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Guide for Designing Energy-Efficient Building Enclosures

for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America

SP-53 FPINNOVATIONS

FPInnovations is a not-for-profit world leader that specializes in the creation of scientific solutions in support of the Canadian forest sector's global competitiveness and responds to the priority needs of its industry members and government partners. It is ideally positioned to perform research, innovate, and deliver state-of-the-art solutions for every area of the sector's value chain, from forest operations to consumer and industrial products. FPInnovations' staff numbers more than 525. Its R&D laboratories are located in Québec City, Ottawa, Montréal, Thunder Bay, Edmonton, and Vancouver, and it has technology transfer offices across Canada. For more information about FPInnovations, visit: www.fpinnovations.ca.

RDH Building Engineering Ltd. is an engineering consulting firm based in the province of British Columbia and in the states of Washington and Oregon. RDH focuses on the integration of building science, engineering, architecture, and construction management services for the building enclosure of new construction projects and existing buildings. In the wake of the Pacific Northwest's leaky building disaster in the 1980s and 1990s, RDH played a major role in restoring confidence in the building design and construction industry. RDH has published numerous research and guideline documents, thus contributing to profound improvements in the performance of building enclosures and in the understanding of building science across North America and around the world. For more information about RDH, visit: www.rdhbe.com.

Acknowledgements

This guide was developed by FPInnovations and RDH Building Engineering Ltd. based on the building industry's design and construction practices and on relevant research. The authors are:

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The guide would not have been possible without generous support of the funding partners. Natural Resources Canada (NRCan) provided funding through the Technology Transfer Program under the contribution agreement existing between NRCan and FPInnovations. The Homeowner Protection Office (HPO), Branch of BC Housing and the Canadian Wood Council (CWC) provided both financial support and in-kind contribution. FPInnovations and RDH Building Engineering Ltd. also provided considerable in-kind contribution.

We would like to express our gratitude to the following individuals for reviewing previous versions of this document, providing comments, and contributing technical information:

Steve Easley, MSc, Steve Easley & Associates Inc.

Hua Ge, Ph.D., P.Eng., Concordia University

Samuel Glass, Ph.D., USDA Forest Products Laboratory

Mario Gonçalves, Eng., Patenaude-Trempe Inc.

Denisa Ionescu, Ph.D., Homeowner Protection Office, Branch of BC Housing

Robert Jonkman, P.Eng., Canadian Wood Council

Mark Lawton, P.Eng., Morrison Hershfield

Paul Morris, Ph.D., FPInnovations

John Straube, Ph.D., P.Eng., University of Waterloo & Building Science Corporation

Constance Thivierge, MSc, P.Eng., FPInnovations

Our thanks also go to Sue Rollinson for designing the cover page. The photos on the front and back (left) covers are courtesy of Sukh Johal c/o Wood ***WORKS!*** BC.

Preface

The *Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America* was developed by FPInnovations in collaboration with RDH Building Engineering Ltd., the Homeowner Protection Office, Branch of BC Housing, and the Canadian Wood Council.

The project is part of efforts within the Advanced Building Systems Program of FPInnovations to assemble and add to the knowledge base regarding Canadian wood products and building systems. The team of the Advanced Building Systems Program works with members and partners of FPInnovations to address critical technical issues that threaten existing markets for wood products or which limit expansion or access to such new markets. This guide was developed in response to the rapidly changing energy-efficiency requirements for buildings across Canada and the United States.

This guide serves two major objectives:

- To assist architects, engineers, designers and builders in improving the thermal performance of building enclosures of wood multi-unit residential buildings (MURBs), in response to the increasingly stringent requirements for the energy efficiency of buildings in the marine to cold climate zones in North America (U.S. DOE/ASHRAE and NECB Climate Zones 5 through 7 and parts of Zone 4);
- To advance MURB design practices, construction practices, and material use based on best knowledge, in order to ensure the durable performance of wood-frame building enclosures that are insulated to higher levels than traditional wood-frame construction.

The major requirements for thermal performance of building enclosures are summarized (up to February 2013), including those for the following codes and standards:

- 2011 National Energy Code of Canada for Buildings (2011 NECB);
- 2013 interim update of the 2010 National Building Code of Canada (2010 NBC, Section 9.36–Energy Efficiency);
- 2012 International Energy Conservation Code (2012 IECC);
- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1–Energy Standard for Buildings Except Low-Rise Residential Buildings (2004, 2007, and 2010 versions).

In addition to meeting the requirements of the various building codes and standards, a building may need to incorporate construction practices that reflect local preferences in material use, design and construction. Regional climate differences will also affect design solutions.

This guide primarily addresses above-grade walls, below-grade walls and roofs of platform wood-frame construction. It also includes information regarding thermal performance of cross-laminated timber (CLT) assemblies as well as the use of non-bearing wood-frame exterior walls (infill walls) in wood post-and-beam and concrete structures.

Examples of thermal resistance calculations, building assemblies, critical interface detailing, and appropriate material selection are provided to help guide designers and builders meet the requirements of the various energy-efficiency codes and standards, achieve above-code performance, and ensure long-term durability. This guide builds on the fundamentals of building science and on information contained within the *Building Enclosure Design Guide: Wood-Frame Multi-Unit Residential Buildings*, published by the Homeowner Protection Office, Branch of BC Housing.

This guide is based on the best current knowledge and future updates are anticipated. The guide is not intended to be a substitute for professional advice that considers specific building parameters.

Disclaimer

The *Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America* can be electronically downloaded without charge from the website www.fpinnovations.ca. Additional information can be obtained by visiting the respective websites of FPInnovations, RDH Building Engineering Ltd., the Homeowner Protection Office, Branch of BC Housing, and the Canadian Wood Council.

The information contained in this publication represents current research and technical information made available from many sources. THE AUTHORS, PARTNERS, PUBLISHERS, OR OTHER CONTRIBUTORS ASSUME NO LIABILITY FOR ANY DIRECT OR INDIRECT DAMAGE, INJURY, LOSS OR EXPENSE THAT MAY BE INCURRED OR SUFFERED AS A RESULT OF THE USE OF THIS PUBLICATION INCLUDING WITHOUT LIMITATION PRODUCTS, BUILDING TECHNIQUES OR PRACTICES. The views expressed herein do not necessarily represent those of any individual contributor, FPInnovations and its Partners. Building science, products and construction practices change and improve over time and rather than relying on this publication, it is advisable to (a) regularly consult up-to-date technical publications on products and practices, (b) seek specific information and professional advice on the use of products in any application or detail from manufacturers or suppliers of the products and consultants with appropriate qualifications and experience, (c) review and comply with the specific requirements of the applicable building codes for each construction project. Nothing in this publication is an endorsement of any particular product or proprietary building system.

Please contact Jieying Wang of FPInnovations at jieying.wang@fpinnovations.ca for comments and questions related to this guide.

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CHAPTER 1: INTRODUCTION

A mixed use multi-unit wood-frame building development under construction in Marine Climate Zone 4 in Seattle, Washington.

Wood-frame construction practices used in North America today have evolved over a long period of time. Changes have been driven by the availability of materials; development of new building materials; population growth (the need for more multi-unit buildings); and pressures to use labour, materials, and energy more efficiently. While this evolution has accelerated rapidly in the last 30 years, the fundamental wood-frame structural system has remained unchanged for much longer. Wood-frame construction has been widely used in North America because it has a proven record of performance under a wide range of climates, provided the system is used in an appropriate manner with proper attention paid to detailing and durability.

With the renewed global focus on energy efficiency, the thermal performance of the building enclosure has gained increasing attention. Building and energy codes and standards across North America have undergone or are currently undergoing revisions, and the minimum thermal requirements for wood-frame building enclosure assemblies are now more stringent. Many of the new requirements exceed the practical thermal insulation limits of traditional wood stud frame construction, prompting the need for alternative assemblies that include insulation outside of the framing spaces, as well as more thermally efficient detailing.

From a thermal perspective, wood-frame building enclosures are inherently more efficient than steel frame, concrete, or masonry construction—largely because of reduced thermal bridging through the wood structural elements, including the wood studs, columns, beams, and floors. Wood frame assemblies can continue to be more energy efficient than steel or concrete as performance requirements become more stringent. Wood also has environmental benefits because it is a renewable resource, sequesters carbon, and has less embodied energy than most alternative materials.

Wood-frame, multi-unit, residential buildings are typically in the townhouse style or are 3 to 4 storeys in height. However, there is also a desire to build taller wood-frame residential buildings—either for social and construction efficiencies or to make use of locally available timber. Five and six-storey, wood-frame, residential buildings have become more common in parts of North America. In Oregon and Washington States the use of 5-storey wood-frame construction over concrete podium slab (5+1) is allowed by the local building code. In British Columbia, the 2006 version of the Provincial Building Code (BCBC) was amended in 2009 to allow for up to 6 storeys of wood-frame construction. The case for even taller wood-frame MURBs, i.e., greater than 10 storeys, is being made and some have already been constructed in Europe and are proposed in North America.

In addition to height increases in wood frame construction, the types of structural systems are now more varied. Cross-laminated timber (CLT), post and beam with infill, and even concrete structures with wood framing infill walls are being used in some areas.

The changes in building height, a wider variety of structural systems, and the more stringent requirements for building energy efficiency in recent years have created the need for design guidance on energy efficient and durable building enclosures.

Platform framing

1.1 Structural Systems for Building Enclosures

Mass timber—CLT

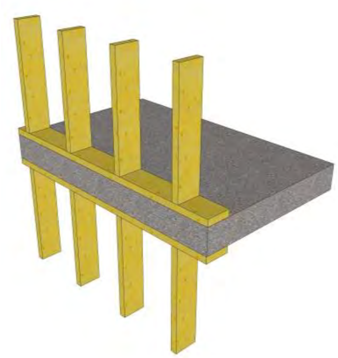
The building enclosure is a system of materials, components, and assemblies that physically separate the exterior environment from the interior environment(s). Thus, it is sometimes also called an environmental separator. The typical elements of a building enclosure include roofs, above-grade walls, windows, skylights, doors, below-grade walls, and the base floor system. Both the thermal performance (R-value) and airtightness of the building enclosure directly affect space-heating and cooling loads and occupant comfort. This guide provides design guidance for above-grade walls, below-grade walls, and roofs. It focuses on thermal efficiency and long-term durability performance.

This guide addresses three building enclosure structural systems:

1. traditional platform framing (and balloon framing)
2. cross-laminated timber (CLT)
3. non-bearing wood-frame exterior walls (infill walls) for wood post-and-beam and concrete structures

Post-and-beam framing

CLT has become popular in Europe for the prefabricated construction of wall, roof, and flooring elements. The use of CLT in North America is gaining interest and locally manufactured CLT products have been made available in recent years, particularly in Canada. CLT and other engineered timber products such as parallel strand lumber (PSL), laminated strand lumber (LSL) and laminated veneer lumber (LVL) have also made it technically easier to design and build structures taller than 6 storeys, because these products offer increased strength properties and reduced shrinkage.



Wood-frame infill

Timber post-and-beam structures with heights equivalent to today's 10-storey buildings were commonly built in large cities in North America around a century ago. In Europe, CLT has been used to construct mid-rise buildings, such as the 9-storey Murray Grove building in London, UK, and the 8-storey Limnolog buildings in Sweden. The use of CLT in construction is covered in the *Cross-Laminated Timber Handbook* (Canadian Edition) published by FPInnovations in 2011, and in the *Cross-Laminated Timber*

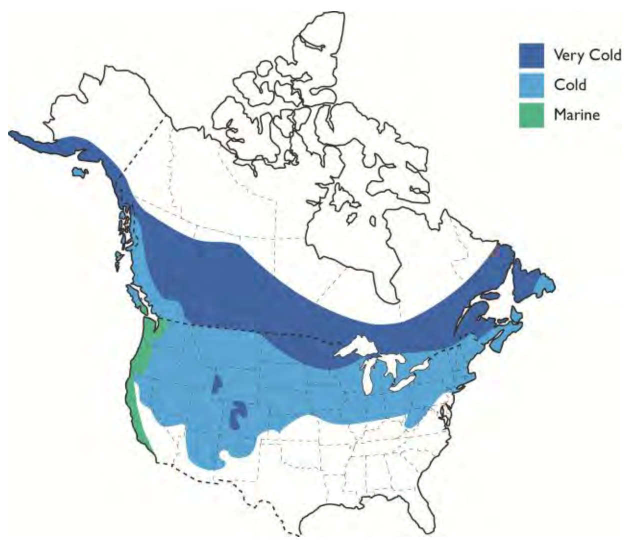
Handbook (US Edition) published by FPInnovations and Binational Softwood Lumber Council in 2013: the design of CLT building enclosure assemblies is addressed in Chapter 10.

This guide also provides brief direction on the use of non-bearing wood-frame exterior walls (infill walls) for both wood post-and-beam and concrete structures. The use of wood infill walls has become dominant for mid-rise and high-rise residential buildings in northern European countries such as Sweden. These systems are generally more energy efficient than concrete and steel assemblies due to the significantly reduced thermal bridging of the assemblies. Wood infill walls are gaining acceptance in North America.

Structurally insulated panels (SIPs), while being an alternative wood-frame construction technique, are not covered within this version of the guide.

1.2 Climate Zones

This guide provides climate-specific recommendations for constructing wood buildings in Marine, Cold, and Very Cold Climate Zones—i.e., essentially the ASHRAE Climate Zones 5 through 7, and parts of Zone 4. These climate zones are heating dominated with the exception of parts of southern California. These zones comprise the most important markets for residential wood frame construction in North America. These areas generally have the most urgent needs for such design guidance in order to meet the increasingly more stringent energy code requirements while ensuring the durability performance of building enclosures. While much of the information contained within this guide is relevant in other climate zones, similar companion guideline documents for the hot–dry / hot–humid and arctic climates will also be developed.



The building enclosure design guidelines within this guide are targeted towards buildings in Marine to Very Cold Climate Zones (DOE/ASHRAE Climate Zones 5 through 7 and parts of Zone 4)

1.3 About this Guide

This guide focuses on the management of heat, air, and moisture transfer in highly insulated enclosure assemblies for wood frame, low- to mid-rise MURB applications. The guide does not deal specifically with structural, acoustic, fire, nor a variety of other parameters that may also effects on the design of a building enclosure. However, these performance criteria must be considered together with the heat, air, and moisture control provisions presented.

This guide is organized to take the user from an understanding of the local building code requirements for thermal performance, air tightness, and energy efficiency, through to the fundamentals of heat, air, and moisture control for highly insulated wood-frame assemblies, before presenting design guidance that is specific to assemblies and details. The guide assumes that the user already has basic understanding of the behaviour of wood as a material and an understanding of heat, air, and moisture control fundamentals.

The guide reflects current good practice in design and construction. Good practice in the context of this guide means the balanced application of currently available technology, materials, and normal skilled workmanship to the design and construction of affordable and durable housing. The perception of good practice may vary by region in North America and some practices recommended within this guide may be considered better than local standard practice.

The guide is not intended to be a research paper or an exploration of innovative technology. Although some of the proposed assemblies have limited field performance history across all regions of North America, they are all based on sound principles and are believed to be conservative for their intended uses. Most of the assemblies are being used successfully in at least some parts of Canada and the United States, as well as in other parts of the world.

A 5+1 storey wood-frame MURB under construction in Portland, Oregon.

This guide is not intended to replace professional advice. When information presented in this guide is incorporated into specific building projects, it must be reviewed by the design team and reflect the unique conditions and design parameters of each building. Use of the guide does not relieve designers of their responsibility to comply with local building codes, standards, and by-laws with respect to the design and construction of the building enclosure. Readers should be aware that there may be local jurisdictional requirements that determine the involvement of architects and engineering professionals.

The guide is not intended for the construction of buildings taller than 6 storeys, which is allowed in some jurisdictions in North America. The different materials and exposure conditions for taller buildings will dictate different—and likely more rigorous—approaches to heat, air, and moisture control than are presented in this guide. Furthermore, the guide is not intended to be applied directly to the rehabilitation of wood-frame buildings. These projects may require quite different detailing, in many cases due to the fact that much of the building form and structure already exists and cannot be changed in a cost-effective manner.

An attempt has been made throughout the document to provide the user with useful reference material. In particular, the construction industry has historically been provided with good research and guidance on wood-frame design and construction practices from many sources, including: the Canada Mortgage and Housing Corporation, the Homeowner Protection Office, Branch of BC Housing, the National Research Council of Canada, the US Department of Energy through its Build America Program, FPInnovations, the Canadian Wood Council, the US Forest Products Laboratory, and many other research organizations across North America. See Chapter 6 for a list of the major references.

CHAPTER 2: BUILDING AND ENERGY CODES

This chapter presents the requirements, as mandated by the building code, for thermal performance and energy efficiency of the wood-based building enclosure assemblies in multi-unit residential buildings (MURBs). Requirements for air-barrier systems are also discussed within the context of energy efficiency.

The information contained within this chapter is current as of March 2013. Consult the website links and references provided in the following sections to confirm that the information provided here is current. Regular updates to the content within this chapter will be published online.

The thermal requirements summarized in this chapter are used to select appropriate assemblies discussed in later chapters. The effective R-values of various wood-frame wall and roof assemblies are provided in Chapter 4.

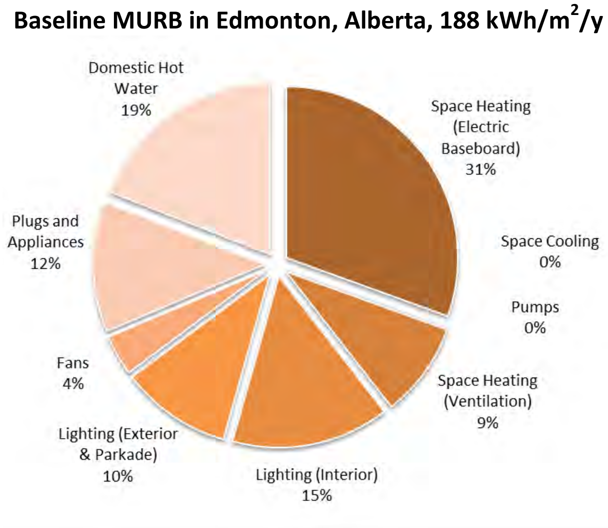
A wood-frame multi-unit residential building (MURB) under construction—how much insulation is needed in the wall and roof assemblies for energy code compliance, or to meet the requirements of a high-performance building?

2.1 Energy Use in Wood-Frame MURBs

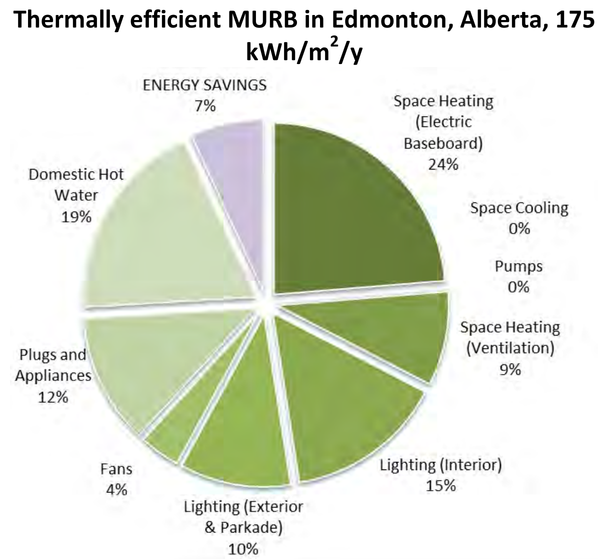
Of all the energy used in North America it is estimated that 30 to 40% is consumed within buildings. In Canada and the northern United States, the majority of space-conditioning energy (natural gas, fuel oil, or electricity) in residential buildings (both single-family and multi-family) is consumed for space heating, whereas in the southern United States the majority of energy (electricity) is used for cooling. Mixed climate zones and coastal climate zones have a mix of heating and cooling needs. The thermal performance and airtightness of the building enclosure play significant roles in controlling a building's heat loss and gain and whole-building energy efficiency. Therefore, thermally efficient and airtight wood-frame enclosure assemblies are desirable features of an energy-efficient MURB.

