.9	8.1	50mm (2") MWB	7.9	1.4	52.9	9.3
104	24	610	14	302	Open Cell Spray Foam	44.6	7.9	50mm (2") MWB	7.9	1.4	51.7	9.1
105	24	610	14	302	Cellulose Fibre	41.2	7.2	50mm (2") MWB	7.9	1.4	47.7	8.4
106	24	610	14	302	F'glass or MW	45.9	8.1	100mm (4") MWB	15.7	2.8	61.0	10.7
107	24	610	14	302	Open Cell Spray Foam	44.6	7.9	100mm (4") MWB	15.7	2.8	59.8	10.5
108	24	610	14	302	Cellulose Fibre	41.2	7.2	100mm (4") MWB	15.7	2.8	56.8	10.0
109	24	610	14	302	F'glass or MW	45.9	8.1	150mm (6") MWB	23.6	4.2	69.0	12.2
110	24	610	14	302	Open Cell Spray Foam	44.6	7.9	150mm (6") MWB	23.6	4.2	67.9	12.0
111	24	610	14	302	Cellulose Fibre	41.2	7.2	150mm (6") MWB	23.6	4.2	64.8	11.4
112	24	610	14	302	F'glass or MW	45.9	8.1	200mm (8") MWB	31.5	5.5	77.0	13.6
113	24	610	14	302	Open Cell Spray Foam	44.6	7.9	200mm (8") MWB	31.5	5.5	75.8	13.4
114	24	610	14	302	Cellulose Fibre	41.2	7.2	200mm (8") MWB	31.5	5.5	72.8	12.8

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table M-10. Effective insulation values: 356-mm (14-inch) wood I-joist and sloped ceiling joists with cavity insulation and exterior-applied mineral wool board insulation.[a]

356mm (14")Wood I Joist Sloped Ceiling Joists With Cavity Insulation and Exterior Applied Mineral Wool Board												
Roof #	Joist Spacing		Wood I Joist Depth		Cavity Insulation	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm	inches	mm		R	RSI		R	RSI	R	RSI
115	16	406	14	356	F'glass or MW	54.2	9.5	50mm (2") MWB	7.9	1.4	58.7	10.3
116	16	406	14	356	Open Cell Spray Foam	52.6	9.3	50mm (2") MWB	7.9	1.4	57.5	10.1
117	16	406	14	356	Cellulose Fibre	48.5	8.5	50mm (2") MWB	7.9	1.4	54.3	9.6
118	16	406	14	356	F'glass or MW	54.2	9.5	100mm (4") MWB	15.7	2.8	67.0	11.8
119	16	406	14	356	Open Cell Spray Foam	52.6	9.3	100mm (4") MWB	15.7	2.8	65.7	11.6
120	16	406	14	356	Cellulose Fibre	48.5	8.5	100mm (4") MWB	15.7	2.8	62.5	11.0
121	16	406	14	356	F'glass or MW	54.2	9.5	150mm (6") MWB	23.6	4.2	75.2	13.2
122	16	406	14	356	Open Cell Spray Foam	52.6	9.3	150mm (6") MWB	23.6	4.2	73.9	13.0
123	16	406	14	356	Cellulose Fibre	48.5	8.5	150mm (6") MWB	23.6	4.2	70.6	12.4
124	16	406	14	356	F'glass or MW	54.2	9.5	200mm (8") MWB	31.5	5.5	83.3	14.7
125	16	406	14	356	Open Cell Spray Foam	52.6	9.3	200mm (8") MWB	31.5	5.5	82.0	14.4
126	16	406	14	356	Cellulose Fibre	48.5	8.5	200mm (8") MWB	31.5	5.5	78.6	13.8

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table M-11. Effective insulation values: 356-mm (14-inch) wood I-joist and sloped ceiling joists with cavity insulation and exterior-applied mineral wool board insulation—*continued*.[a]

356mm (14")Wood I Joist Sloped Ceiling Joists With Cavity Insulation and Exterior Applied Mineral Wool Board												
Roof #	Joist Spacing		Wood I Joist Depth		Cavity Insulation	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm	inches	mm		R	RSI		R	RSI	R	RSI
127	24	610	14	356	F'glass or MW	54.2	9.5	50mm (2") MWB	7.9	1.4	60.4	10.6
128	24	610	14	356	Open Cell Spray Foam	52.6	9.3	50mm (2") MWB	7.9	1.4	59.0	10.4
129	24	610	14	356	Cellulose Fibre	48.5	8.5	50mm (2") MWB	7.9	1.4	54.3	9.6
130	24	610	14	356	F'glass or MW	54.2	9.5	100mm (4") MWB	15.7	2.8	68.6	12.1
131	24	610	14	356	Open Cell Spray Foam	52.6	9.3	100mm (4") MWB	15.7	2.8	67.2	11.8
132	24	610	14	356	Cellulose Fibre	48.5	8.5	100mm (4") MWB	15.7	2.8	63.7	11.2
133	24	610	14	356	F'glass or MW	54.2	9.5	150mm (6") MWB	23.6	4.2	76.7	13.5
134	24	610	14	356	Open Cell Spray Foam	52.6	9.3	150mm (6") MWB	23.6	4.2	75.3	13.3
135	24	610	14	356	Cellulose Fibre	48.5	8.5	150mm (6") MWB	23.6	4.2	71.7	12.6
136	24	610	14	356	F'glass or MW	54.2	9.5	200mm (8") MWB	31.5	5.5	84.7	14.9
137	24	610	14	356	Open Cell Spray Foam	52.6	9.3	200mm (8") MWB	31.5	5.5	83.3	14.7
138	24	610	14	356	Cellulose Fibre	48.5	8.5	200mm (8") MWB	31.5	5.5	79.7	14.0

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table M-12. Effective insulation values: 406-mm (16-inch) wood I-joist and sloped ceiling joists with cavity insulation and exterior-applied mineral wool board insulation.[a]

406mm (16")Wood I Joist Sloped Ceiling Joists With Cavity Insulation and Exterior Applied Mineral Wool Board												
Roof #	Joist Spacing		Wood I Joist Depth		Cavity Insulation	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm	inches	mm		R	RSI		R	RSI	R	RSI
127	16	406	16	406	F'glass or MW	61.8	10.9	50mm (2") MWB	7.9	1.4	65.3	11.5
128	16	406	16	406	Open Cell Spray Foam	59.9	10.6	50mm (2") MWB	7.9	1.4	64.0	11.3
129	16	406	16	406	Cellulose Fibre	55.3	9.7	50mm (2") MWB	7.9	1.4	60.4	10.6
130	16	406	16	406	F'glass or MW	61.8	10.9	100mm (4") MWB	15.7	2.8	73.7	13.0
131	16	406	16	406	Open Cell Spray Foam	59.9	10.6	100mm (4") MWB	15.7	2.8	72.3	12.7
132	16	406	16	406	Cellulose Fibre	55.3	9.7	100mm (4") MWB	15.7	2.8	68.6	12.1
133	16	406	16	406	F'glass or MW	61.8	10.9	150mm (6") MWB	23.6	4.2	81.9	14.4
134	16	406	16	406	Open Cell Spray Foam	59.9	10.6	150mm (6") MWB	23.6	4.2	80.5	14.2
135	16	406	16	406	Cellulose Fibre	55.3	9.7	150mm (6") MWB	23.6	4.2	76.7	13.5
136	16	406	16	406	F'glass or MW	61.8	10.9	200mm (8") MWB	31.5	5.5	90.1	15.9
137	16	406	16	406	Open Cell Spray Foam	59.9	10.6	200mm (8") MWB	31.5	5.5	88.6	15.6
138	16	406	16	406	Cellulose Fibre	55.3	9.7	200mm (8") MWB	31.5	5.5	84.8	14.9

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table M-13. Effective insulation values: 302-mm (11 7/8-inch) wood I-joist and sloped ceiling joists with cavity insulation and exterior-applied mineral wool board insulation—*continued*.[a]

406mm (16")Wood I Joist Sloped Ceiling Joists With Cavity Insulation and Exterior Applied Mineral Wool Board												
Roof #	Joist Spacing		Wood I Joist Depth		Cavity Insulation	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
139	24	610	16	406	F'glass or MW	61.8	10.9	50mm (2") MWB	7.9	1.4	67.3	11.9
140	24	610	16	406	Open Cell Spray Foam	59.9	10.6	50mm (2") MWB	7.9	1.4	65.8	11.6
141	24	610	16	406	Cellulose Fibre	55.3	9.7	50mm (2") MWB	7.9	1.4	60.4	10.6
142	24	610	16	406	F'glass or MW	61.8	10.9	100mm (4") MWB	15.7	2.8	75.6	13.3
143	24	610	16	406	Open Cell Spray Foam	59.9	10.6	100mm (4") MWB	15.7	2.8	74.0	13.0
144	24	610	16	406	Cellulose Fibre	55.3	9.7	100mm (4") MWB	15.7	2.8	70.1	12.3
145	24	610	16	406	F'glass or MW	61.8	10.9	150mm (6") MWB	23.6	4.2	83.7	14.7
146	24	610	16	406	Open Cell Spray Foam	59.9	10.6	150mm (6") MWB	23.6	4.2	82.1	14.5
147	24	610	16	406	Cellulose Fibre	55.3	9.7	150mm (6") MWB	23.6	4.2	78.1	13.8
148	24	610	16	406	F'glass or MW	61.8	10.9	200mm (8") MWB	31.5	5.5	91.7	16.2
149	24	610	16	406	Open Cell Spray Foam	59.9	10.6	200mm (8") MWB	31.5	5.5	90.1	15.9
150	24	610	16	406	Cellulose Fibre	55.3	9.7	200mm (8") MWB	31.5	5.5	86.1	15.2