Minimum thermal insulation requirements vary by climate zone and space-conditioning needs. Buildings in colder climate zones generally require more insulation than those in temperate or warm climate zones. As the cost of energy increases, higher R-value targets in all climate zones become economically justifiable. There are, however, depreciating energy savings and returns on the super-insulation of wall and roof assemblies, and consideration for a whole-building systems approach is most appropriate.

To demonstrate the value of a highly thermally efficient and airtight building enclosure, the energy consumption of a 4-storey 40 unit MURB in Edmonton, Alberta (Climate Zone 7, heating dominated) was simulated using a calibrated energy model. The comparative scenario presented in the following graphs demonstrates the importance of the effects of the building enclosure on space-conditioning loads. In the first scenario (baseline, left) the building enclosure consists of R-10 (RSI-1.76)-effective wood-frame walls, and an R-20 (RSI-3.52)-effective wood-frame roof; the U-0.35 (USI-2.0) windows occupy 30% of the wall area. In the second scenario (thermally efficient, right) the building enclosure consists of R-20 (RSI-3.52)-effective wood-frame walls and an R-40 (RSI-7.04)-effective wood-frame roof; U-0.17 (USI-0.97) windows occupy 30% of the wall area.



Energy consumption distribution for a baseline MURB in Edmonton, Alberta (cold climate, heating only). Total 188 kWh/m^2/y (R-10 effective for walls, R-20 effective for roof, and U-0.35 for windows with a 30% glazing ratio).



Energy consumption distribution for MURB with a thermally efficient building enclosure in Edmonton, Alberta (cold climate, heating only). Total 175 kWh/m^2/y (R-20 effective for walls, R-40 effective for roof, and U-0.17 for windows with a 30% glazing ratio).

The energy-consumption distribution plots highlight the relative improvements in energy efficiency that can be made by the use of more energy-efficient building enclosure assemblies. In general, heating-dominated colder climate zones benefit more from higher effective R-values than cooling-dominated hotter climate zones. Buildings in cooling-dominated climate zones benefit more from strategies to reduce solar heating (e.g., lower window solar heat gain coefficient (SHGC), exterior shading, thermal mass, etc.) These differences are reflected in building code requirements and local energy-efficiency practices by climate zone. For example, light-coloured, low-solar-absorptivity roofs are required in hot climate zones, but not in cold climates as per ASHRAE 90.1 covered later in this chapter.

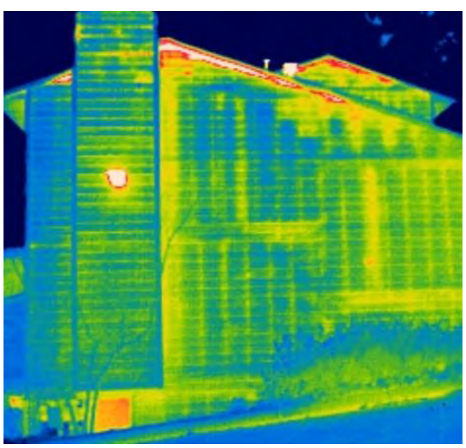
2.1.1 Nominal vs. Effective R-Values

The requirements for thermal performance of insulated assemblies pertain to minimum nominal R-values of the insulation or to effective R-values of the assembly. **Nominal insulation R-value** refers to the rated R-value of the insulation material being installed and does not account for losses due to thermal bridging. Thermal bridging is when a more conductive material (e.g., aluminum, steel, concrete, wood, etc.) provides a path for heat to flow such that it bypasses a less conductive material (insulation). This bypassing, or "bridging", of the less conductive material significantly reduces its effectiveness as an insulator. Specifically in wood-frame buildings, thermal bridging involves the heat loss that occurs through wood framing, air gaps, metal fasteners, and other penetrations through the installed insulation.

Fibreglass insulation placed between wood framing in a 5-storey MURB under construction. The effective R-value of the wall assembly is much less than the R-20 nominal batt insulation due to thermal bridging of framing, particularly when heavy timber elements are used at lower floors.

R-values such as R-20 (RSI-3.5) to represent fibrous batt insulation in a 2x6 stud space, or R-5 (RSI-0.9) to represent a 1-inch layer of rigid polystyrene, are examples of nominal insulation values. Historically, most building codes have specified nominal insulation R-values in order to simplify the requirements for builders and designers of small buildings. The **effective assembly R-values** that could be constructed using the nominal insulation value would of course vary depending on the type of framing and on the extent of other thermal bridging, resulting in a significant range of actual, or effective, thermal performance. Therefore, the use of effective assembly R-values is a more rational measure of true thermal performance.

The use of effective R-values rather than nominal R-values in building codes and energy codes is also becoming more common because two- and three-dimensional, finite-element, heat-flow calculation software is readily available and used by practitioners to calculate effective R-values. This shift also moves the thermal requirements for wood frame buildings closer to those used for commercial and larger buildings for which energy codes and standards have required effective R-values for some time. Further guidance for detailed wood-frame assemblies is provided in Chapter 4.



Infrared image of a wood-frame MURB, showing thermal bridging and heat loss through the wood framing and by means of air leakage.

Building codes, energy codes, and standards that use effective rather than nominal R-value compliance paths include: ASHRAE 90.1 (all versions), 2011 National Energy Code for Buildings (NECB) in Canada, and the 2012 Interim Update of the 2010 National Building Code of Canada (NBC). Guidance is provided within these codes and standards regarding how to calculate the effective R-values of common wood-frame assemblies.

Nominal insulation requirements are still used in codes such as the 2012 International Energy Conservation Code (IECC) as well as in some provincial building codes in Canada for Part 9 buildings (i.e., houses and smaller wood-frame MURBs).

Continuous insulation (ci) is a term used within ASHRAE 90.1 and other energy codes and standards and refers to the intended purpose of providing at least a minimum continuous layer of insulation that has an effective R-value equal to or very close to its nominal R-value (i.e., little to no thermal bridging). Continuous insulation is often specified in energy codes as a stand-alone prescriptive requirement, or alternatively is specified in conjunction with thermally bridged, nominal insulation (e.g., between wood studs) values in order to achieve higher effective R-values. Common industry practice is to achieve the continuous insulation requirement with exterior rigid or semi-rigid insulation installed on the exterior of a framed assembly. Continuous insulation could also be installed to the interior or within the middle of some assemblies, although it would be challenging to meet the requirement for continuity at floor levels in multi-storey buildings.

ASHRAE 90.1 Definition of continuous insulation (ci): "Insulation that is continuous across all structural members without thermal bridges other than fasteners and service openings. It is installed on the interior or exterior or is integral to any opaque surface of the building envelope (enclosure)."

An industry issue with this requirement stems from the attachment of claddings through exterior insulation. The interpretation of this definition in the industry is mixed as to what constitutes a fastener; however, ASHRAE 90.1 does define 20-gauge, 1-inch brick ties spaced no closer than 24x16 inches as a fastener, and anything smaller or having equal or less thermal bridge effect could therefore be deemed to meet the intent of continuous insulation. Continuous- or large-clip cladding supports and brick shelf angles would not meet this definition.

In a similar way, the **National Energy Code for Buildings (NECB)** provides requirements for "continuity of insulation" (3.2.1.2). The thermal bridging caused by closely spaced, repetitive structural members such as studs, joints, lintels, and plates should be considered in calculations.

2.2 Heating and Cooling Degree Days and Climate Zones

Building enclosure thermal performance requirements are prescribed based on climate zones. Higher energy performance is required for more extreme climate zones. Climate zones are defined based on heating degree days (HDDs) and cooling degree days (CDDs), solar radiation, and humidity levels. An HDD is a measure of how cold a location is over a period of time, relative to a base temperature (typically 18°C, or 65°F). The HDD is the difference between that day's average temperature and the base temperature. If the day's average temperature is equal to or above the base temperature, the HDD is zero. Similarly, a CDD is a measure of how hot a location is over a period of time relative to a base temperature (typically 18°C, or 65°F). The CDD is the difference between that day's average temperature and the base temperature. If the day's average temperature is less than the base temperature, the CDD is zero. Yearly HDDs and CDDs are simply the cumulative daily values. So if the daily average temperature for a location is 6°C below the baseline temperature for every day of the year, then the yearly HDD, which is used to establish climate zones, is 6 x 365 = 2,190 HDD.

Climate data from Environment Canada and the National Oceanic and Atmospheric Administration (NOAA) in the United States are used to determine climatic conditions within each city or area in Canada and the United States. Typically climate data are analyzed using 30-year averages (e.g., 1971 through 2000 or 1981 through 2010) developed for each decade. Depending on the building code or energy standard in place, and on the time of each revision, a different data set may be utilized. Because of the global impacts of climate change, the effects of urban heat islands, and the effects of other factors that influence air temperatures within cities where these data are measured, climate data are constantly evolving, thus cities periodically shift climate zones.

2.3 Canadian Building Codes and Energy Codes

In Canada there are two national model codes that specify energy-efficiency provisions for buildings: the National Building Code of Canada (NBC), and the National Energy Code for Buildings (NECB) (which was previously called the

Model National Energy Code for Buildings (MNECB)). These national codes have been adopted either with or without modifications by each of the provinces and territories. The city of Vancouver, British Columbia has a modified version of the provincial building code written into their respective municipal building bylaws. Buildings on federal land (e.g., national parks, Canadian forces bases, and First Nations reserves) are required to meet the current National Building Code and National Energy Code for Buildings requirements regardless of the province.

Within the 2012 interim update of the 2010 NBC, the thermal performance requirements for the building enclosures are intended for housing and low-rise buildings (Part 9 buildings), including some low-rise wood-frame MURBs. The thermal performance requirements within the 2011 National Energy Code for Buildings (updated from 1997 Model National Energy Code for Buildings) are generally intended for larger buildings (Part 3) which includes larger wood-framed MURBs and all other non-residential buildings. The adoption of either the 1997 Model National Energy Code for Buildings or 2011 National Energy Code for Buildings requirements depends on the reference within each provincial building code.

Regarding the compliance of large buildings with energy-efficiency code, British Columbia has adopted ASHRAE 90.1-2004 and Ontario has adopted a combination of ASHRAE 90.1-1989 and 2004. The City of Vancouver, through its Building Bylaw, has adopted ASHRAE 90.1-2007. British Columbia, Ontario, and Vancouver, and other jurisdictions are currently considering the adoption of, or have plans to adopt, the more recent 2010 version of ASHRAE 90.1.

Provinces use some local interpretation around the thermal insulation requirements for residential buildings; and therefore practitioners must be aware of what applies for certain multi-unit residential building heights or storeys in their jurisdiction. For example, within British Columbia, energy-efficiency requirements for wood-frame MURBs up to 6 storeys are outlined in Part 10 of the 2012 BCBC. For MURBs that are 4 storeys and lower, prescriptive nominal R-value requirements apply, while for 5- and 6-storey MURBS the effective R-value requirements within ASHRAE 90.1-2004 apply. Further complicating this is that the climate zone definition associated with the prescriptive requirements is different than the one associated with the effective R-value requirements.

The requirements of the 1997 Model National Energy Code for Buildings for building enclosure performance are often used in LEED energy simulations, and the new 2011 National Energy Code for Buildings is currently undergoing review for adoption into many of the provinces. The 2012 update of the 2010 National Building Code contains more stringent energy-efficiency measures than previous versions and includes reference to the new 2011 National Energy Code for Buildings. Quebec released its new energy requirements for Part 9 housing in 2012.

More information on the National Building Code and National Energy Code for Buildings can be found at the following websites:

- nationalcodes.ca
- nrc-cnrc.gc.ca

A summary of the provinces' adoption of the model national codes can be found here:

- nationalcodes.nrc.gc.ca/eng/code_adoption.html

Links to the various ministries responsible for building codes in each province and territory can be found here:

- nationalcodes.nrc.gc.ca/eng/links_provincial.shtml

Additional provincial building code websites can be found here by province:

- Bureau de Normalisation du Quebec (BNQ): rbq.gouv.qc.ca
- Ontario Building Code (OBC): obc.mah.gov.on.ca

- British Columbia Building Code: bccodes.ca
- Nova Scotia Building and Plumbing Code: gov.ns.ca/snsmr/muns/code/
- Alberta Building Code: municipalaffairs.gov.ab.ca
- Manitoba Building Code: firecomm.gov.mb.ca
- Saskatchewan's building code: sboa.sk.ca/index.php/licensing-inspectors/9-codes-and-regulations

Municipal building code for Vancouver:

- Vancouver Building Bylaw: vancouver.ca/home-property-development/building-and-renovating.aspx

The thermal performance requirements for building enclosure assemblies that are in the 2011 National Energy Code for Buildings (NECB) and in the 2012 revision of the National Building Code (NBC) are discussed in the following sections. The requirements that are in ASHRAE 90.1 for jurisdictions in Canada are also covered.

2.3.1 National Building Code of Canada (NBC)

The December 2012 interim update of part 9.36 of the 2010 National Building Code of Canada (NBC) includes substantially more stringent minimum thermal resistance values for across Canada compared with values in the previous revisions and the 1997 Model National Energy Code for Buildings. Climate zones have also been realigned to 1000 HDD increments to align with the 2011 National Energy Code for Buildings and also ASHRAE 90.1. The 2012 update of the 2010 National Building Code applies to Part 9 buildings and will therefore apply to some wood-frame MURBs in some jurisdictions across Canada.

The minimum thermal resistance values are effective R-values and account for thermal bridging (i.e., all framing component, attachments, etc. that penetrate the insulation and reduce its thermal effectiveness). Two tables are presented, one where the building has heat recovery ventilators (HRVs) and one where other ventilation systems are used (Table 2.3.1), thus recognizing the energy-efficiency improvements that heat recovery ventilators have on whole-building energy consumption (Table 2.3.2). Further information about the requirements for heat recovery ventilators is included in the National Building Code.

Table 2.3.1 The minimum effective R-value requirements for building enclosure assemblies, as per the 2012 update of the National Building Code, by climate zone and heating degree day (HDD): buildings *without* heat recovery ventilators (HRVs).

Climate Zone and HDD (°C)	Wood-frame, above-grade wall [R-value (RSI)]	Wood-frame roof–ceiling [R-value (RSI)]
Zone 4: <3000 HDD	15.8 (2.78)	39.2 (6.91)
Zone 5: 3000 to 3999 HDD	17.5 (3.08)	49.2 (8.67)
Zone 6: 4000 to 4999 HDD	17.5 (3.08)	49.2 (8.67)
Zone 7a: 5000 to 5999 HDD	17.5 (3.08)	59.2 (10.43)
Zone 7b: 6000 to 6999 HDD	21.9 (3.85)	59.2 (10.43)
Zone 8: >7000 HDD	21.9 (3.85)	59.2 (10.43)

Table 2.3.2 The minimum R-value requirements for building enclosure assemblies, as per the 2012 update of the National Building Code, by climate zone and heating degree day (HDD): buildings with heat recovery ventilators (HRVs).

Climate Zone and HDD (°C)	Wood-frame, above-grade wall [R-value (RSI)]	Wood-frame roof–ceiling [R-value (RSI)]
Zone 4: <3000 HDD	15.8 (2.78)	39.2 (6.91)
Zone 5: 3000 to 3999 HDD	16.9 (2.97)	39.2 (6.91)
Zone 6 – 4000 to 4999 HDD	16.9 (2.97)	49.2 (8.67)
Zone 7a: 5000 to 5999 HDD	16.9 (2.97)	49.2 (8.67)
Zone 7b: 6000 to 6999 HDD	17.5 (3.08)	59.2 (10.43)
Zone 8: >7000 HDD	17.5 (3.08)	59.2 (10.43)

2.3.2 National Energy Code for Buildings (NECB)

The 2011 National Energy Code for Buildings is substantially updated from the previous 1997 Model National Energy Code for Buildings. Thermal resistance requirements for building enclosure assemblies have been increased and the use of effective R-values is required. Climate Zones have been realigned into 1000 HDD (°C) increments and climate data for cities across Canada has been updated. It has split what used to be climate zone 7 into zones 7A and 7B. Fig. 2.3.1 shows generally the divisions between HDD increments; however, in mountainous areas some jurisdictions will have higher HDD than shown on the map. Always refer to the currently referenced climate data within the Table C-2 of Appendix C of the National Building Code. Data for cities or locations not contained within the National Building Code can be found at Environment Canada (climate.weatheroffice.gc.ca - Climate Normals). From the prescriptive path of the National Energy Code for Buildings, the minimum effective R-value requirements for above-grade wood-frame assemblies are provided in Table 2.3.3. The compliance options are outlined in Appendix A-1.1.2.1 of the 2011 National Energy Code for Buildings and include a prescriptive path, trade-off path, and performance path.

Fig. 2.3.1 Canadian heating degree days (HDD °C) and climate zone divisions, as per the 2011 National Energy Code for Buildings. (Reproduced with the permission of the National Research Council of Canada.)

Table 2.3.3 The minimum effective R-value requirements for building enclosure assemblies, as per the 2011 National Energy Code for Buildings, by climate zone and heating degree day (HDD).

Climate Zone and HDD(°C)	Wood-frame, above-grade wall [R-value (RSI)]	Wood-frame roof, flat or sloped: [R-value (RSI)]
Zone 4: <3000 HDD	18.0 (3.17)	25.0 (4.41)
Zone 5: 3000 to 3999 HDD	20.4 (3.60)	31.0 (5.46)
Zone 6: 4000 to 4999 HDD	23.0 (4.05)	31.0 (5.46)
Zone 7a: 5000 to 5999 HDD	27.0 (4.76)	35.0 (6.17)
Zone 7b: 6000 to 6999 HDD	27.0 (4.76)	35.0 (6.17)
Zone 8: >7000 HDD	31.0 (5.46)	40.0 (7.04)

2.3.3 Airtightness Requirements in Canadian Codes

Canadian construction codes including the 2012 interim update of the 2010 National Building Code and 2011 National Energy Code for Buildings have general air-barrier continuity requirements. The 2011 National Energy Code for Buildings states that “the building envelope shall be designed and constructed with a continuous air-barrier system comprised of air-barrier assemblies to control air leakage into and out of the conditioned space” and that “all opaque building assemblies that act as environmental separators shall include an air barrier assembly”. Materials used as part of the air-barrier systems must be air impermeable (less than 0.004 cfm/ft^2 (0.02 L/s·m^2) at 75 Pa), free of holes and cracks, and compatible with adjoining materials. Prescriptive air-sealing measures are included to ensure air-barrier continuity.

In addition to opaque enclosure assemblies, the airtightness of manufactured fenestration must meet certain testing requirements as tested to AAMA/WDMA/ASTM/CSA requirements (range of 0.04 cfm/ft^2 (0.2 L/s·m^2) at 75 Pa to 0.1 cfm/ft^2 (0.5 L/s·m^2) at 75 Pa) and air-barrier continuity between opaque assemblies and fenestration must be maintained.

Within Canada there are currently no building or energy code requirements for the measurement or quantitative testing of whole-building airtightness of MURBs.

2.4 U.S. Building and Energy Codes

In the United States, energy efficiency and thermal insulation requirements for the building enclosures of wood-frame MURBs will either fall under a version of the ASHRAE 90.1 or a version of the International Energy Conservation Code (IECC) depending on the size of the building and local jurisdiction. These requirements will vary by state, and even between state counties and cities, as to whether the IECC requirements or ASHRAE 90.1 thermal insulation and energy-efficiency compliance paths must be followed. This can be problematic for practitioners who are responsible for assessing minimum insulation requirements for a project.

The Energy Policy Act of 1992 mandated that all states must review and consider adopting the national model energy standard. The Energy Policy Act of 2005 specifies the IECC 2004 and ASHRAE 90.1-2004 model energy codes and since this Act several model energy codes have occurred. Energy codes therefore vary from state to state and from edition to edition of the IECC and ASHRAE 90.1. In addition, several states still do not have mandatory energy code requirements or use a version of IECC or ASHRAE 90.1.

The IECC defines a “commercial” building as anything other than a low-rise (1 to 3 storeys) house, condominium, or apartment (R-2, R-3, and R-4 occupancy classification). The R-2, R-3, and R-4 occupancy classifications are buildings that are 3 storeys or less in height. Therefore the building-enclosure requirements for most MURBs will fall under the commercial building requirements of the IECC or, if referenced by the state, under ASHRAE 90.1. The building-enclosure requirements for some small MURBs may fall under the residential building requirements of the IECC. Wood-frame building-enclosure requirements for residential or “commercial” MURBs are provided here for both.

Practitioners within their jurisdiction will be familiar with their local requirements for MURBs (year of IECC or ASHRAE 90.1) and are therefore not covered in detail here because the state requirements are constantly changing and being updated. Two useful online references for the current status of U.S. state energy codes include:

- energycodes.gov/states/
- bcap-ocean.org/code-status

As of March 1, 2013, Fig. 2.4.1 presents the status of residential state energy codes (IECC) and Fig. 2.4.2 presents the status of the commercial state energy codes (ASHRAE 90.1).

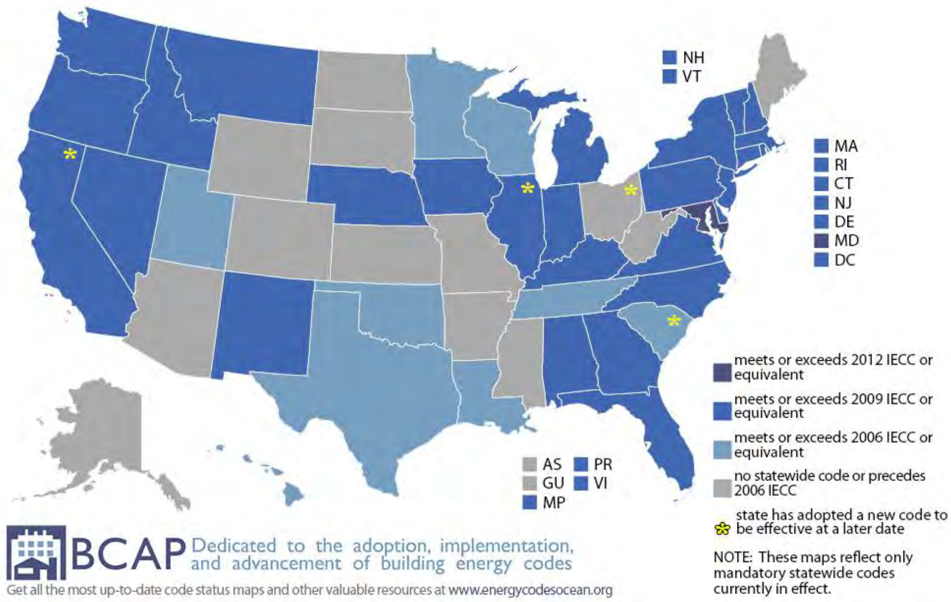


Fig. 2.4.1 Status of residential energy codes by state (IECC), as of March 1, 2013 (Online Code Environment & Advocacy Network 2013a).

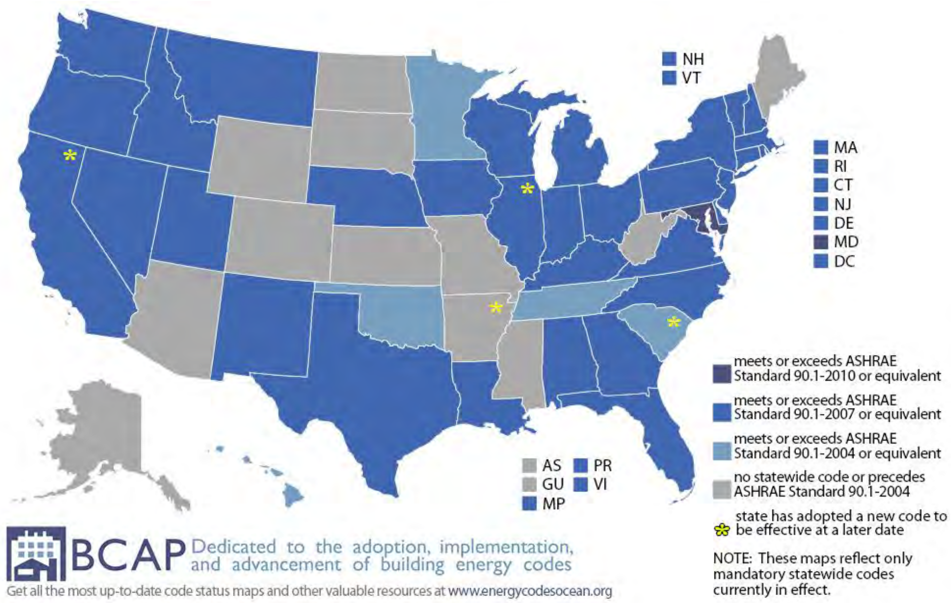


Fig. 2.4.2 Status of commercial energy codes by state (ASHRAE 90.1), as of March 1, 2013 (Online Code Environment & Advocacy Network 2013b).

2.4.1 International Energy Conservation Code (IECC) 2012 Requirements

The minimum R-value requirements for above-grade wood-frame building enclosure assemblies in the International Energy Conservation Code (IECC) 2012, are provided in Table 2.4.1 for Residential Buildings and Table 2.4.2 for "Commercial" Buildings (includes most MURBs) broken down by Climate Zone, as per the climate zones in the U.S. Department of Energy's climate zone map (Fig. 2.4.3).

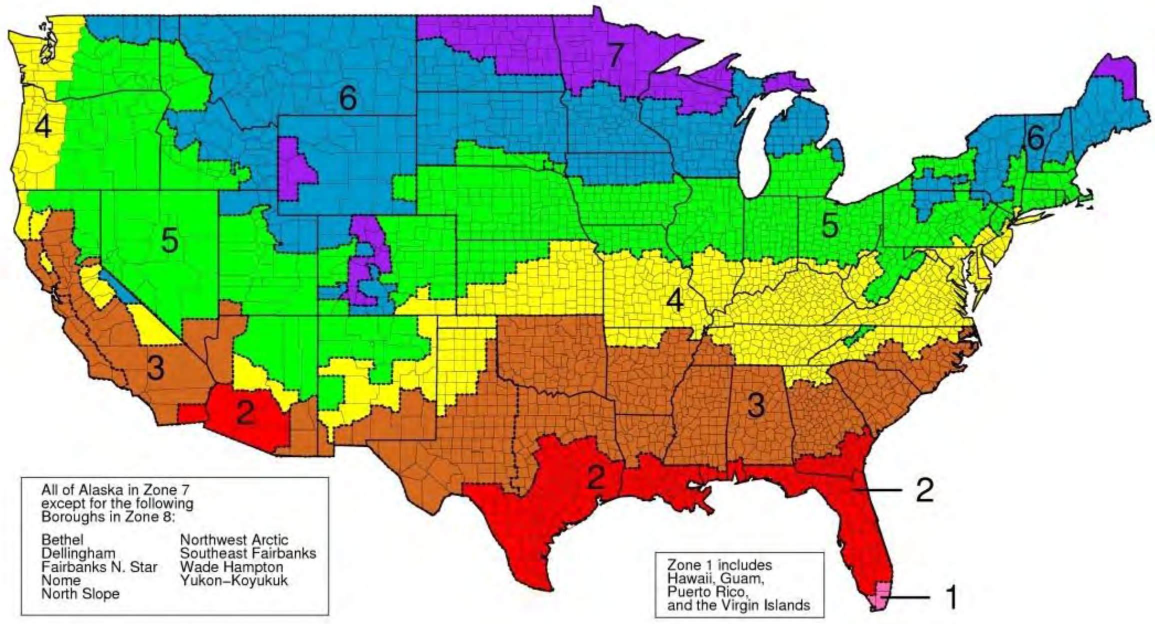


Fig. 2.4.3 U.S. IECC/DOE (Department of Energy) Climate Zones 1 to 8, for use with the 2012 IECC (image: ASHRAE 90.1-2007)

This climate zone map, often referred to as the "DOE climate zone map" was first utilized in the 2004 IECC supplement and ASHRAE 90.1-2004, and in subsequent versions of the IECC and ASHRAE 90.1 Standard. The eight primary climate zones are based on heating degree days and other climatic conditions including cooling and solar radiation factors. Previous versions of the IECC and ASHRAE 90.1 used heating degree day data as a primary indicator to define different climate zones which led to many zones being in the same jurisdiction.

Table 2.4.1 The minimum nominal R-value requirements for the assemblies of residential building enclosures, as per IECC 2012 (from Table R402.1.1 Residential Buildings), by climate zone.

Climate Zone	Wood-frame, above-grade wall [R-value (RSI)]	Wood-frame roof–ceiling insulation: [R-value (RSI)]
Zone 1 (A & B)	13 (2.3)	30 (5.3)
Zone 2 (A & B)	13 (2.3)	38 (6.7)
Zone 3 (A, B, & C)	20 or 13+5 ci (3.5 or 2.3+0.9 ci)	38 (6.7)
Zone 4 (A & B)	20 or 13+5 ci (3.5 or 2.3+0.9 ci)	49 (8.6)
Zones 4 C & 5 (A, B, & C)	20 or 13+5 ci (3.5 or 2.3+0.9 ci)	49 (8.6)
Zone 6 (A & B)	20+5 ci or 13+10 ci (3.5+0.9 ci or 2.3+1.8 ci)	49 (8.6)
Zone 7	20+5 ci or 13+10 ci (3.5+0.9 ci or 2.3+1.8 ci)	49 (8.6)
Zone 8	20+5 ci or 13+10 ci (3.5+0.9 ci or 2.3+1.8 ci)	49 (8.6)
ci = continuous insulation, where denoted		

Table 2.4.2 The minimum nominal R-value requirements for the assemblies of commercial (including most MURBs) building enclosures, as per IECC 2012 (from Table C402.2 Commercial Buildings), by climate zone.

Climate Zone	Wood-frame, above-grade wall [R-value (RSI)]	Wood-frame roof—insulation above deck [R-value (RSI)]	Wood-frame roof—attic and other: [R-value (RSI)]
Zone 1 (A & B)	20 or 13+3.8 ci (3.5 or 2.3+0.7 ci)	20 ci (3.5 ci)	38 (6.7)
Zone 2 (A & B)	20 or 13+3.8 ci (3.5 or 2.3+0.7 ci)	20 ci (3.5 ci)	38 (6.7)
Zone 3 (A, B, & C)	20 or 13+3.8 ci (3.5 or 2.3+0.7 ci)	20 ci (3.5 ci)	38 (6.7)
Zone 4 (A & B)	20 or 13+3.8 ci (3.5 or 2.3+0.7 ci)	25 ci (4.4 ci)	38 (6.7)
Zone 4 C & 5 (A, B, & C)	20+3.8 ci or 13+7.5 ci (3.5+0.7 ci or 2.3+1.3 ci)	25 ci (4.4 ci)	49 (8.6)
Zone 6 (A & B)	20+3.8 ci or 13+7.5 ci (3.5+0.7 ci or 2.3+1.3 ci)	30 ci (5.3 ci)	49 (8.6)
Zone 7	20+3.8 ci or 13+7.5 ci (3.5+0.7 ci or 2.3+1.3 ci)	35 ci (6.2 ci)	49 (8.6)
Zone 8	20+10 ci or 13+15.6 ci (3.5+1.8 ci or 2.3+2.8 ci)	35 ci (6.2 ci)	49 (8.6)
ci = continuous insulation, where denoted			

IECC Airtightness Requirements

The requirements in the 2012 IECC for air-barrier assemblies and air-leakage control in residential buildings are different than those for commercial buildings.

For residential buildings (less than 3 storeys and some small MURBs), Section R402.4 states that "the building envelope shall be constructed to limit air leakage" and includes performance-based requirements for whole-building air-leakage testing. A requirement for a whole-house or dwelling unit fan-door test to meet an air-leakage rate of 5 ACH@50 Pa or less is required in Climate Zones 1 to 3, and a rate of 3 ACH@50Pa or less is required in Climate Zones 4 to 8. Testing, where required by the code official, is to be performed by an approved third party in which all building enclosure components are inspected and verified for compliance.

Air-leakage testing of a single suite in a wood-frame MURB. Testing is often performed as part of building commissioning to measure the enclosure airtightness as well as the compartmentalization of the individual suites prior to whole building airtightness testing.

For commercial buildings (including most MURBs), Section C402.4 states that in Climate Zones 4 to 8 "a continuous air barrier shall be provided throughout the building thermal envelope". The air barrier can be installed inside or outside, or within the building envelope, and it must be continuous and sealed. In Climate Zones 1 to 3, the installation of air barriers is not required for buildings following the commercial requirements of the IECC. Materials must be air impermeable (<0.004 cfm/ft^2 @75Pa), and the assemblies of materials and components must have an average air leakage rate not exceeding 0.04 cfm/ft^2 @75 Pa. The completed building must be tested and the air leakage rate of the building envelope cannot exceed 0.40 cfm/ft^2 of enclosure area at 75 Pa when tested in accordance to ASTM E779 or equivalent (e.g., the U.S. Army Corps of Engineers (USACE) Standard).

The Washington State Building Code and the City of Seattle Building Code recently added whole-building air-leakage requirements for large buildings, including wood-frame MURBs. Within both of these codes a maximum air-leakage rate of 0.40 cfm/ft^2 @75 Pa must be met. For large buildings, testing is much more involved than a house and typically requires the use of multiple fan-door setups running simultaneously to measure the whole-building enclosure at once or in compartments. In the author's experience, this Washington State target is regularly being met within large multi-storey wood-frame MURBs where good air barrier design and construction is being implemented. Several MURBs recently tested by the authors achieved whole building airtightness values below 0.20 cfm/ft^2 @75 Pa following several different air barrier strategies. Further information on appropriate wood-frame MURB air barrier strategies are covered within Chapter 3.

International Green Construction Code (IGCC)

The first edition of the International Green Construction Code (IGCC) was published in September 2012. The 2012 IGCC requires that the building thermal envelope exceed the requirements of Tables C402.1.2 and C402.3 of the 2012 IECC by not less than 10% and that mandatory airtightness testing with a target of 0.25 cfm/ft^2 @ 75 Pa is required for all buildings.

2.4.2 ASHRAE Standard 90.1

Many jurisdictions within Canada and the United States currently require that the minimum building enclosure thermal performance and whole-building energy efficiency meet the requirements of the American Society of Heating, Refrigerating and Air Conditioning Engineers' ASHRAE Standard 90.1—Energy Standard for Buildings except Low-Rise Residential Buildings. Depending on the jurisdiction, either the 1989, 2001, 2004, 2007, or 2010 version of ASHRAE Standard 90.1 is referenced.

North America is broken down into eight primary climate zones by heating degree days and other climatic conditions as defined by the U.S. IECC/DOE Climate Zones (Fig. 2.4.4).

Climate data for each city is taken from the ASHRAE Standard 90.1 database included in the Appendix, not from the IECC or NBCC/National Energy Code for Buildings nor from the provincial building codes in Canada unless stated by the local jurisdiction. For many cities, ASHRAE climate data are not available, requiring the use of local data from Environment Canada or from the National Oceanic and Atmospheric Administration (NOAA) (U.S.). This may result in slightly different interpretations of the climate zone map shown in Fig. 2.4.4.

It should be noted that the climate data and zones used within ASHRAE Standard 90.1 may not necessarily line up with local building code data (particularly for Canada). This is relevant for the south coast of British Columbia, which falls under Zone 5 using ASHRAE data but under Zone 4 if using National Building Code data (i.e., 2011 National Energy Code for Buildings). This is a result of lower heating degree days in the past decades and of a more up-to-date data set being referenced in the Canadian code. The presiding authority may provide its own interpretation as to what climate zone a city falls within, based on local preference or technical reasoning.

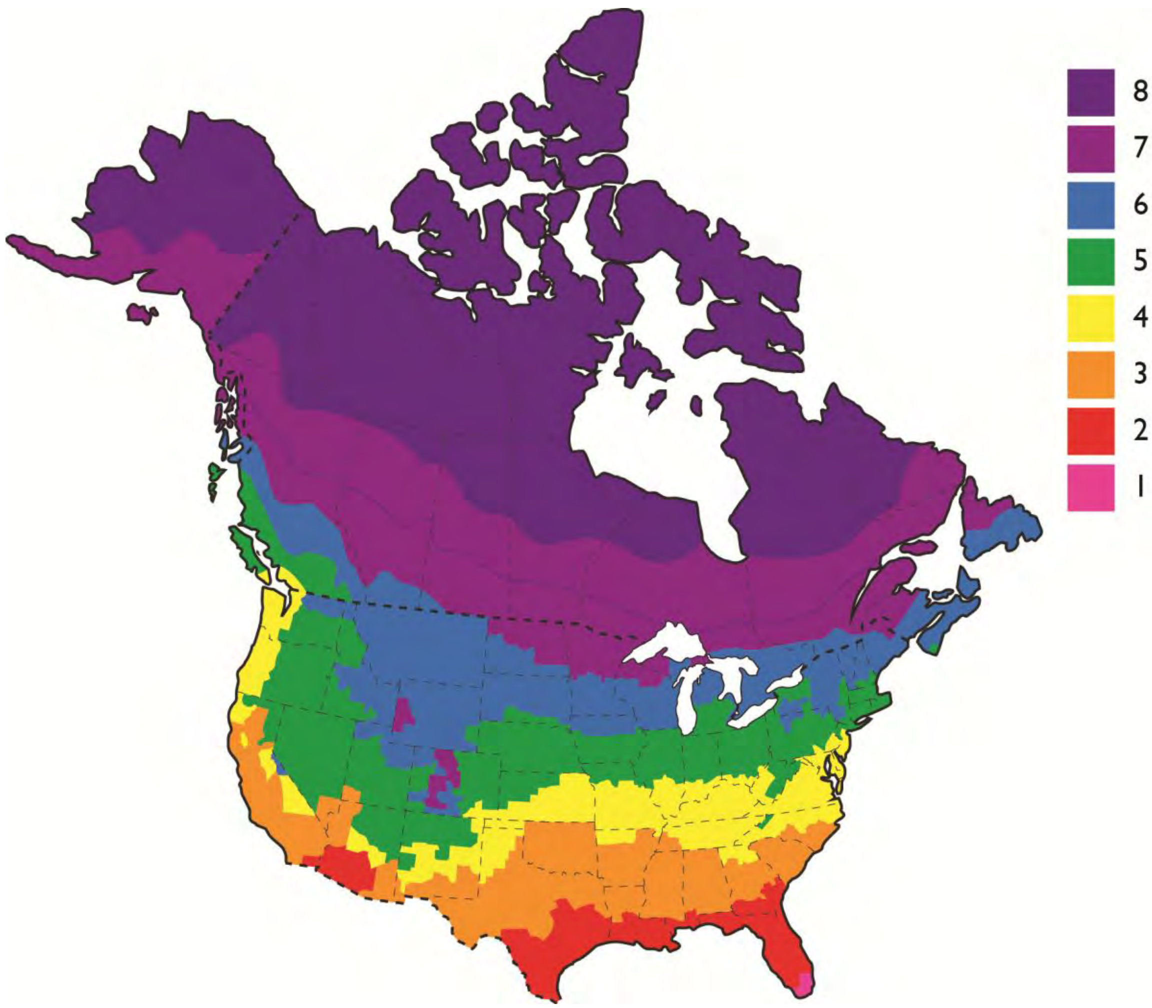


Fig. 2.4.4 ASHRAE climate zone map, based on current U.S. IECC/DOE and Canadian Climate Zones 1 to 8.

Compliance of the building enclosure with ASHRAE Standard 90.1 requires meeting prescriptive mandatory requirements related to insulation installation and protection, product labelling, and air sealing, as well as meeting one of the three building-enclosure compliance paths as outlined in Section 5 of the standard. In order from least to most complex, and from least to most work required to demonstrate building project compliance, the three compliance paths are:

- Prescriptive Building Envelope (Enclosure) Option,
- Building Envelope (Enclosure) Trade-off Option, and
- Energy Cost Budget Method.