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Appendix N. Effective Insulation Values for Suspended Floors

In high-performance housing, the insulation of suspended floors over unheated crawl spaces or cantilevered floors are insulated, at a minimum, to levels that equal that of the walls (Figure N-1 and Tables N-1 to N-8).

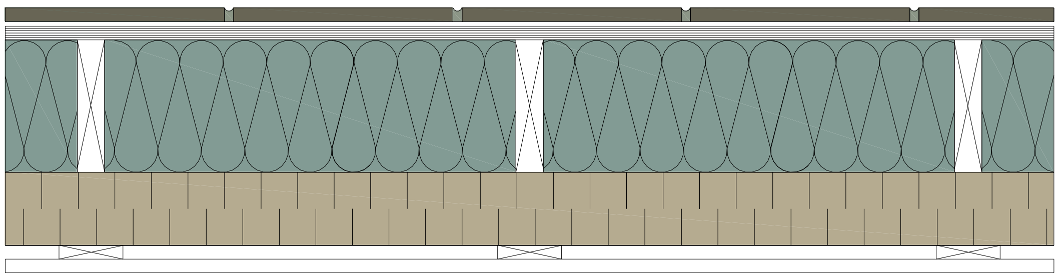


Figure N-1. A suspended or cantilevered floor with cavity insulation, vapour-permeable rigid insulation, strapping, and vented exterior finish.

Table N-1. Effective insulation values: suspended or cantilevered floor with cavity insulation, vapour-permeable rigid insulation, strapping, and vented exterior finish.[a]

Suspended or cantilevered floor with cavity fill insulation, vapour permeable rigid insulation, strapping and vented exterior finish.											
#	Floor Joist Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm		R	RSI		R	RSI	R	RSI
1	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	20	3.5	50mm (2") MWB	8	1.4	28.9	5.1
2	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	20	3.5	100mm (4") MWB	16	2.8	37.1	6.5
3	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22	3.9	50mm (2") MWB	8	1.4	30.3	5.3
4	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	22	3.9	100mm (4") MWB	16	2.8	38.6	6.8
5	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24	4.2	50mm (2") MWB	8	1.4	31.7	5.6
6	2x6 @ 16	38 x 140 @ 406	Fibreglass or Mineral Wool Batt	24	4.2	100mm (4") MWB	16	2.8	40.1	7.1
7	2x6 @ 16	38 x 140 @ 406	Cellulose Fibre	19.9	3.5	50mm (2") MWB	8	1.4	28.8	5.1
8	2x6 @ 16	38 x 140 @ 406	Cellulose Fibre	19.9	3.5	100mm (4") MWB	16	2.8	37.0	6.5
9	2x6 @ 16	38 x 140 @ 406	Open Cell Spray Foam	20.7	3.6	50mm (2") MWB	8	1.4	29.4	5.2
10	2x6 @ 16	38 x 140 @ 406	Open Cell Spray Foam	20.7	3.6	100mm (4") MWB	16	2.8	37.6	6.6

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table N-2. Effective insulation values: suspended or cantilevered floor with cavity insulation, vapour-permeable rigid insulation, strapping, and vented exterior finish—*continued*.[a]