The first path, which is administratively the simplest, is the **Prescriptive Building Envelope (Enclosure) Option**. There are two main requirements that the building enclosure design must meet in order to follow this option. Firstly the window-to-wall ratio must not exceed 40 or 50% (50% in ASHRAE Standard 90.1 versions prior to 2007, 40% in 2007 and 2010), and secondly all enclosure assemblies (walls, roof, windows, doors, skylights, below grade, floors) must meet the minimum prescriptive R-value requirements. The minimum prescriptive R-value requirements are outlined in Tables 5.5-1 through 5.5-8 of ASHRAE Standard 90.1 based on the eight primary North American climate zones.

These tables provide two compliance options for wood-frame buildings: either a prescriptive nominal insulation value—which usually includes some level of continuous insulation outside of the insulation between framing, or an minimum effective assembly R-value. (Both values work out to approximately the same effective R-value). Because of the limitations of some enclosure assembly designs with respect to continuous insulation or use of certain nominal insulation, it is often more practical to follow the minimum effective R-value (maximum U-value) requirement. Table 2.4.3 through Table 2.4.7 show these minimum requirements for wood-frame enclosures, as per ASHRAE 90.1 versions from 2001 through 2010.

Example of a Simple Trade-off Allowed within the Prescriptive Compliance Option

A wood-frame MURB is being constructed in Climate Zone 5 under ASHRAE 90.1-2007. The minimum effective R-value for the above-grade walls is R-19.6. The designer is constrained on one floor (20% of total wood-frame wall area) of the building; practically, only a 2x4 framed wall with an effective R-11 will work. On the other 4 floors, a 2x6 wall with exterior insulation can be used to achieve an effective R-25 (which exceeds the R-19.6 minimum). A simple UxA trade-off can be performed to demonstrate compliance of the overall wood-frame assemblies in this scenario.

$U_{effective}$= 20% (1/11) + 80% (1/25)
= 0.0501
$R_{effective}$=19.9

As the effective R-value for the combined R-25 and R-11 walls is R-19.9, which exceeds the minimum assembly R-value of R-19.6, this scenario would comply with the prescriptive assembly requirements.

Similar examples can be used to allow for large structural members (e.g., post-and-beam construction) within wall assemblies and to account for thermal bridging at wood-frame balconies/decks that are not adequately insulated.

This type of trade-off also applies in several other codes/standards (e.g., National Energy Code for Buildings). There may be exceptions in what items can be traded off against each other, for example trading off wall insulation for roof insulation would not be allowed.

The minimum R-value requirements should be compared to the proposed building-enclosure assemblies and details at the preliminary stage of design to assess if the prescriptive building-enclosure path can be followed. Further guidance on effective R-values of wood-frame assemblies is provided in Chapter 4. If all of the building enclosure assemblies proposed in the design include the minimum nominal insulation R-values, or if all of the assemblies (including details) meet the minimum effective
R-values in the tables, then the prescriptive path can be followed to achieve compliance. Note that some simple, area-weighted, U-value trade-offs are allowed within a particular assembly type (e.g., between wood-frame assemblies) to make up for details that do not meet the minimum requirements for effective assembly R-value. Examples could include heavier framing at lower levels for structural loads, walls built on lot lines, floor-level details, protruding framing at balconies, and framing at parapets, etc. This simple trade-off allows for some flexibility within the prescriptive compliance path, thus avoiding having to adhere to the more detailed Building Enclosure Trade-Off Option.

ASHRAE 90.1 often has different requirements for different materials but it is generally easier to comply with the ASHRAE 90.1's prescriptive R-value requirements for wood-frame MURBs than to comply with those for steel- or concrete-framed MURBs due to the higher amount of thermal bridging in the more conductive steel and concrete assemblies.

If the wood-frame MURB designs exceed the maximum window-to-wall ratio, or have enclosure assemblies and details that do not meet the minimum prescriptive R-value requirements as outlined in Table 5.5, then either the Building Enclosure Trade-off Option or Energy Cost Budget Option must be followed in order to achieve ASHRAE 90.1 compliance. Both of these compliance options require detailed calculations to determine the effective, overall thermal performance of the building enclosure, i.e., including the walls, roofs, fenestration, and floors. These options also require an in-depth understanding of the effective R-values for many wood-frame enclosure assemblies (see Chapter 3 and 4).

The **Building Envelope (Enclosure) Trade-off Option** requires a whole building enclosure effective R-value calculation. Within this path, the thermal performance of the walls, roof, and windows, as well as that of the below-grade and floor elements, are calculated for the design building and compared to a baseline building that is assumed to be minimally compliant. This requires a greater amount of time and effort to determine effective R-values for each enclosure assembly by area and orientation. This trade-off path uses simulation software provided by ASHRAE called Envelope Standard (ENVSTD) (provided with the standard on CD or as a download) to calculate an EPF factor (envelope performance factor). An EPF factor is essentially an area-weighted 'UxA' calculation with provisions for thermal mass, assembly orientation, solar heat gain, and daylighting benefits of windows. The EPF factor for the design building is compared to the baseline building; a lower value is better. A percentage above or below compliance can be determined from the output from ENVSTD.

An ENVSTD analysis is typically supplemented with a spreadsheet 'UxA' calculation to assess the relative thermal performance of each assembly/detail. In using this analysis, certain details or assemblies can be flagged for improvement. This allows for the optimization of building-enclosure elements and the improvement of details to reduce thermal bridging and maintain insulation continuity. This typically involves addressing the large thermal bridging details first, and does not necessarily mean adding more insulation to assemblies.

If a building cannot meet the Prescriptive Building Enclosure Option, typically the building enclosure can comply using the Building Enclosure Trade-off Path by addressing the large thermal bridges in the opaque enclosures and by improving baseline window performance and optimizing window-to-wall ratios. Whole-building enclosure R-values are further discussed in Chapters 3 and 4.

A mandatory provision within ASHRAE Standard 90.1 for most multi-unit residential buildings is a vestibule or revolving entrance door for the main entrance to the building. Some exceptions apply for smaller buildings, but generally this is a mandatory requirement that cannot be traded off.

If the building enclosure cannot comply using either of the first two options, the final compliance path is the whole-building **Energy Cost Budget Option**. Within the Energy Cost Budget Option, the effective thermal performance of the design building enclosure is an input to an energy model, which includes all building mechanical systems, lighting, power, etc. It essentially allows for determining trade-offs in the performance of the building enclosure with other building mechanical systems (e.g., heating, cooling, and lighting). There are many commercially available programs for modelling whole-building energy.

The Energy Cost Budget Option requires the same level of thermal analysis and component calculation effort as that undertaken in the Building Enclosure Trade-off method, but instead of using the trade-off path, the input for the enclosure assemblies is used within the whole-building energy model. The proposed energy model of the design building is compared to a baseline compliant building model and to a certain baseline mechanical system as specified in ASHRAE 90.1. The **energy cost** of the design building must be less than the baseline building for the building to comply, and therefore enclosure improvements that reduce space-conditioning will affect energy consumption savings. The Energy Cost Budget Option takes into account local utility prices for heating and cooling energy; savings in electricity are generally more beneficial than savings in natural gas (due to high energy unit cost of electricity relative to natural gas).

The Energy Cost Budget Option does allow for greater flexibility in energy code compliance; however, designers may find it difficult to make up for thermally inefficient building enclosure assemblies unless energy-efficient space conditioning and ventilation systems are used in the design (e.g., heat pumps, efficient radiant heating, and heat recovery ventilation). These decisions are best made at the preliminary design stage with involvement from the architect, mechanical engineer, and building enclosure consultant. This option is the most complicated and time consuming, but it is also considered the most accurate and may be necessary for some building designs (e.g., those with high window-to-wall ratios).

ASHRAE Standard 90.1 does not have specific requirements for the air-leakage control of the building enclosure, but it does state that a building enclosure should be sealed, caulked, gasketed, or weather stripped to minimize air leakage. Airtightness of manufactured fenestration must meet certain requirements as tested by NFRC. ASHRAE 90.1-2010 clarifies the requirement for a continuous air-barrier system as part of the building enclosure but does not include testing requirements.

ASHRAE 90.1—2001, Minimum R-Value Requirements for Building Enclosures of Wood-frame MURBs

Table 2.4.3 The minimum effective and nominal R-value requirements for residential building enclosure assemblies, as per ASHRAE 90.1-2001 (adapted from Tables 5.5-1 through 5.5-8 for IP R-values), by climate zone.

Climate Zone	Wood-frame, above-grade wall		Wood-frame roof—insulation entirely above deck		Wood-frame roof—attic and other	
	Effective [R-value (RSI)]	Nominal [R-value (RSI)]	Effective [R-value (RSI)]	Nominal [R-value (RSI)]	Effective [R-value (RSI)]	Nominal [R-value (RSI)]
Zone 1 (A & B)	11.2 (2.0)	13.0 (2.3)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 2 (A & B)	11.2 (2.0)	13.0 (2.3)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 3 (A, B, & C)	11.2 (2.0)	13.0 (2.3)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 4 (A, B, & C)	11.2 (2.0)	13.0 (2.3)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 5 (A, B, & C)	11.2 (2.0)	13.0 (2.3)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 6 (A & B)	15.6 (2.8)	13.0 + 3.8 ci (2.3 + 0.7 ci)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 7	19.6 (3.5)	13.0 + 7.5 ci (2.3 + 1.3 ci)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 8	19.6 (3.5)	13.0 + 7.5 ci (2.3 + 1.3 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
ci = continuous insulation, where denoted						

ASHRAE 90.1—2004, Minimum R-value Requirements for Building Enclosures of Wood-frame MURBs

Table 2.4.4 The minimum effective and nominal R-value requirements for the assemblies of residential building enclosures, as per ASHRAE 90.1-2004 (adapted from Tables 5.5-1 through 5.5-8 for IP R-values), by climate zone.

Climate Zone	Wood-frame, above-grade wall		Wood-frame roof—insulation entirely above deck		Wood-frame roof—attic and other	
	Effective [R-value (RSI)]	Nominal [R-value (RSI)]	Effective [R-value (RSI)]	Nominal [R-value (RSI)]	Effective [R-value (RSI)]	Nominal [R-value (RSI)]
Zone 1 (A & B)	11.2 (2.0)	13.0 (2.3)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 2 (A & B)	11.2 (2.0)	13.0 (2.3)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 3 (A, B, & C)	11.2 (2.0)	13.0 (2.3)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 4 (A, B, & C)	11.2 (2.0)	13.0 (2.3)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 5 (A, B, & C)	11.2 (2.0)	13.0 (2.3)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 6 (A & B)	15.6 (2.8)	13.0 + 3.8 ci (2.3 + 0.7 ci)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 7	19.6 (3.5)	13.0 + 7.5 ci (2.3 + 1.3 ci)	15.9 (2.8)	15.0 ci (2.6 ci)	37.0 (6.5)	38.0 (6.7)
Zone 8	19.6 (3.5)	13.0 + 7.5 ci (2.3 + 1.3 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
ci = continuous insulation, where denoted						

Table 2.4.5 The minimum effective and nominal R-value requirements for building-enclosure assemblies of wood-frame MURBs, as per ASHRAE 90.1-2007 (adapted from Tables 5.5-1 through 5.5-8 for IP R-values), by climate zone.

Climate Zone	Wood-frame, above-grade wall		Wood-frame roof—insulation entirely above deck		Wood-frame roof—attic and other	
	Effective [R-value (RSI)]	Nominal [R-value (RSI)]	Effective [R-value (RSI)]	Nominal [R-value (RSI)]	Effective [R-value (RSI)]	Nominal [R-value (RSI)]
Zone 1 (A & B)	11.2 (2.0)	13.0 (2.3)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 2 (A & B)	11.2 (2.0)	13.0 (2.3)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 3 (A, B, & C)	11.2 (2.0)	13.0 (2.3)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 4 (A, B, & C)	15.6 (2.7)	13.0 + 3.8 ci (2.3 + 0.7 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 5 (A, B, & C)	19.6 (3.5)	13.0 + 7.5 ci (2.3 + 1.3 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 6 (A & B)	19.6 (3.5)	13.0 + 7.5 ci (2.3 + 1.3 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 7	19.6 (3.5)	13.0 + 7.5 ci (2.3 + 1.3 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 8	27.8 (4.9)	13.0 + 15.6 ci (2.3 + 2.7 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	47.6 (8.4)	49.0 (8.6)
ci = continuous insulation, where denoted						

Within the 2007 version of ASHRAE 90.1, insulation reductions are permitted in Climate Zones 1 to 3 where high-albedo roofs are used (e.g., cool roofing materials, white roofs, etc.). A high-albedo roof is defined as having a minimum solar reflectance of 0.70 and a minimum thermal emissivity of 0.75 or a minimum Solar Reflective Index (SRI) of 82.

Table 2.4.6 The minimum effective and minimal R-value requirements for the assemblies of high-albedo residential roofs, as per ASHRAE 90.1-2007 (adapted from Table 5.5.3.1 for IP R-values), by climate zone.

Climate Zone	Wood-frame roof—insulation entirely above deck: high-albedo roof insulation		Wood-frame roof—attic and other: high-albedo roof insulation	
	Effective [R-value (RSI)]	Nominal [R-value (RSI)]	Effective [R-value (RSI)]	Nominal [R-value (RSI)]
Zone 1 (A & B)	12.3 (2.2)	12.0 ci (2.1 ci)	28.6 (5.0 ci)	30.0 (5.3)
Zone 2 (A & B)	13.2 (2.3)	13.0 ci (2.3 ci)	31.3 (5.5 ci)	30.0 (5.3)
Zone 3 (A, B, & C)	13.5 (2.4)	13.0 ci (2.3 ci)	31.3 (5.5 ci)	30.0 (5.3)
Zone 4 (A, B, & C)	Not permitted	Not permitted	Not permitted	Not permitted
Zone 5 (A, B, & C)	Not permitted	Not permitted	Not permitted	Not permitted
Zone 6 (A & B)	Not permitted	Not permitted	Not permitted	Not permitted
Zone 7	Not permitted	Not permitted	Not permitted	Not permitted
Zone 8	Not permitted	Not permitted	Not permitted	Not permitted
ci = continuous insulation, where denoted				

ASHRAE 90.1—2010, Minimum R-value Requirements for Building Enclosures of Wood-frame MURBs

Table 2.4.7 The minimum effective and nominal R-value requirements for the assemblies of residential building enclosures, as per ASHRAE 90.1-2010 (adapted from Tables 5.5-1 through 5.5-8 for IP R-values), by climate zone.

Climate Zone	Wood-frame, above-grade wall		Wood-frame roof—insulation entirely above deck		Wood-frame roof—attic and other	
	Effective [R-value (RSI)]	Nominal [R-value (RSI)]	Effective [R-value (RSI)]	Nominal [R-value (RSI)]	Effective [R-value (RSI)]	Nominal [R-value (RSI)]
Zone 1 (A & B)	11.2 (2.0)	13.0 (2.3)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 2 (A & B)	11.2 (2.0)	13.0 (2.3)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 3 (A, B, & C)	11.2 (2.0)	13.0 (2.3)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 4 (A, B, & C)	15.6 (2.7)	13.0 + 3.8 ci (2.3 + 0.7 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 5 (A, B, & C)	19.6 (3.5)	13.0 + 7.5 ci (2.3 + 1.3 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 6 (A & B)	19.6 (3.5)	13.0 + 7.5 ci (2.3 + 1.3 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 7	19.6 (3.5)	13.0 + 7.5 ci (2.3 + 1.3 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	37.0 (6.5)	38.0 (6.7)
Zone 8	27.8 (4.9)	13.0 + 15.6 ci (2.3 + 2.7 ci)	20.8 (3.7)	20.0 ci (3.5 ci)	47.6 (8.4)	49.0 (8.6)
ci = continuous insulation, where denoted						

Within the 2010 version of ASHRAE 90.1, high-albedo surfaces are essentially mandatory within Climate Zones 1 to 3 for roofs where the insulation is entirely above the roof deck. A high-albedo roof in ASHRAE 90.1-2010 is defined as having a roof surface with a minimum solar reflectance of 0.55 (3-year aged) and a minimum thermal emissivity of 0.75 (3-year aged) or a minimum Solar Reflective Index (SRI) of 64 (3-year aged). If these solar properties are not met (e.g., dark-coloured roofing), then the assemblies must meet a minimum effective R-value of R-34.5 or the insulation must meet a minimum nominal R-value of R-34 (compared to R-20 in Table 2.4.7). Exceptions to this requirement include steep-slope roofs, roofs over ventilated attics, roofs with sufficient stone or paver ballast, vegetated (green) roof systems, roofs covered with solar arrays, and some other exceptions in Climate Zones 2 and 3.

ASHRAE Standard 189.1

ASHRAE Standard 189.1—Standard for the Design of High-Performance Green Buildings, except Low-Rise Residential Buildings was developed to be a design standard for green buildings. Neither the 2009 nor 2011 versions of ASHRAE Standard 189.1 are mandated in any jurisdiction, but are in use by many practitioners across North America in the design of energy-efficient green buildings. ASHRAE Standard 189.1 references ASHRAE Standard 90.1 and others as being the minimum baseline performance and it upgrades many of the requirements in the baseline standards (Table 2.4.8). In the future, ASHRAE Standard 189.1 may be referenced as part of other green-design and performance-rating systems.

ASHRAE 189.1—2011, Minimum R-value Requirements for Building Enclosures of Wood-frame MURBs

Table 2.4.8 The minimum effective and nominal R-value requirements for the assemblies of residential building enclosures, as per ASHRAE 189.1-2011 (adapted from Tables A-1 to A-8 for IP R-values), by climate zone.

Climate Zone	Wood-frame, above-grade wall		Wood-frame roof—insulation entirely above deck		Wood-frame roof—attic and other	
	Minimum effective assembly [R-value (RSI)]	Nominal [R-value (RSI)]	Minimum effective assembly [R-value (RSI)]	Nominal [R-value (RSI)]	Minimum effective assembly [R-value (RSI)]	Nominal [R-value (RSI)]
Zone 1 (A & B)	15.6 (2.7)	13.0 + 3.8 ci (2.3 + 0.7 ci)	25.6 (4.5)	25.0 ci (4.4 ci)	47.6 (8.4)	49.0 (8.6)
Zone 2 (A & B)	15.6 (2.7)	13.0 + 3.8 ci (2.3 + 0.7 ci)	25.6 (4.5)	25.0 ci (4.4 ci)	47.6 (8.4)	49.0 (8.6)
Zone 3 (A, B, & C)	15.6 (2.7)	13.0 + 3.8 ci (2.3 + 0.7 ci)	25.6 (4.5)	25.0 ci (4.4 ci)	47.6 (8.4)	49.0 (8.6)
Zone 4 (A, B, & C)	19.6 (3.5)	13.0 + 7.5 ci (2.3 + 1.3 ci)	25.6 (4.5)	25.0 ci (4.4 ci)	47.6 (8.4)	49.0 (8.6)
Zone 5 (A, B, & C)	22.2 (3.9)	13.0 + 10.0 ci (2.3 + 1.8 ci)	25.6 (4.5)	25.0 ci (4.4 ci)	47.6 (8.4)	49.0 (8.6)
Zone 6 (A & B)	22.2 (3.9)	13.0 + 10.0 ci (2.3 + 1.8 ci)	31.3 (5.5)	30.0 ci (5.3)	47.6 (8.4)	49.0 (8.6)
Zone 7	22.2 (3.9)	13.0 + 10.0 ci (2.3 + 1.8 ci)	35.7 (6.3)	35.0 ci (6.2 ci)	58.8 (10.4)	49.0 (8.6)
Zone 8	31.3 (5.5)	13.0 + 18.8 ci (2.3 + 3.3 ci)	35.7 (6.3)	35.0 ci (6.2 ci)	58.8 (10.4)	49.0 (8.6)
ci = continuous insulation, where denoted						

2.5 Performance Rating and Labelling Systems

It is often worthwhile to certify a building under a third-party rating or labelling system. For owners who manage a rental building, this can raise the profile of their building and increase occupied percentage, while developers can benefit from improved marketing abilities. A few jurisdictions mandate compliance with a rating or labelling system, for example, the City of Vancouver requires that all buildings undergoing re-zoning be at least LEED Gold certified.

While some of the rating or labelling systems are more energy focused, others encompass a wider range of sustainable parameters such as material choice, waste management, indoor comfort, etc. However, all include minimum standards for energy performance that must be met in order to achieve certain labels. For the purpose of this chapter, only the energy-performance parameters are discussed, because they relate to the building enclosure.

Some of the better-known rating or labelling systems include:

- BuiltGreen, by the Building Owners and Managers Association of Canada (BOMA)
- BOMA Building Environmental Standards (BOMA BESt), by BOMA
- CalGreen, in California's mandatory green building code (since 2011)
- EnerGuide, by Natural Resources Canada, Office of Energy Efficiency (NRCan OEE)
- Green Globes, by the Green Building Initiative (U.S.) and Environment Canada (Canada)
- Leadership in Energy and Environmental Design (LEED), by the U.S. Green Building Council (USGBC) and the Canada Green Building Council (CaGBC)
- Living Building Challenge, by the International Living Future Institute
- NetZero, by the Living Futures Institute
- NGBS (National Green Building Standard)-ICC 700
- Passive House, by The International Passive House Association (iPHA)
- R-2000, by NRCan OEE and the Canadian Home Builders' Association

The minimum energy requirements to achieve certain energy or green labels under these systems are very different. Some allow varying levels of performance certification to be achieved, often evaluated on a points-based system, whereas others require the same minimum performance by each building undergoing certification. A simplified summary of the performance requirements is included in Table 2.5.1.

Performance Rating or Labelling Systems

Table 2.5.1 North American performance-rating systems, and their energy and enclosure requirements: summary.

Performance-rating system	Method of energy assessment, and mandated software (if any)	Specific enclosure requirements
BOMA BESt (Canada, based on Green Globes)	Energy audit of occupied building (new buildings can use model)	None
BuiltGreen[a] (Canada)	Energy Model, relies on EnerGuide results	None
EnerGuide (Canada and U.S.)	Energy Model (Hot2000) Energy model predictions are compared to historical data for final rating On-site verification of envelope Airtightness Test	None
Green Globes (Canada and U.S.)	Energy Model	Exceed MNECB 1997
LEED 2009 for New Construction[b] (Canada and U.S.)	Energy Model [multiple] Building energy costs must be at least: • 10% better than ASHRAE 90.1-2007 OR • 23% better than MNECB (Canada)	None (It is generally expected that each assembly shall be better than the referenced standard)
Net Zero (Canada and U.S.)	Energy data from 1-year of operation proving all energy is generated on-site	None
Passive House (International)	Energy Model [PHPP]	None, but suggested assemblies provided, particularly for wood-frame
R-2000[c] (Canada)	Energy Model [Hot2000] Airtightness Test	Must meet or exceed provincial/local requirements

[a] R-2000 is focused on single- or two-family dwellings. Previous iterations of R-2000 outlined prescriptive R-value requirements before switching to the performance method.

[b] LEED programs are available for a range of specific building types, including LEED for Homes; however, LEED for New Construction is the most commonly used program and is therefore chosen as a reference.

[c] BuiltGreen has programs for both single-family dwellings and MURBS; the latter are summarized here.

As Table 2.5.1 shows, most rating or labelling systems rely upon energy-modelling results to evaluate compliance with respect to energy efficiency. This means that although the enclosure plays an important role in producing energy savings, there may not be prescriptive guidelines on what values should be used; rather, a trade-off method is used, i.e., between the envelope, mechanical system, and other energy-saving features. It is therefore up to the design team to select assemblies that will effectively reduce building loads and maintain a comfortable environment for indoor occupants.

An excellent starting point is to improve upon the minimum requirements outlined by the standards referenced in each rating or labelling system. In addition, the energy models that will be used for compliance can be invaluable tools if employed during the design process. Energy models are commonly used for comparing the performance of various design parameters (for example, examining the effect of added insulation on an assembly), and evaluating different trade-off options (such as increased window area along with better-performing glazing). It is important to realize, however, that energy models provide only a prediction of a building's energy use. The accuracy of this prediction depends on the ability of the modeller to determine all of the parameters affecting energy use of the building in actual operation, including factors such as weather, occupant schedules, ventilation rates, etc. Because the accurate prediction of all of these parameters can be difficult, energy models are best used for comparative studies where the energy consumption of alternative designs are compared against each other, but the actual predicted energy consumption is not relied upon.

2.6 Retrofitting Existing Building Enclosures

Existing buildings account for the majority of building energy use. Because most energy consumption in buildings is typically for space conditioning (either heating or cooling), addressing existing enclosure assemblies through energy retrofits (either alone or as part of other enclosure repairs or renewals) presents one of the largest opportunities to efficiently reduce greenhouse gas emissions and increase overall energy efficiency of the building stock.


Wood-frame MURB undergoing a building enclosure rehabilitation to address moisture ingress damage. Thermal improvements to the building enclosure can easily be made when this type of work is already being performed for incrementally much lower costs than doing the work solely for an energy upgrade.

A study by Architecture 2030 looked at the existing housing stock in the United States in 2005 (300 billion ft^2) and estimated that by 2035, 150 billion ft^2 will be remodelled, 52 billion ft^2 will be demolished, and a further 150 billion ft^2 will be added by new construction. Therefore more than half of the buildings that will be around in 2035 are around today. The 150 billion ft^2 that will be remodelled provide opportunities for energy-efficiency improvements.

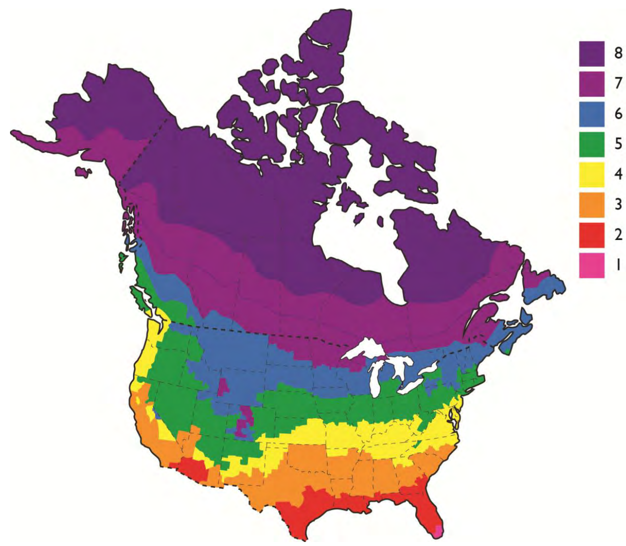
Existing buildings, particularly MURBs, present unique challenges for building enclosure retrofits. MURBs that are owned by multiple owners as part of condominium corporations or homeowner associations are particularly difficult to address due to multiple-owner interests and ownership generally lasting less than 5 to 10 years. As a result, building enclosure retrofits are typically performed during the life of a MURB only to address necessary moisture damage repairs or for cladding and window renewals. Retrofits of wood-frame MURB enclosures solely for the purposes of energy efficiency are rarely performed due to costs and relatively long payback periods; however, energy-efficiency upgrades can easily be made cost effective if other work is already being performed (i.e., incremental improvements).

Building enclosure retrofits do not usually fall under mandated energy-performance requirements due to constraints with existing buildings. In some jurisdictions, thermal insulation requirements for the existing building may be equal to or less than the new energy-code requirements. Thermal performance requirements for existing buildings can pose challenges with respect to building lot line set-backs due to the use of thicker walls, and can potentially affect durability if the principles of building science are not properly considered.

While retrofits of existing buildings are not the focus of this guide, the principles and design guidance provided for new buildings are in most cases also applicable to retrofits.

2.7 Summary

Within the current North American building codes, energy codes, and standards, a range of minimum requirements for the thermal performance of assemblies in wood-frame building enclosures are summarized in Table 2.7.1 for hot climate zones (U.S. IECC/DOE Zones 1 to 3), mixed climate zones (U.S. IECC/DOE Zones 4 to 5), and cold climate zones (U.S. IECC/DOE Zones 6 to 8). The minimum R-values cover the low-to-high ranges provided in current codes and standards for above-grade walls and roofs (sloped attic ceiling and flat roof). In many climate zones, this requires the construction of more thermally efficient enclosure assemblies than has been standard wood-frame practice (i.e., beyond 2x6 framed walls with batt insulation). Assemblies that achieve higher performance levels are covered within Chapter 4.



A range of higher effective R-values is also suggested based on green-building design standards and energy-efficient building programs such as LEED. The R-values in Table 2.7.2 are suggested as targets for high-performance building-enclosure assemblies and are covered in Chapter 4.

Table 2.7.1 Range of effective R-value targets for minimum compliance with energy codes compliance.

Climate Zones	Wood-frame, above-grade wall [R-value (RSI)]	Wood-frame roof—insulation entirely above deck [R-value (RSI)]	Wood-frame roof—attic and other [R-value (RSI)]
Zones 1 to 3: hot, cooling dominated	R-10 to R-16 (1.8 to 2.8)	R-20 to R-25 (3.5 to 4.4)	R-30 to R-40 (5.3 to 7.0)
Zones 4 to 5: mixed, heating and cooling	R-15 to R-23 (2.6 to 4.1)	R-25 to R-35 (4.4 to 6.2)	R-35 to R-50 (6.2 to 8.8)
Zones 6 to 8: cold, heating dominated	R-20 to R-31 (3.5 to 5.5)	R-30 to R-40 (5.3 to 7.0)	R-40 to R-50 (7.0 to 8.8)

Table 2.7.2 Range of effective R-value targets for exceeding minimum compliance with energy codes: high performance wood-frame building enclosures.

Climate Zones	Wood-frame, above-grade wall [R-value (RSI)]	Wood-frame roof—insulation entirely above deck: [R-value (RSI)]	Wood-frame roof—attic and other: [R-value (RSI)]
Zones 1 to 3: hot, cooling dominated	R-16 to R-22 (2.8 to 3.9)	R-25 to R-30 (4.4 to 5.3)	R-40 to R-50 (7.0 to 8.8)
Zones 4 to 5: mixed, heating and cooling	R-22 to R-28 (3.9 to 4.9)	R-30 to R-40 (5.3 to 7.0)	R-50 to R-60 (8.8 to 10.6)
Zones 6 to 8: cold, heating dominated	R-28 to R-40 (4.9 to 7.0)	R-40 to R-50 (7.0 to 8.8)	R-60 to R-80 (10.6 to 14.1)

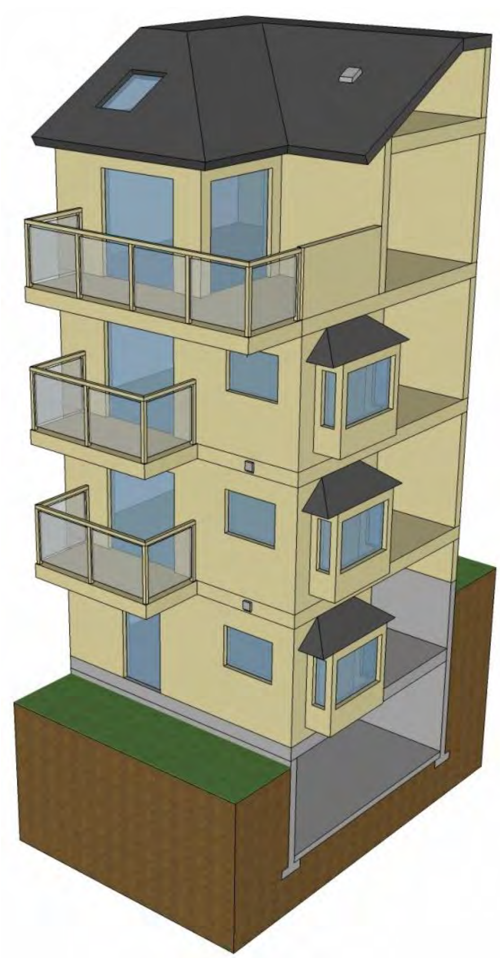
CHAPTER 3: MOISTURE, AIR, AND THERMAL CONTROL

The building enclosure must control heat flow, rain penetration, air flow, vapour flow, fire and smoke, and noise, as well as transfer structural loads, and be the primary aesthetic element of the building. Because this publication focusses on the energy efficiency and durability of building enclosures, the key control functions considered are thermal and moisture control (rain, air flow, and vapour flow).

Energy-efficient building-enclosure assemblies tend to be well-insulated, with thermal bridging that is minimized in order to reduce heat flow through the building enclosure. Well-insulated enclosures are a key factor in reducing whole-building energy consumption; however, well-insulated assemblies do introduce additional considerations with respect to moisture control.

This chapter of the guide presents principles for improving the thermal performance of above-grade walls, below-grade walls, and roofs, and it discusses the related moisture-control functions. Several related issues are also addressed: means to reduce thermal bridging, cladding attachment over exterior insulation, and computer simulation of thermal and hygrothermal performance.

The fundamentals of heat-, air-, and moisture-control principles, and further information about best practices for designing building enclosures for wood-frame buildings, can be found in the *Building Enclosure Design Guide—Wood-Frame Multi-Unit Residential Buildings* (Homeowner Protection Office, Branch of BC Housing, 2011), *Building Science for Building Enclosures* (Straube and Burnett 2005), in several of Building America's Best Practices Series, and in related publications on the website of Building Science Corporation.



Elements of a building enclosure for a 4-storey wood-frame MURB over a below-grade concrete structure. MURBS tend to be more exposed and have more construction details to consider than a house. Chapter 4 and 5 of this guide cover the design of energy-efficient and durable assemblies and details.

3.1 Moisture Control

Appropriate moisture control is critically important in order to achieve long-term durable performance of multi-unit buildings. This is especially true for a highly insulated building enclosure due to its lower heat flux and air movement, which results in reduced drying ability.

The major moisture sources for building enclosures include rain, snow and ice, ground moisture, construction moisture, and vapour condensation. The frequency and intensity of wind-driven rain is usually a determining factor in the amount of water likely available from outside. Snow, ice, and ground moisture are also potential sources of water and contributors to the risk of water penetration. Ground moisture is the determining factor for the design of below-grade and adjacent assemblies. Occupants also generate a significant amount of indoor moisture, which should be taken into consideration.

In highly insulated building-enclosure assemblies the potential for interstitial vapour condensation becomes a major consideration in terms of durability. In heating-dominated climates, condensation most often results from outward migration of water vapour because the warmer indoor air is at a higher dew point or vapour pressure than the colder exterior. Vapour-control layers installed at the interior side of the insulation, or the use of insulation on the exterior of moisture-sensitive components to make them warmer and prevent moisture entrapment, as discussed later, are typically used to control this vapour flow and potential for condensation.

In cooling-dominated climates, condensation typically results from the inward migration of water vapour during the cooling season (particularly when the indoors is air conditioned and has a lower dew point than the exterior). The use of vapour-control layers and or/exterior insulation on the exterior of assemblies or vapour-open assemblies are typically used to control vapour from the outside. Inward vapour drive can be exacerbated in situations where an absorbent cladding has been used (such as brick, stucco, stone, concrete, or fibre cement board) and wetting of the cladding has occurred just prior to sunny weather.

The exterior of building-enclosure assemblies can also be wetted by condensation or dew resulting from night sky radiation. This occurs when the exterior wall surfaces are cooled by radiation to the night sky to a temperature below the air dew point. Condensation can occur for many hours during the night, leading to wetting. This formation of dew can be a significant moisture source on claddings and roofs.

3.1.1 Exterior Climate

The diversity of exterior climates across North America dictate the need for practitioners to consider a wide range of climate design parameters in the design and construction of building enclosures. Eight general climate zones can be classified within North America (Fig. 3.1.1), each with their own unique considerations for the design of appropriate building-enclosure assemblies, components, and detailing.

Climate governs several important parameters that impact thermal- and moisture-control performance in building enclosures:

- The frequency and intensity of wind-driven rain is a determining factor in the amount of water potentially entering the enclosure from outside.
- The difference between indoor and outdoor temperatures determines whether, how much, and where condensation may form inside the enclosure assembly.
- The combination of temperature, humidity, and sunshine determines the rate and direction of vapour diffusion and, therefore, the drying potential.
- The outdoor temperature determines the temperature of materials in the outer part of an assembly (e.g., wood sheathing). Fungal decay of wood will not progress unless the temperature and the moisture content of the materials are within certain ranges.
- If there is no indoor RH control, then the outdoor absolute humidity levels affect the indoor RH. Thus there is the potential that enclosure assemblies will become wetted from interior moisture, or that drying potential to the interior will be affected.

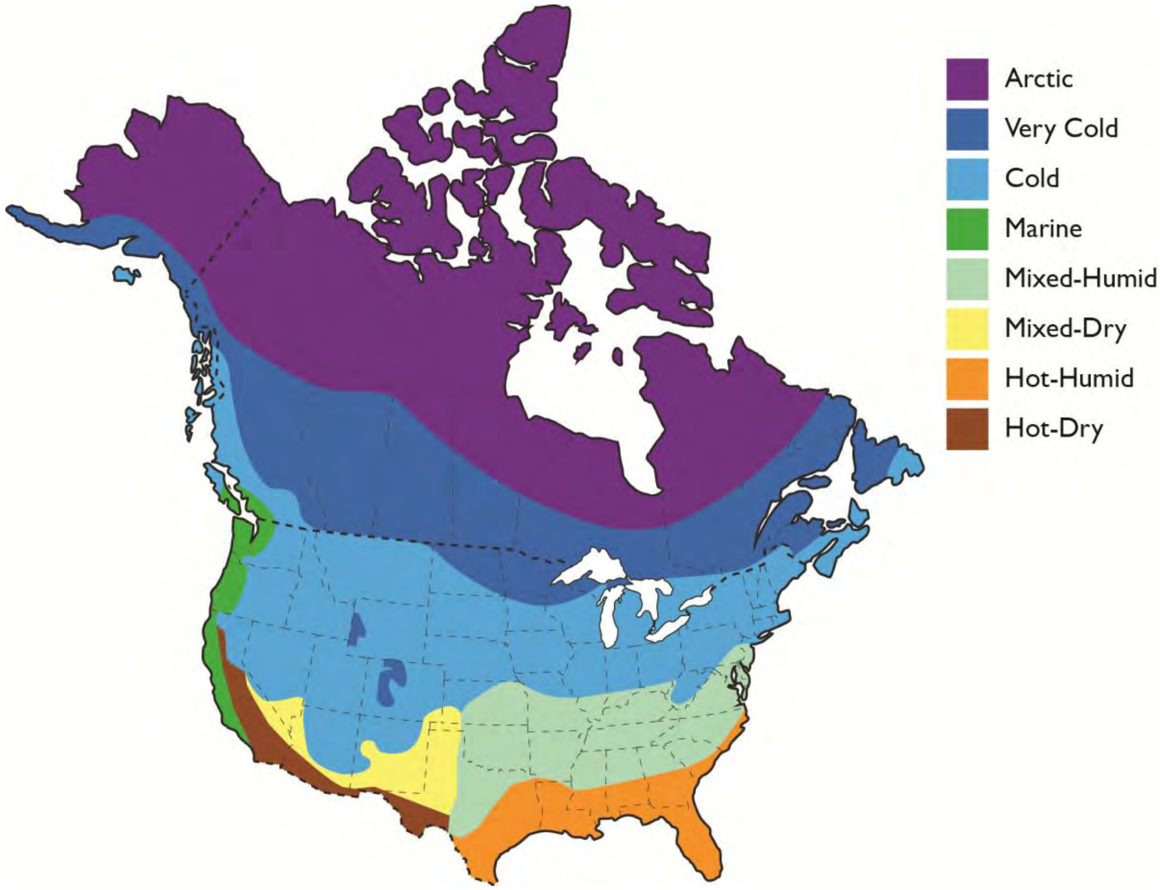
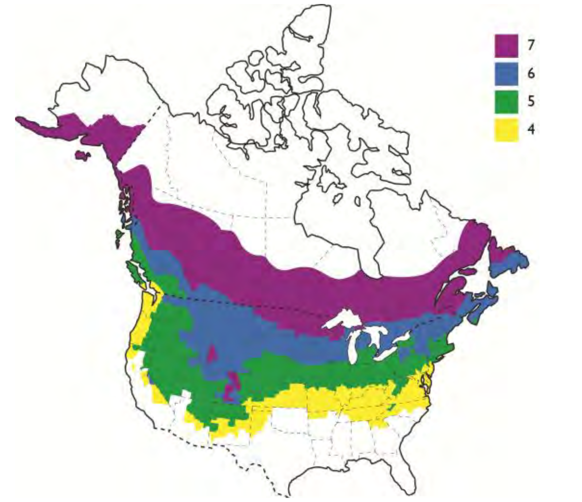


Fig. 3.1.1 The eight broad climate zone classifications for Canada and the United States. Climate zones are based on historical temperature, humidity, rainfall data, and standardized climate zone definitions. (Image by RDH, adapted from similar climate zone maps produced by Building Science Corporation and ASHRAE and from base Canadian and U.S. Atlas data.)