#	Floor Joist Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm		R	RSI		R	RSI	R	RSI
11	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	20	3.5	50mm (2") MWB	8	1.4	29.6	5.2
12	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	20	3.5	100mm (4") MWB	16	2.8	37.7	6.6
13	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22	3.9	50mm (2") MWB	8	1.4	31.1	5.5
14	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	22	3.9	100mm (4") MWB	16	2.8	39.3	6.9
15	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24	4.2	50mm (2") MWB	8	1.4	32.6	5.7
16	2x6 @ 24	38 x 140 @ 610	Fibreglass or Mineral Wool Batt	24	4.2	100mm (4") MWB	16	2.8	40.9	7.2
17	2x6 @ 24	38 x 140 @ 610	Cellulose Fibre	20.0	3.5	50mm (2") MWB	8	1.4	29.5	5.2
18	2x6 @ 24	38 x 140 @ 610	Cellulose Fibre	20.0	3.5	100mm (4") MWB	16	2.8	37.6	6.6
19	2x6 @ 24	38 x 140 @ 610	Open Cell Spray Foam	20.7	3.6	50mm (2") MWB	8	1.4	30.1	5.3
20	2x6 @ 24	38 x 140 @ 610	Open Cell Spray Foam	20.7	3.6	100mm (4") MWB	16	2.8	38.3	6.7

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table N-3. Effective insulation values: suspended or cantilevered floor with cavity insulation, vapour-permeable rigid insulation, strapping, and vented exterior finish—*continued*.[a]

Suspended or cantilevered floor with cavity fill insulation, vapour permeable rigid insulation, strapping and vented exterior finish.										
#	Floor Joist Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm		R	RSI		R	RSI	R	RSI
21	2x8 @ 16	38 x 184 @ 406	Fibreglass or Mineral Wool Batt	28	4.9	50mm (2") MWB	8	1.4	35.3	6.2
22	2x8 @ 16	38 x 184 @ 406	Fibreglass or Mineral Wool Batt	28	4.9	100mm (4") MWB	16	2.8	43.7	7.7
23	2x8 @ 16	38 x 184 @ 406	Cellulose Fibre	26.1	4.6	50mm (2") MWB	8	1.4	34.0	6.0
24	2x8 @ 16	38 x 184 @ 406	Cellulose Fibre	26.1	4.6	100mm (4") MWB	16	2.8	42.3	7.5
25	2x8 @ 16	38 x 184 @ 406	Open Cell Spray Foam	27.2	4.8	50mm (2") MWB	8	1.4	34.7	6.1
26	2x8 @ 16	38 x 184 @ 406	Open Cell Spray Foam	27.2	4.8	100mm (4") MWB	16	2.8	43.1	7.6

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table N-4. Effective insulation values: suspended or cantilevered floor with cavity insulation, vapour-permeable rigid insulation, strapping, and vented exterior finish—*continued*.[a]

#	Floor Joist Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm		R	RSI		R	RSI	R	RSI
27	2x8 @ 24	38 x 184 @ 610	Fibreglass or Mineral Wool Batt	28	4.9	50mm (2") MWB	8	1.4	36.3	6.4
28	2x8 @ 24	38 x 184 @ 610	Fibreglass or Mineral Wool Batt	28	4.9	100mm (4") MWB	16	2.8	44.6	7.8
29	2x8 @ 24	38 x 184 @ 610	Cellulose Fibre	26.1	4.6	50mm (2") MWB	8	1.4	34.9	6.1
30	2x8 @ 24	38 x 184 @ 610	Cellulose Fibre	26.1	4.6	100mm (4") MWB	16	2.8	43.1	7.6
31	2x8 @ 24	38 x 184 @ 610	Open Cell Spray Foam	27.2	4.8	50mm (2") MWB	8	1.4	35.6	6.3
32	2x8 @ 24	38 x 184 @ 610	Open Cell Spray Foam	27.2	4.8	100mm (4") MWB	16	2.8	43.9	7.7

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table N-5. Effective insulation values: suspended or cantilevered floor with cavity insulation, vapour-permeable rigid insulation, strapping, and vented exterior finish—*continued*.[a]

Suspended or cantilevered floor with cavity fill insulation, vapour permeable rigid insulation, strapping and vented exterior finish.										
#	Floor Joist Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm		R	RSI		R	RSI	R	RSI
33	2x10 @ 16	38 x 184 @ 406	Fibreglass or Mineral Wool Batt	31	5.5	50mm (2") MWB	8	1.4	38.3	6.7
34	2x10 @ 16	38 x 184 @ 406	Fibreglass or Mineral Wool Batt	31	5.5	100mm (4") MWB	16	2.8	46.6	8.2
35	2x10 @ 16	38 x 184 @ 406	Cellulose Fibre	33.4	5.9	50mm (2") MWB	8	1.4	39.9	7.0
36	2x10 @ 16	38 x 184 @ 406	Cellulose Fibre	33.4	5.9	100mm (4") MWB	16	2.8	45.0	7.9
37	2x10 @ 16	38 x 184 @ 406	Open Cell Spray Foam	34.7	6.1	50mm (2") MWB	8	1.4	40.8	7.2
38	2x10 @ 16	38 x 184 @ 406	Open Cell Spray Foam	34.7	6.1	100mm (4") MWB	16	2.8	45.8	8.1