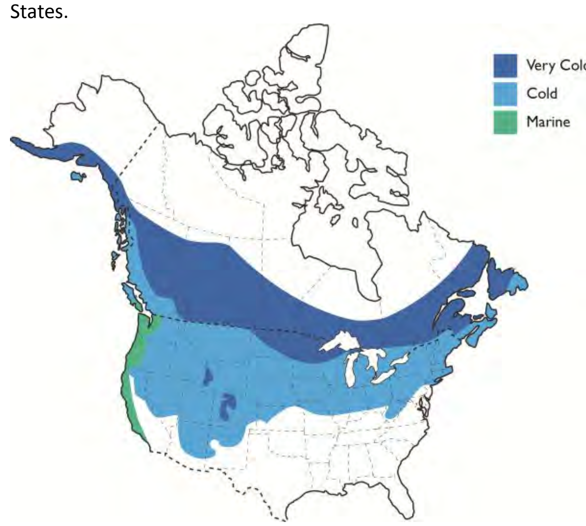
The exterior climate generally dictates the best practice approach to the placement of additional insulation and to selecting vapour-control strategies, as discussed in later sections of this chapter and in Chapter 4.

This guide focuses on building-enclosure assemblies within the Marine, Cold, and Very Cold Climate Zones (ASHRAE Climate Zones 5 through 7, and most of Zone 4). These climate zones, which cover the majority of Canada and northern United States, are heating dominated with the exception of parts of southern California. The southern United States is divided into predominantly hot and mixed climates which are either dry or humid (ASHRAE Climate Zones 1 to 3, and part of 4). Northern Canada and northern Alaska (ASHRAE Climate Zone 8) have greater insulation requirements, and they also have issues around permafrost and foundations because of the extreme cold. These other climate zones will be addressed in separate guides.

In addition to macro-level climate differences, each city or location has more localized climatic factors that need to be considered during building design. For example, elevation differences can create particular environments within one broad climate zone category. The national and provincial building codes in Canada, and the IECC and state building codes in the United States, provide climatic design data for many specific municipalities. Of particular interest are the temperature and relative humidity data (important for condensation control and wetting/drying potential), heating degree days (important for energy usage), annual rainfall data, wind pressure data, and driving rain wind pressure data (important for water penetration control).



ASHRAE Climate Zones 4 through 7, for Canada and the United States.



General classifications for the climate zones that are covered in this guide: Marine, Cold, and Very Cold Climate Zones in Canada and the United States.

Within Canadian building codes, the concept of a moisture index (MI) has also been introduced. The moisture index is a relative indicator of the severity of the overall moisture load imposed on a building, taking into account both wetting and drying potential. The moisture index concept, in combination with other factors such as overhang and local terrain, can be used to establish overall exposure categories, thereby creating an appropriate context for the development of building-enclosure assemblies, the selection of components, and the design of an interface for controlling water penetration. A moisture index and supplemental map was produced for Canada and the United States by NRC-CNRC (Cornick and Dalgliesh 2003), which is used in the National Building Code of Canada.

Snow and Ice

Snow and ice can cause water entry in building assemblies that do not normally suffer from rain penetration. For example, blowing snow can enter vents and holes that are well protected from rain.

A more common problem results from snow collecting on horizontal or modestly sloped surfaces, and the subsequent formation of ice that tends to block drainage paths. Snow melts in places where it receives heat from interior or exterior sources. The melt water can then run to locations where it freezes, such as at the eaves, creating an ice dam that restricts further drainage of melt water. The hydrostatic pressure and raised water level can lead to leakage that would not otherwise occur.

Metal roofs, in particular, are susceptible to sliding snow and significant icicle formations at roof edges, which can cause damage to elements of the building enclosure and create safety hazards.

Condensation of Exterior Air

Condensation will occur whenever air contacts a surface that is at a temperature below the dew point of the air. In heating climates, it is most often thought of as a phenomenon resulting from outward migration of water vapour during the heating season. This occurs because the warmer indoor air is at a higher dew point or vapour pressure than the colder exterior as a result of indoor moisture generation. Vapour-control layers installed at the interior side of the insulation, or the use of insulation on the exterior of moisture-sensitive components (as discussed later in this chapter), are typically used to control this vapour flow and the potential for condensation in heating climates.

In heating climates, there are some circumstances where condensation can occur within assemblies due to an inward migration of water vapour from the exterior air (i.e., during the summer or under solar heating of an absorptive cladding). This condensation typically occurs on the exterior surface of the interior sheathing (or sheet polyethylene, if used) in traditional wood-frame assemblies. This risk is elevated when the indoors are cooled and dehumidified using air conditioning; the indoors will therefore have a lower dew point than the outdoors.

In cooling-dominated climates, condensation typically results from the inward migration of water vapour during the cooling season (particularly when the indoors is air conditioned and has a lower dew point than the exterior). Typically, vapour-control layers and or/exterior insulation are used on the exterior of assemblies or vapour-open assemblies to control vapour from the outside.

Inward vapour drive can be exacerbated in situations where an absorptive cladding (brick, stucco, stone, concrete, or fibre cement board) has been used and wetting of the cladding has occurred just prior to sunny weather. The inward drive usually occurs for a sufficiently short duration such that accumulation of moisture is unlikely to occur to the extent that most assemblies would incur damage. This phenomenon is of particular relevance in face seal assemblies or concealed barrier assemblies. A rainscreen wall assembly moderates this environment of high vapour pressure on the exterior by means of ventilation of the cavity, and is a proven strategy to reduce inward vapour drive and the potential for condensation of exterior air within enclosure assemblies. The use of vapour-impermeable exterior insulation can also be a strategy for minimizing this phenomenon, and is discussed later in this chapter.

The exterior of building-enclosure assemblies can also be wetted by condensation or dew from night sky radiation. This occurs when the exterior wall surfaces are cooled by radiation to the night sky to a temperature below the air dew point. Condensation can occur for many hours during the night, leading to wetting of the surface and materials. This formation of dew can be a significant moisture source on claddings, and in addition to adding a moisture load to the building enclosure can also lead to algae and microbial growth on claddings and other surfaces. This phenomenon is becoming more common with highly insulated wall assemblies. The use of rainscreen claddings decoupled for the backup wall when the cladding surfaces regularly drop below the air dew point on clear nights.

Groundwater

The below-grade and above-grade exterior environments are quite different and dictate different responses in the design of the building enclosure. The key differences in the below-grade environment are the potential for hydrostatic pressure to exist, and the lesser temperature variation within the soil.

Typically, reinforced concrete below-grade wall and slab-on-grade assemblies are used for the below-grade areas of wood-frame MURBs. Below-grade assemblies are not a focus of this wood-frame guide, and we are typically not relying on wood-frame assemblies to manage groundwater conditions.

Assuring performance of below-grade poured-in-place concrete walls must include normal good concrete construction practices such as proper mix design, construction and control joint waterproofing, and crack control. For many walls at “dry” sites, these techniques, combined with damp proofing, will be sufficient. However, when hydrostatic pressure exists, much more robust assemblies and details need to be used, and the design must employ better insulated and energy-efficient assemblies. Drainage details at grade as well as at the footing level are important to the performance of the below-grade wall assembly.

Below-grade concrete walls need to dry primarily to the interior due to the presence of moisture and damp proofing or waterproofing on the exterior side of the wall. Drying cannot occur towards the exterior in these instances. The inner layers of the below-grade wall assembly must therefore allow drying to the interior to occur.

This is particularly an issue early in the life of the building when the concrete itself is still drying. This is considered along with foundation drainage and waterproofing details within in the assembly summaries presented Chapter 4 and as part of the below-grade details shown in Chapter 5.

3.1.2 Interior Climate and HVAC Systems

Just as exposure to exterior climatic conditions creates requirements for the desired performance, material selection, and building-enclosure design, so does the exposure of building enclosures to the interior climate. The relationship between interior environment and building enclosure is influenced by many factors including the detailed building-enclosure assembly; airtightness; design and operation of the heating, ventilation, and air conditioning (HVAC) system: interior space layout: and type of usage and occupancy of the space. Generally in older less airtight buildings, interior humidity conditions are influenced by exterior conditions to a greater degree due to the greater air exchange with the outdoor environment. In newer, more airtight buildings, occupant behaviour and the design and operation of the HVAC system influence interior conditions to a greater degree than exterior conditions.

In heating climates, maintaining a sufficient air exchange during the winter is important for indoor humidity control. The indoor RH may be uncomfortably low due to an air exchange rate that is too high. On the other hand, an air exchange rate that is too low, particularly in coastal climates, may cause the indoor RH to be too high and thus increase the indoor moisture load on the enclosure assemblies. High indoor RH poses an increased risk for condensation within assemblies due to air leakage or vapour diffusion, and results in a reduced drying potential to the interior.

The majority of MURBs utilize space-heating and cooling systems that do not require ducts, while most single-family residences and commercial buildings utilize ducted, forced-air systems. One of the primary goals in both instances should be the delivery of conditioned air to each room, and, in heating climates, to the exterior wall and window surfaces. In heating climates the potential for condensation associated with exterior walls and windows is greatly reduced if air at the appropriate temperature and relative humidity is consistently delivered to these surfaces. In cooling climates the uniform delivery of conditioned air within the suite results in better comfort for the occupants.

Perhaps the most common occupant complaints related to MURBs are associated with the control of heat, noise, and odours. On the surface these complaints may not appear to be closely related, but they are. The primary mechanism for the transfer of heat, noise, and odours within buildings is by air movement.

Just as uncontrolled air movement can lead to problems when it flows through elements of the building enclosure, unintended air flow between floors, between dwelling units, and between dwelling units and corridors, can lead to performance problems in MURBs. Control of relative humidity, temperature, odours, and noise is made much more difficult by the lack of air-flow control between units, as well as the exterior environment.

Air flow through the building enclosure, and within buildings, occurs because of pressure differences created by the wind, stack effect, and mechanical supply and exhaust fans.

Winds generally create the highest peak pressure difference across the enclosure. Positive pressure occurs on the windward side of the building, forcing air into the building through openings. At the same time, a negative pressure on the roof and leeward sides will draw air out. However, on an annual basis, wind pressure does not cause the most air leakage because the wind is not sustained. Continuous stack pressures and mechanical forces usually create the most overall air movement and have the most impact on air flow within the building.

Stack pressure force is caused in heating climates by the density difference between heated indoor air and cold outdoor air (and the other way around if the outdoor air is warmer than the indoor air, such as during the summer or in hot climates). During the winter months in a cold climate this stack pressure creates a positive pressure on the enclosure at ceiling and upper wall levels (forcing air out), and it creates a negative pressure at the lower portions of the building (drawing air in) (Fig. 3.1.2). If the building enclosure as well as the interior walls and doors within the building are not airtight then an overall air-flow pattern can occur due to stack effect. If the outdoor air is hotter than the indoor air then the pressure and airflows are reversed. It is this flow of air that causes noise, odours, and heat to migrate throughout the building.

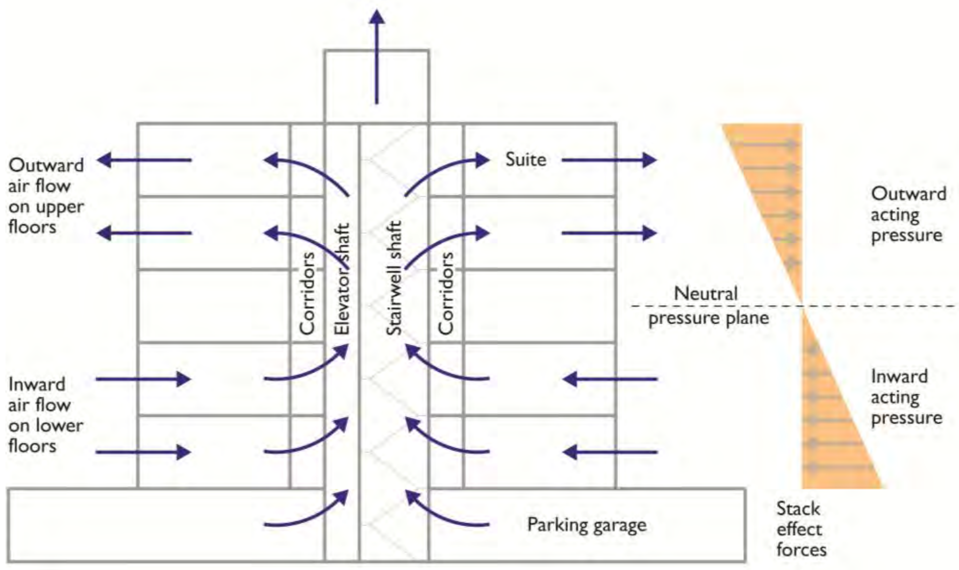


Fig. 3.1.2 Stack-effect forces across the exterior enclosure, and air flow within MURBs, when exterior temperatures are colder than the interior. Pressure forces and flows will be opposite when the exterior temperature is warmer than that of the interior.

Ventilation equipment such as exhaust fans and corridor ventilation, and other supply fans, modify the pressure profile within the building and across the building enclosure. A corridor pressurization system will slightly pressurize the corridors and suite relative to the outdoors. Operation of exhaust equipment within suites acts to depressurize suites relative to corridors, adjacent suites, and the outdoors.

The combination of supply and exhaust-fan pressurization, stack-effect forces and the wind, together with varying airtightness levels, creates a very complex pressure profile and complex air movement patterns within the building. This often results in poor indoor air-quality and ventilation rates within suites. Strategies that simplify these variables will serve to better control heating, cooling, de-humidification, ventilation, noise, odours, and overall indoor air quality as part of an energy-efficient MURB.

One air-flow control strategy involves compartmentalizing spaces within the building. This can be done by creating an airtight perimeter between the dwelling unit and the common corridor (if present) and the adjacent dwelling units (sides, above, and below). In practice, this is not a difficult task because a separation is intended between dwelling units, as well as between dwelling units and corridors or other public spaces. The two primary focal points are sealing-wall and ceiling penetrations, and creating a relatively airtight entry door (assuming that the ventilation strategy does not utilize the corridor pressurization approach). Proper detailing for fire, smoke, and sound control will tend to be airtight. Compartmentalizing the interior spaces of the building also changes the impacts of stack-effect forces. The lack of internal air flow means that these forces now act over each floor rather than the entire height of the building. As a result the driving forces for air movement through the building enclosure are much smaller. This strategy allows for the use of more-effective and energy-efficient in-suite ventilation systems— such as individual in-suite heat recovery ventilators (HRVs) or energy recovery ventilators (ERVs)—to be used in MURBs.

Selection of a suitable ventilation strategy is a critical design consideration, not only for occupant health (indoor air quality) but also for the energy efficiency and durability performance of the building. Providing sufficient ventilation air to individual suites is often a challenge in MURBs that utilize traditional ventilation. Ventilation designs that rely on fresh supplies of air from the corridor via the entry door undercuts are very unreliable due to the complex pressure regime that exists within buildings. The undercut door also significantly compromises the airtightness of the suite-to-corridor separation, thereby limiting compartmentalization. The energy used to temper or condition outdoor air as part of a pressurized corridor approach also consumes a significant amount of energy in a MURB, and can in some cases be the single largest component of energy use. The space-heat energy from make-up air, which is uncontrolled by the occupants, essentially travels from the corridors, into the suite and potentially right out the window or through imperfections in the air-barrier system, highlighting yet another need for compartmentalization.

For these reasons, the corridor pressurization and undercut-door/suite ventilation strategy should be avoided in a building where the aim is to be energy efficient. The use of a balanced supply and exhaust airflow that is ducted directly to each in-suite HRV is suggested as more being effective and energy efficient. The compartmentalized corridors would then be slightly pressurized, for odour and smoke control.

The interior layout of rooms, closets, and furniture can dramatically affect the distribution of heat within dwelling units. For example, layouts that dictate the placement of a couch against an exterior wall will result in poor air circulation at exterior walls, causing the exterior wall surface to be insulated, and lowering temperatures at the exterior wall or window. This can lead to condensation on the interior surface of the wall or window, with an associated risk of damage to finishes and microbial growth. Similarly, space layouts that result in high humidity spaces (bathrooms), or poorly ventilated spaces (closets) being adjacent to exterior walls will require special attention to avoid condensation problems. The occupant's use of space is the wild card in the overall efforts to control the interior environment, with only limited opportunities for control by design.

While this guide is not intended to provide comprehensive direction related to space planning and layout, or HVAC design, it is important to understand the interrelationship between these aspects of the design.

The large overhangs and steep-slope roofs at this 4-storey MURB are suitable for this rainy climate zone (Marine Climate, 5C) to help reduce the driving rain from wetting the walls and to manage rain and occasional snowfall on the roof. Steep slope roofs in snowfall regions are also prone to ice-damming and icicle formation at eaves as a result of heat-loss and poor-detailing which can damage the building enclosure and result in leaks.

3.1.3 Architectural Form

Wood-frame MURB architecture varies across North America. Designs are based on the architect's response to the client brief, site conditions, and the local environment. Consideration of orientation, building form, and massing, as well as the ratios of enclosure area to volume, are also essential factors in achieving energy-efficient MURB designs. The use of building features to protect the enclosure is a fundamental architectural design principle. Roof overhangs, balconies, and other projections shelter the walls, windows, and details below from driving rain, wind, snow, and ice, and they provide solar shading.

In rainy areas, the use of roof overhangs goes a long way to protect the building enclosure below from driving rain and potential rainwater penetration. Several studies have shown the dramatically reduced instance of rainfall wetting on walls protected by overhangs, and they have linked these features to reduced instances of rainwater penetration damage. Energy-efficient enclosure assemblies tend to have a reduced drying capacity; therefore, managing exposure to wetting by the use of roof overhangs (small or large) underscores the need for better control of wetting. The use of overhangs, along with giving consideration to site and surrounding topography, such as proximity to large open bodies of water, or being located on a hill in or open terrain, determines the extent and duration of exposure to wind-driven rain for building-enclosure assemblies and details. This exposure is a key factor in the selection of assemblies and in the development of details for ensuring durable construction.

Roof overhangs and other horizontal projections can also provide shading from the sun, and can form part of a passive design strategy to control overheating in the summer and utilize solar energy to reduce space-heating loads in the winter. Overhangs for the purpose of shading are most effective on south and west elevations. They are typically only effective at shading the upper floors of multi-storey buildings; the use of exterior shades is therefore often a more effective shading strategy. Operable exterior shading devices are becoming more common, however not without many reported challenges in operation and maintenance in taller MURBs.

The adjacent figures illustrate a number of different architectural characteristics of MURBs in different climate zones. Table 3.1.1 summarizes some of the factors that drive the architectural design and some energy-efficiency considerations of MURBs.

The roof overhangs of this MURB in Climate Zone 4 (hot)) are an architectural feature that provides some solar shading to reduce solar heat gain through the upper-floor windows. Adjacent buildings will also shade some orientations of the building over the course of a day.

Californian style MURB Architecture in Southern California - While a face-seal stucco application may perform well in a hot and dry climate zone, in wetter climate zones the lack of overhang protection will result in the need for more robust wall assemblies and details (rainscreen).

Table 3.1.1 Primary factors that drive the architectural design of MURBs.[a]

Factors	Building size, height, etc.	Building form	Building materials	Glazing ratio	Design features (roofs, balconies, etc.)
Local planning regulations	★★★	★★	★		★
Building and energy codes			★★	★★	
Marketing, style, purchaser preferences		★★	★★	★★	★★★
Developer preference and direction		★★	★★	★★	★★
Site Conditions: Views		★★		★★★	
Sit Conditions: Adjacent building sites		★★			
Local climate conditions				★	★★

[a] number of stars indicates the relative importance each factor plays in the design of MURBs

3.1.4 Wetting and Drying

The design and construction of a building enclosure for the purpose of moisture control is a process of balancing moisture-entry mechanisms (wetting) and moisture-removal mechanisms (drying). An imbalance may result in the moisture accumulation and deterioration of less moisture tolerant materials. Heat flow through building-enclosure assemblies plays an important role in helping to maintain this balance. Thermally efficient building-enclosure assemblies are particularly sensitive to moisture accumulation, and arguably have a smaller zone of moisture balance than less insulated assemblies, due to the reduced heat flow through the assembly and the lower temperatures of the exterior components.

Interior finishes are typically subject to mould, mildew, and deterioration in the presence of moisture. Cladding may deteriorate if it remains wet and/or is subject to freeze–thaw cycles. Steel fasteners corrode in the presence of air and moisture. Wood changes dimension when it is exposed to sustained high moisture content and suitable temperature conditions; and, more importantly, it can decay.

Wood and wood-based materials always contain some moisture; the amount varies over time with exposure to humidity and water. Fortunately, the equilibrium moisture content of wood exposed to humidity alone is generally below levels conducive to the growth of decay fungi. As a general rule, liquid water needs to be present to lead to decay conditions. Sustained high humidity conditions coupled with warm temperatures is the primary exception to this rule; in these conditions, the presence of liquid water on the surface of wood sufficient to initiate fungal growth.

Wetting Mechanisms

Aside from accidental sources of water such as pipe leaks, moisture can enter a building enclosure from any of the following (see Fig. 3.1.3).

Exterior Moisture: It enters from the outside environment into a completed building. It has several forms, including:

- rain
- groundwater

- snow (and snow melt from snow build-up)
- moisture from warm humid air, or wet materials; migrates inward, via air movement or vapour diffusion

Interior Moisture: It is generated from inside by the use and occupancy of the building; moisture migrates outward via air movement or vapour diffusion.

Construction Moisture: It is built into the structure through the use of wet lumber or other building materials, or by precipitation during construction.

Drying Mechanisms

Water in an enclosure assembly can be removed by several mechanisms (see Fig. 3.1.4).

Drainage: Water will drain down and out of assemblies on hydrophobic materials as well as from oversaturated materials. Elements like sloped flashings use gravity to divert and drain water to a safe disposal area, usually to the exterior of the building enclosure.

Drying: Moisture within hygroscopic building-enclosure materials such as wood will dry by surface evaporation until the moisture content of the material is in equilibrium with its local RH environment.

Initially, moisture moves by capillarity to the surface of these materials where it evaporates until the material is no longer saturated. Once below saturation, drying continues to occur due to desorption, but at a lower rate. In addition to the local RH environment, the rate of drying is also affected by material properties and the geometry of the material.

Water-vapour movement due to diffusion also has the potential to dry an assembly; diffusion drying can occur either to the exterior or interior depending on the direction of the vapour pressure gradient and the vapour flow resistance of the layers within the enclosure assemblies. Vapour diffusion drying of moisture inwards or outwards is often restricted depending on the local climate and seasonal conditions, and may only be relied upon during certain times of the year.

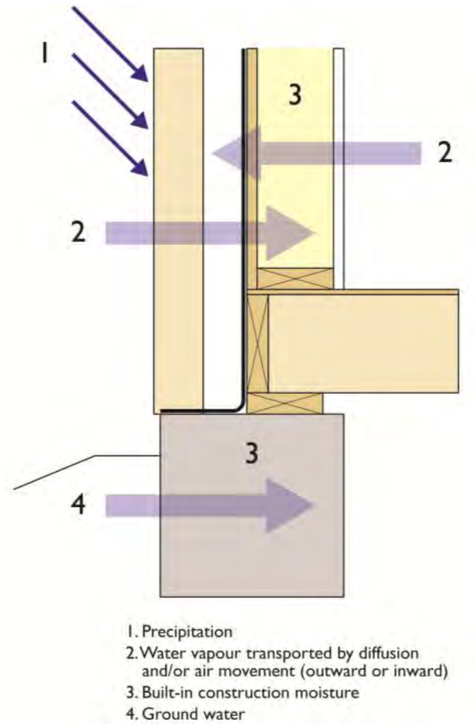


Fig. 3.1.3 Wetting sources. (Image by RDH, adapted from Straube and Burnett 2005)

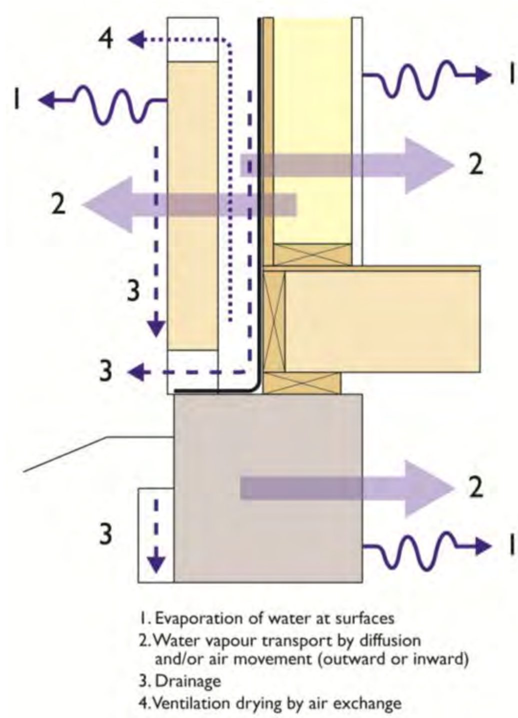


Fig. 3.1.4 Drying mechanisms. (Image by RDH, adapted from Straube and Burnett 2005)

Air movement within or through the assembly can also contribute to drying. This mechanism involves the replacement of air that has a high water-vapour content with air that has a lower water-vapour content; it is a distinctly different process than vapour diffusion. The venting capabilities within assemblies will generally determine the rate at which this type of drying can occur.

There is a quantitative difference in the amount of drying that can occur in a vented assembly versus the amount of drying that can occur in a ventilated assembly. Vented assemblies typically have holes along one edge that allow for drainage, some degree of vapour diffusion, and air mixing through the vents. A ventilated assembly generally contains more ideally located holes through the cladding elements such that convection (air movement) is encouraged through the cavity—in the holes at one side and out of the holes in the other side. For example, holes through the wall cladding (suitably protected from rainwater entry) at the top and bottom of a wall assembly create a ventilated assembly. A ventilated assembly has much greater drying capacity than a vented assembly. The use of ventilated assemblies is preferred for highly insulated walls.

In addition to wetting and drying, wood materials also have the capacity to safely store some moisture or act as a hygric buffer. As long as safe moisture levels are not exceeded, this moisture storage capacity will allow for seasonal or short-term storage of moisture accumulating that accumulates within assemblies (either from seasonal humidity or infrequent wetting) until drying occurs. Wood studs and sheathing have a significantly higher moisture storage capability than steel studs and gypsum sheathing. This may be a consideration where the local building code requires gypsum sheathing instead of plywood/OSB for fire safety considerations.

3.1.5 Deflection, Drainage, Drying, and Durability

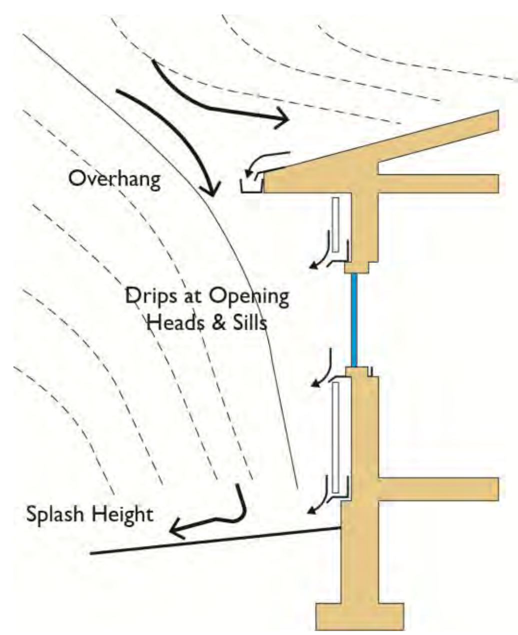
Although perhaps an oversimplification of the building science, the four Ds—**D**eflection, **D**rainage, **D**rying, and **D**urability—provide a ready reminder of the considerations and priorities for achieving moisture management of energy-efficient walls.

Deflection: The use of components and features of the building to limit exposure of assemblies to rain. These include:

- overhangs to protect an assembly from direct exposure to rain
- Flashing with drip edges to divert water running down surfaces and direct it off the face of the assembly, such as cross cavity flashings within walls and kick-out flashing at roof and wall intersections.

Drainage: The use of drainage surfaces within cavities to redirect any water that enters the enclosure back to the exterior. This cavity space also stops capillary transport from the cladding to moisture-sensitive materials.

Drying: The provision of features that speed the drying of wet materials.



Protection of the building enclosure begins with rain **d**eflection. Any incidental moisture that does get into building-enclosure assemblies is able to **d**rain or **d**ry out. **D**urability is the safe use of materials and, in the case of wood construction, the use of naturally durable wood, or treated wood where appropriate. (Image by RDH, adapted from Straube and Burnett 2005).

Durability: The use of assemblies and materials that are tolerant of moisture.

Deflection of rain is the first priority in assuring moisture removal. If most of the water is diverted before it has a chance to impact on and enter an assembly, then the requirements for drainage, drying, and durability are significantly reduced.

Drainage is the next most important principle. Provision for the drainage of large quantities of water is important in wet environments. This is a major advantage of drained cavity or rainscreen wall assemblies. Sloping roofs, decks, balconies, and walkways are fundamental for effective drainage of near-horizontal features. An air space to the outside of the drained surface is generally required for good drainage. Draining water must be intercepted at appropriate locations and directed to the outside by properly detailed flashing. Flashing should be sloped to the outside. When the flashing is interrupted, it should have end dams to stop water from running off the ends into the building-enclosure assemblies. Poor flashing detailing is a major cause of moisture problems in buildings. This "D" can also be extended to good site drainage.

The drying ability of an insulated wood-frame assembly depends on a number of variables, including the vapour permeability and other hygrothermal properties of layers within the assembly, the placement of insulation, the adjacent environmental conditions, the building's venting capability, and the geometry of the building. While drying cannot generally be relied upon as the primary moisture-management strategy for an assembly, assemblies should be designed and constructed to incorporate features that facilitate drying. The consideration of these variables can result in walls that are less sensitive to the presence of minor amounts of moisture.

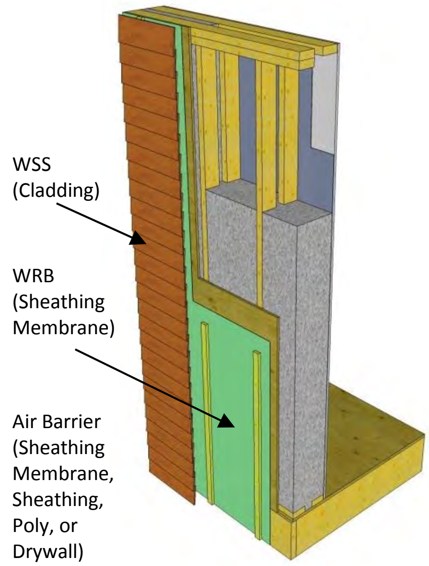
Durability requires that the surface upon which moisture accumulates, or where moisture is stored within the material, is durable enough to accommodate the moisture until it drains or dries. Use of materials that are not susceptible to moisture damage, such as stainless steel fasteners and pressure-treated wood products in specific locations, is therefore a part of viable moisture-management strategies. For example, in temperate and humid climate zones the use of treated sheathing and strapping may be recommended for highly insulated enclosure assemblies with low drying potential to reduce risk of fungal growth on wood exposed to high humidity or potential wetting.

3.1.6 Critical Barriers

The term **critical barrier** is used within this guide to refer to materials and components that together perform a moisture-control function (as well as air and heat control) within the building enclosure. It has been common to think of, and define, some critical barriers within an enclosure assembly, such as a **vapour retarder or air barrier**. This guide also refers to a **water-shedding surface (WSS)** (first plane of protection, in the terminology of the Canadian building code) and a **water-resistive barrier (WRB)** (second plane of protection) to facilitate discussion of water penetration control strategies. The use of critical barriers to evaluate assemblies and details is consistent with industry best practices and are easier to assess in the context of specific assemblies and details being considered for a project.

Water-Shedding Surface

The water-shedding surface (WSS) refers to the outer surface of assemblies, interfaces, and details that deflect and/or drain the vast majority of the exterior water from the assembly. For wall assemblies the water-shedding element is the cladding—fibre cement siding, vinyl, masonry veneer, metal panel, or other materials. The amount of water that impacts on the water-shedding surface depends on a variety of factors related to climate zone and exposure. The continuity of the water-shedding surface is maintained by laps, joints, sealants, flashings, overhanging components, etc., and, in cases of open rainscreen claddings, by protected gaps/joints.



Critical barriers within an insulated double stud wall assembly

Properties of the water-shedding surface vary immensely with cladding type. There are claddings which are absorptive to varying degrees and those which are non-absorptive. Brick, stone, and concrete are examples of highly absorptive claddings. Fibre cement board, wood, thinly sliced brick and other thin veneers made of wood or cement are considered moderately absorptive. To some extent vinyl siding and other profiled sidings can also be considered absorptive because they may hold water by capillary forces between the laps. Metal panel, plastic composite sheets, and other non-hygroscopic materials are considered non-absorptive. Certain surface or penetration coatings can reduce the absorptivity of some absorptive materials; however, the joints and edges may not be equally as affected. In addition to moisture absorptivity, if the cladding is vapour impermeable, in most climate zones it then must be back ventilated to prevent the entrapment of vapour behind the cladding. This is commonly achieved by incorporating an airspace behind the cladding and incorporating bottom drain holes or vents (drained and vented rainscreen), or possibly open top and bottom vents (drained and ventilated rainscreen).

Water-Resistive Barrier

The water-resistive barrier (WRB) is the surface farthest from the exterior that can accommodate moisture without incurring damage to interior finishes or materials within the assembly, and it is intended to prevent liquid water from travelling further to the interior. It is not always easy to establish this surface because some surfaces can accommodate small amounts of moisture for a limited time without damage, while larger quantities of water or longer exposure to moisture will lead to premature deterioration of the assembly or to migration of moisture further into the assembly. For many wall assemblies the water-resistive barrier is the sheathing membrane in combination with flashing and sealants at penetrations. In exterior-insulated assemblies, this may be the surface of the insulation if it is taped and sealed, or it may be a sheathing membrane installed behind the insulation. The continuity of the water-resistive barrier is maintained by membrane laps, tapes, sealants, and occasionally projections that act to shed water and provide drainage. Where the water-resistive barrier is also part of the air-barrier system, it will be made airtight by tapes, sealants, gaskets, and other airtight components.

The amount of water that reaches the water-resistive barrier in an assembly depends on a variety of factors which are affected by the exterior environment, as well as on the effectiveness of the water-shedding surface. In assemblies where the water-shedding surface and water-resistive barrier are distinct layers, the assembly has two lines of defence against water penetration. Even better control of water penetration can occur when two lines of defence are provided with a drainage space between them and when an air barrier is incorporated to control driving forces. Fundamentally, this is the definition of a rainscreen water-penetration control strategy. Further discussion of water-penetration control strategies can be found in the following sections.

Water-resistive barrier materials can be classed in terms of suitability as an air barrier (durable and air impermeable), and also in terms of whether or not the material is vapour impermeable (i.e., a vapour barrier). Traditionally, a housewrap is a vapour-permeable membrane that may or may not be suitable as an air barrier. (Synthetic spun-boned polyolefin (SBPO) housewrap can be made into an air barrier, whereas building paper cannot due to its material properties and strength characteristics). A bitumen-modified or butyl-based self-adhered membrane with polyethylene or other plastic/metal facer would be considered a vapour- and air-impermeable membrane suitable as a vapour barrier and air barrier as well as a water-resistive barrier.

Vapour-permeable but airtight (air-impermeable) properties are desirable for the water-resistive barrier on the exterior of wood sheathings in most climate zones. These include synthetic housewraps, self-adhered permeable membranes, liquid-applied vapour-permeable membranes, and other products with similar properties. The thermally efficient, airtight, wood-frame enclosure assemblies presented in this guide would all utilize these types of vapour-open but airtight products, as covered in Chapter 4.

The use of vapour-impermeable and airtight self-adhered membranes commonly used in non-combustible construction and for the purpose of waterproofing may be used in some exterior-insulated assemblies, depending on insulation levels and the climate zone.

Air Barrier

The air-barrier controls flow of air through the building enclosure, either inward or outward. Air flow is significant with respect to space-conditioning costs, condensation control, and rain-penetration control. Air-flow control is critical in thermally efficient enclosure assemblies because of the potential for interstitial condensation and unwanted energy loss or gain. Detailed air-barrier strategies are discussed in Section 3.2.5; assemblies and details are presented in Chapters 4 and 5.

Sheet polyethylene located to the exterior side of the interior gypsum board in heating climates is often used as a vapour retarder (or vapour barrier). The vapour retarder limits the flow of water vapour through materials and is important with respect to condensation control. Vapour retarders/barriers are not considered critical barriers because they are not needed within all climate zones and assemblies. Some assemblies may stop or restrict the flow of vapour using vapour retarders or barriers while others will allow vapour to flow through. Vapour flow is further discussed in Section 3.2.6; and, in the context of each assembly, more information is presented in Chapter 4.

3.1.7 Controlling Rainwater Penetration

Rain is usually the largest moisture source for building enclosures, and the control of rainwater penetration is essential in the majority of climatic regions across North America. While climate zone is important, steps can be taken in the design of the building enclosure to reduce its exposure to wind-driven rain and to minimize loads. Only in hot dry desert regions where rainfall is very infrequent is the control of rainwater penetration not generally a local building concern. In Fig. 3.1.5 the rainfall exposure map for Canada and the United States shows historical annual rainfall rates from Environment Canada and NOAA climatic data.