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table N-6. Effective insulation values: suspended or cantilevered floor with cavity insulation, vapour-permeable rigid insulation, strapping, and vented exterior finish—*continued*.[a]

#	Floor Joist Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm		R	RSI		R	RSI	R	RSI
39	2x10 @ 24	38 x 184 @ 610	Fibreglass or Mineral Wool Batt	31	5.5	50mm (2") MWB	8	1.4	39.3	6.9
40	2x10 @ 24	38 x 184 @ 610	Fibreglass or Mineral Wool Batt	31	5.5	100mm (4") MWB	16	2.8	47.5	8.4
41	2x10 @ 24	38 x 184 @ 610	Cellulose Fibre	33.4	5.9	50mm (2") MWB	8	1.4	41.0	7.2
42	2x10 @ 24	38 x 184 @ 610	Cellulose Fibre	33.4	5.9	100mm (4") MWB	16	2.8	46.7	8.2
43	2x10 @ 24	38 x 184 @ 610	Open Cell Spray Foam	34.7	6.1	50mm (2") MWB	8	1.4	42.0	7.4
44	2x10 @ 24	38 x 184 @ 610	Open Cell Spray Foam	34.7	6.1	100mm (4") MWB	16	2.8	47.6	8.4

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table N-7. Effective insulation values: suspended or cantilevered floor with cavity insulation, vapour-permeable rigid insulation, strapping, and vented exterior finish—*continued*.[a]

Suspended or cantilevered floor with cavity fill insulation, vapour permeable rigid insulation, strapping and vented exterior finish.										
#	Floor Joist Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm		R	RSI		R	RSI	R	RSI
45	2x12 @ 16	38 x 184 @ 406	Fibreglass or Mineral Wool Batt	40	7.0	50mm (2") MWB	8	1.4	45.4	8.0
46	2x12 @ 16	38 x 184 @ 406	Fibreglass or Mineral Wool Batt	40	7.0	100mm (4") MWB	16	2.8	53.9	9.5
47	2x12 @ 16	38 x 184 @ 406	Cellulose Fibre	40.6	7.2	50mm (2") MWB	8	1.4	45.8	8.1
48	2x12 @ 16	38 x 184 @ 406	Cellulose Fibre	40.6	7.2	100mm (4") MWB	16	2.8	54.4	9.6
49	2x12 @ 16	38 x 184 @ 406	Open Cell Spray Foam	42.2	7.4	50mm (2") MWB	8	1.4	46.9	8.3
50	2x12 @ 16	38 x 184 @ 406	Open Cell Spray Foam	42.2	7.4	100mm (4") MWB	16	2.8	55.5	9.8

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

Table N-8. Effective insulation values: suspended or cantilevered floor with cavity insulation, vapour-permeable rigid insulation, strapping, and vented exterior finish—*continued*.[a]

#	Floor Joist Dimensions and Spacing		Cavity Fill Insulation Type	Cavity Insulation		Exterior Insulation	Exterior Insulation		Effective Thermal Resistance	
	inches	mm		R	RSI		R	RSI	R	RSI
51	2x12 @ 24	38 x 184 @ 610	Fibreglass or Mineral Wool Batt	40	7.0	50mm (2") MWB	8	1.4	46.8	8.2
52	2x12 @ 24	38 x 184 @ 610	Fibreglass or Mineral Wool Batt	40	7.0	100mm (4") MWB	16	2.8	55.2	9.7
53	2x12 @ 24	38 x 184 @ 610	Cellulose Fibre	40.6	7.2	50mm (2") MWB	8	1.4	47.2	8.3
54	2x12 @ 24	38 x 184 @ 610	Cellulose Fibre	40.6	7.2	100mm (4") MWB	16	2.8	55.6	9.8
55	2x12 @ 24	38 x 184 @ 610	Open Cell Spray Foam	42.2	7.4	50mm (2") MWB	8	1.4	48.4	8.5
56	2x12 @ 24	38 x 184 @ 610	Open Cell Spray Foam	42.2	7.4	100mm (4") MWB	16	2.8	56.9	10.0

[a] MWB = semi-rigid mineral wool board insulation, 128 kg/m^3 (8 lb/ft^3).

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