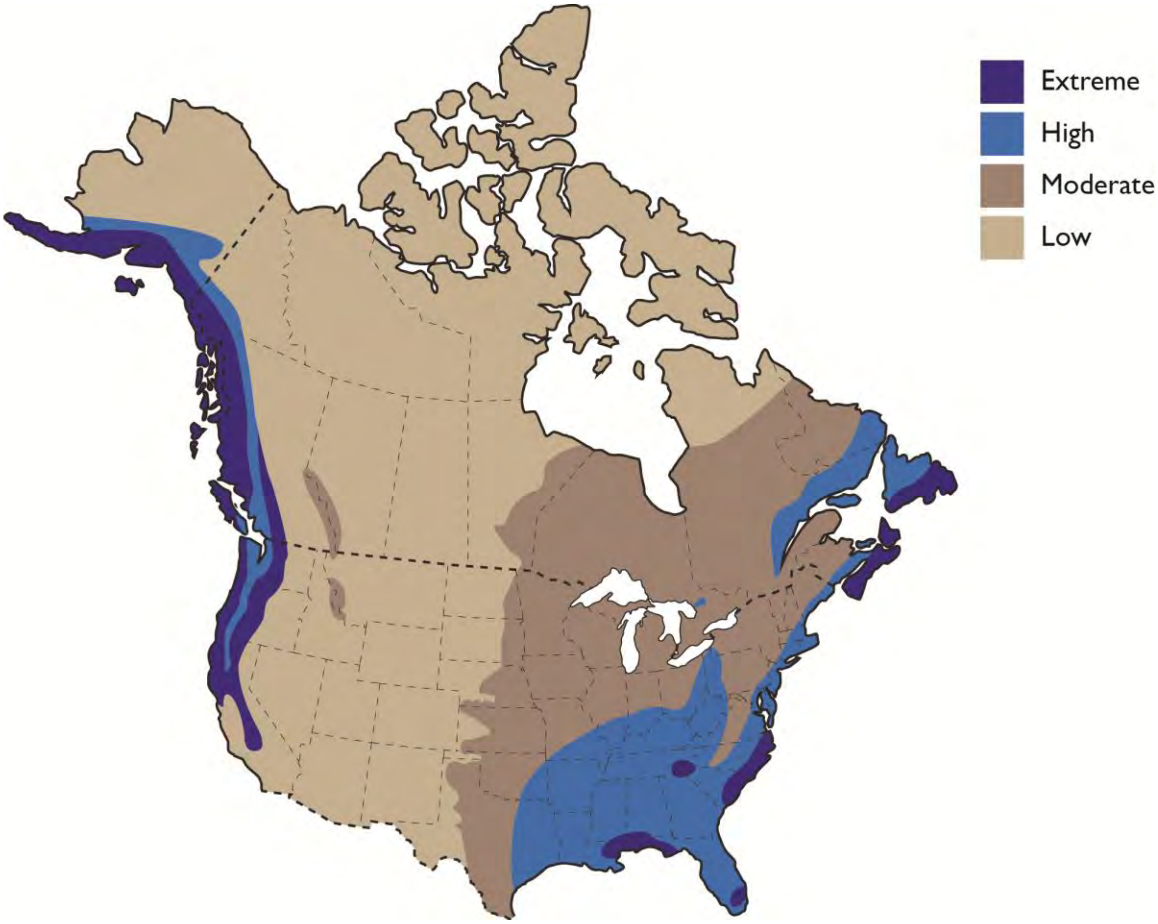


Fig. 3.1.5 Rainfall exposure map, Canada and the United States. (Image by RDH Building Engineering Ltd., adapted from several sources including Lstiburek (2008), Environment Canada, NOAA, and from Canadian and U.S. atlas maps)

The basic principles of water-penetration control have been well understood for many years. Far too often, the application of those principles in real buildings has been less than ideal. Perhaps the best overview of rain-penetration control principles is provided in the April 1963 *Canadian Building Digest No.40*, by G.K. Garden. A summary of those principles follows here.

Three conditions are required to move water through a surface:

- a source of water at the surface of the material
- openings through which it can pass: water-entry paths
- a force to move the water through the openings: driving force

The elimination of any one of these three conditions will prevent water entry. In practice, most building assemblies rely on the partial elimination of a combination of these conditions.

This section discusses strategies for controlling rainwater penetration including strategies for appropriate wall assemblies, relative to climate and rainfall exposure zone.

Controlling Exposure to Rainwater

Controlling exposure to rainwater is a two-step process:

1. Limit, through the use of overhangs and drip edges, the amount of water that is able to come in contact with the building-enclosure assemblies.
2. Use appropriate assemblies to control the water that does reach the building enclosure such that it does not penetrate through or into the enclosure and cause damage.

This first step was discussed earlier in this chapter, while the selection of appropriate assemblies is discussed in this section.

By their nature, roofing elements of the building enclosure will be exposed to wetting every time it rains or snows. However, the exposure of walls and windows to wetting is more complex and is determined by a combination of the exterior climatic environment (wind and rain), local topography, and building form. Over the service life of the building, exposure of these elements can be thought of as a measure of how often, and for what duration, a wall or window is likely to be wet.

While climate and local topography impact exposure conditions, the designer has limited control over these factors. Therefore, the most direct way to control exposure to wetting is through features of the building, i.e., the provision of overhang protection utilizing projecting elements such as roofs, canopies, rebating windows, and drip edges to limit runoff on vertical surfaces. As previously mentioned, using features that control exposure through the use of overhangs pays enormous benefits.

If most of the water is deflected before it impacts the wall, then the need to rely on drainage and drying mechanisms is significantly reduced. If a wall or detail is rarely wetted then water penetration control is less of a performance issue.

The use of material combinations and arrangements that are waterproof is required to eliminate openings. Most importantly, however, joints and interface details that are waterproof and durable are needed. An assembly of layers where the holes in one layer do not align with the holes from another layer, such as roof shingles, can be a successful strategy. However, elimination of openings as the sole means of controlling exterior sources of moisture is very difficult to achieve. Successful designs generally combine the elimination of most openings with other control strategies.

Limiting Entry Paths

The use of material combinations and arrangements that are waterproof is required to eliminate openings. Most importantly, however, joints and interface details that are waterproof and durable are needed. An assembly of layers where the holes in one layer do not align with the holes from another layer, such as roof shingles, can be a successful strategy. However, the elimination of openings as the sole means of controlling exterior sources of moisture is very difficult to achieve. Successful designs generally combine the elimination of most openings with other control strategies.

Controlling Driving Forces

The four main forces that drive water leakage are:

Kinetic energy or raindrop momentum: Wind-driven raindrops can have a significant horizontal velocity. Near the top of the building, there may even be an upward component. The raindrops' momentum can carry them directly through openings of sufficient size. Intentional openings, such as drains and vents, can be protected from direct entry of rain by cover battens, splines. or internal baffles.

Gravity: The force of gravity will cause water to move down the wall face and into any downward-sloped passages. Therefore drainage elements are typically designed to slope downwards and toward the exterior. However, unintentional cracks or openings are more difficult to control. The provision of a cavity directly behind the cladding will allow any water that penetrates past the cladding to be directed downward by gravity on the inside face of the exterior cladding. At the bottom of the cavity, the water can then be drained back to the outside through the use of flashing.

Capillary action and surface tension: Surface tension draws water into small gaps and fissures in a material until the material reaches saturation. Brick head joints are a good example of a situation that may experience this type of moisture drive. If these gaps extend from the exterior to the interior, water is drawn through the wall. Capillary transfer is characteristic of porous cladding materials, but the introduction of an air space or cavity behind the cladding can break the capillary movement of water through the wall.

Pressure differentials: An air-pressure difference across a building-enclosure assembly can be created by wind, stack effect, or mechanical ventilation. If the pressure on the exterior face of the wall is higher than on the interior of the wall, water can be forced through water-entry paths in the wall, even those having a limited upward slope. Air movement driven by pressure differences can also carry droplets directly through larger openings. From the perspective of controlling water penetration, pressures created by strong winds are of the most concern because they are generally of much higher magnitude than those caused by stack effect or mechanical systems.

In some cases, only one or two of these forces may be present, but in a windy rainstorm all of them will likely be acting to move the water through any available opening. Each must be addressed in the design of the enclosure.

Strategies for Controlling Water Penetration of the Assembly

The basic principles for controlling water penetration (as presented in the previous section) as well as those for interface and penetration detailing, are fundamental to a classification system for assemblies. This categorization system (Straube and Burnett, 2005) is independent of materials, building function, and assembly type—see Fig. 3.1.6. The application of this categorization system tends to be thought of primarily in connection with wall assemblies because walls have the greatest possible range of strategies and materials available for consideration, and these vary by climatic zone and rainfall exposure. Fig. 3.1.6 presents the categorization strategies for wood-frame assemblies only, adapted from Straube and Burnett's full chart. Note that the "mass or storage" categorization is not included in this guide, because it is not suitable for wood-frame assemblies or details due to the inherent risk of large quantities of water being stored within wood elements which in turn would lead to weathering or deterioration.

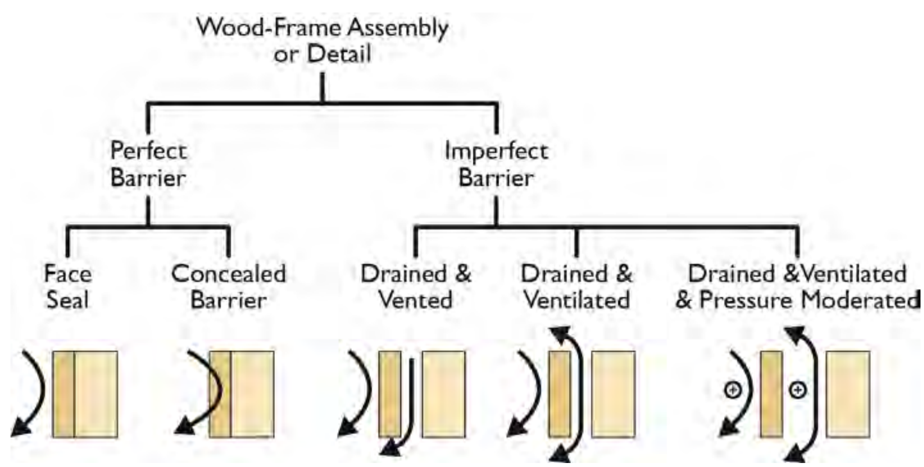


Fig. 3.1.6 Classification of a water-penetration control strategy for wood-frame assemblies and details. (Image created and modified by RDH, originally adapted from Straube and Burnett (2005))

Perfect barrier strategies rely solely on the elimination of holes to control rain penetration. Face seal and concealed barrier strategies vary slightly in their application to building assemblies.

A **face seal strategy** relies on stopping all water at a single surface located on the exterior face of the assembly or detail. This strategy combines the water-shedding surface, water-resistive barrier, and the air barrier into one layer at the exterior of the assembly. This strategy relies solely on the elimination of all holes through the cladding.

Achieving perfection in practice is very difficult and few enclosure assemblies are successful in utilizing this strategy. Some exterior-insulated finish systems (EIFS) for walls are designed to utilize this strategy. Membrane roofs are also an example of the application of the face seal strategy; most roofing assemblies tend to fall into a perfect barrier approach in which the placement of insulation (above or below the membrane) defines different attributes (i.e., conventional versus inverted approaches). Assemblies that use a face seal strategy for wall assemblies and joints have proven to be unreliable because installing and maintaining perfect and durable seals at all joints and intersections between assemblies is very difficult. Even if the problem of job site inaccuracies and imperfect workmanship could be overcome and a perfect seal could be achieved initially, the materials used to seal all the openings are themselves exposed to extremes of weather as well as movements of the building. These factors will eventually cause deterioration and failure of the seals, creating openings through which water can pass. The lack of drainage or venting of the cladding in face seal assemblies, combined with the use of cladding or finishes with moderate or low vapour permeability, also limit the ability of these assemblies to dry.

The lack of appropriate protection of the face seal stucco walls and poor interface detailing have resulted in the deterioration of many wood-frame building enclosures in wet climate zones.

A face seal strategy should not be used for typical wood-frame wall construction if the walls are exposed to wetting at all. Adequate performance may be anticipated in no-exposure situations where the building is located in a dry climate zone or in a wet climate zone whereby the wall assembly is completely protected by overhangs.

A **concealed barrier assembly** is similar to a face seal assembly in that it utilizes a perfect barrier strategy. The difference is that this barrier is located at the sheathing membrane where it is concealed and protected by the cladding. It may therefore provide more durable water penetration resistance. However, these walls do not incorporate an air space between the cladding and the sheathing membrane. This omission can significantly limit drainage and drying capability, depending on the cladding type, and therefore this strategy should only be used in lower exposure situations. This strategy is utilized in some wood-frame assemblies, such as a stucco wall with a layer of building paper located directly behind the stucco layer. In this instance the building paper is designed to be the perfect barrier and the stucco conceals and protects the building paper. Because the barrier is protected, it is more likely to provide adequate performance than a face sealed assembly.

Compared with the "perfect" barriers, **imperfect barrier strategies** rely on a combination of the fundamentals for controlling rain penetration, i.e., the elimination of water at a surface, the elimination of holes, and the elimination of driving forces. In some cases the ability to store moisture is also a key part of the strategy.

A drained or screened approach (rainscreen) acknowledges that some water will penetrate the outer surface and provide additional drainage surfaces and a cavity to help control rain penetration. A rainscreen strategy for controlling water penetration of wood-frame walls has, at a minimum, the following characteristics:

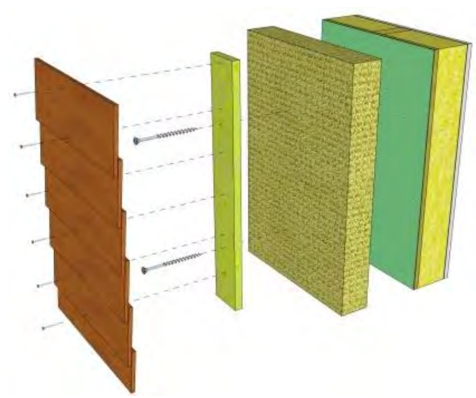
- a continuous water-shedding surface
- an air space behind the cladding that is vented to the outside to facilitate drainage and drying
- a water-resistive barrier, such as a sheathing membrane, placed on the exterior face of the wall sheathing (water-shedding surface and water-resistive barrier are separated)
- drain holes or gaps through the cladding so the water can leave the cavity, with flashing at wall base, doors, and windows, etc. to direct the water to the outside

In addition to these requirements, many rainscreen wall assemblies will also have a continuous air-barrier system at the water-resistive barrier to improve the control of rainwater penetration.

The cavity creates a capillary break to prevent water from migrating further into the assembly, as well as an opportunity for air movement to facilitate drying. Openings provided at the perimeter of the cladding allow for diffusion and mixing of cavity and outdoor air to dry the assembly (**drained and vented** rainscreen). If these holes are large enough and are arranged to encourage air movement through the cavity, then the assembly can be considered to be ventilated and has a much-improved drying capability (**drained and ventilated** rainscreen). If some attention is paid to the details of cavity size, the compartmentalization and stiffness of the cladding, and the air barrier, then some degree of moderation of the wind-induced pressure drop can be achieved, thus less water will penetrate past the cladding surface (**drained and ventilated and pressure moderated** rainscreen).

In the thermally efficient wall assemblies presented within this guide, the installation of insulation to the exterior of the sheathing typically requires vertical strapping for cladding attachment. The use of strapping over the insulation in this manner makes the transition to thermally efficient rainscreen walls relatively simple from the detailing and cost standpoints. It is also beneficial from a durability standpoint.

The presence of the multiple lines of resistance (water-shedding surface and water-resistive barrier) separated by a drained cavity in rainscreen construction provides enormous benefit. Holes in the inner and outer surface are generally not aligned so that direct rain passage by momentum is eliminated. Water that passes through the outer surface (the rainscreen) is driven either by gravity, capillary action, or air pressure differences. It tends to run down the back side of the cladding where it can be intercepted and drained back to the outside at a cross-cavity flashing location. These features mean that the amount of water reaching the inner surface of the cavity and remaining in contact with potentially moisture-sensitive materials is greatly reduced.



A split insulated wall utilizes vertical strapping screwed through the insulation to attach the cladding to (so that long fasteners aren't needed to attach each piece of cladding). This vertical strapping creates a capillary gap, drainage space and if detailed properly with top and bottom openings – a ventilation space.

Openings at the top and bottom of each section of wall cavity also encourages the circulation of outdoor air through the cavity to help evaporate the minor amounts of water that may have accumulated on materials within the cavity. Together with the other features of rainscreen walls noted above, this creates a ventilated rainscreen wall assembly.

The provision of an effective air barrier within the stud wall assembly together with some compartmentalization of the cavity help to moderate air pressure drop at the cladding. Vent area is another variable; generally the greater the vent area, the more responsive the cavity is to pressurization. Pressure-moderated rainscreen walls somewhat improve the effectiveness of the assembly in managing rain penetration because they further limit the amount of water that passes beyond the water-shedding surface.

It is important to note that the use of rainscreen wall assemblies that have good resistance to water penetration and are fundamentally less sensitive does not eliminate the need for good details and construction practice. Improper details are frequently sources of water entry; many of these details are addressed in Chapter 5.

Five and Six-Storey Wood-frame Buildings—Cladding Compartmentalization

Compartmentalizing the cavity in rainscreen wall assemblies can assist in moderating the pressure drop over the cladding. This is not usually critical to performance in low-rise wood-frame buildings. However, for highly exposed sites and taller five- and six-storey wood-frame buildings some compartmentalization may be warranted. This can be accomplished by blocking the cavity vertically (resisting horizontal flow) at building corners and possibly at some intermediate locations. Note that efforts to compartmentalize should never compromise the capacity for drainage and ventilation.

Within Canada, the NBC and provincial codes, such as the British Columbia Building Code, include mandatory requirements for rainscreen walls in wet areas. The Canadian building codes use the moisture index (MI), which is a relative indicator of the severity of the moisture load imposed on a building enclosure and which takes into account both wetting and drying potential. The moisture index is used within Part 9.27 of the NBC and within the British Columbia Building Code to essentially require a minimum 10-mm gap behind the cladding and rainscreen detailing at all enclosure interfaces if:

- the heating degree day is less than 3400 (°C) and the moisture index is greater than 0.90 (high), or
- the heating degree day is 3400 (°C) and the moisture index is greater than 1.00 (severe).

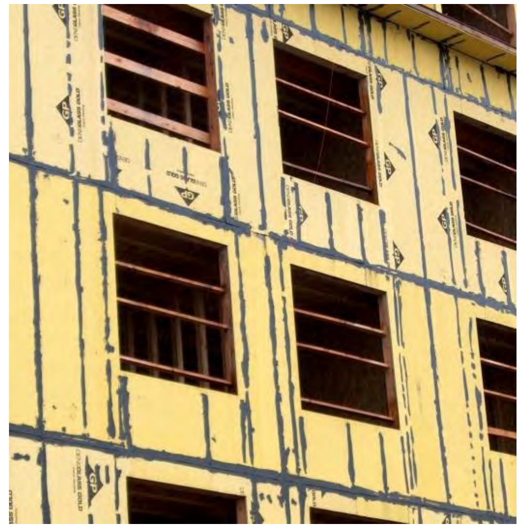
In summary, appropriate wall assemblies should be designed to minimize the water that reaches the building enclosure and which will cause damage. The basic principles of water penetration control are fundamental to a classification system for assemblies, as well as to interface and penetration detailing. In terms of assessing appropriateness for a certain assembly, Lstiburek (2008) suggests the following strategies for controlling rainwater penetration of walls (refer to Fig. 3.1.5 for loads and definitions for Extreme through Low):

- Extreme (over 60 inches (1500 mm) rainfall/y): ventilated rainscreen (ventilated cavity and top and bottom vents)
- High (40 to 60 inches (1000 to 1500 mm) rainfall/y): vented rainscreen (vented cavity and bottom vents)
- Moderate (20 to 40 inches (500 to 1000 mm) rainfall/y): drained (drainage cavity with bottom drain weeps)
- Low (less than 20 inches (500 mm) rainfall/y): face seal (surface water management, no provisions for water past cladding)

3.1.8 Control of Air Flow

The control of air flow by the use of air-barrier systems is important to minimize rain penetration, interstitial vapour wetting/condensation, and space-heat loss from building enclosures. Air-barrier systems are required for all MURBs in all climate zones. The air-barrier system must comply with five design requirements in order to function adequately.

1. All the elements (materials) of the air-barrier system must be adequately **air-impermeable**. They must have air permeability less than 0.004 cfm/ft^2 (0.02 L/s·m^2) at 75 Pa, based on typical definition in building codes.
2. The air-barrier system must be **continuous** throughout the building enclosure. It must span across dissimilar materials and joints. It must be sealed around penetrations such as ducts and pipes.
3. The air-barrier system must be **structurally adequate** or be supported to resist air pressure forces due to peak wind loads, sustained stack effect, or fans.
4. The air-barrier system must be **sufficiently rigid,** or be supported, so that displacement under pressure does not compromise its performance or that of other elements of the assembly.
5. The air-barrier system should have a service life as long as that of the wall and roof assembly components; alternatively, it must be easily accessible for repair or replacement (be **durable**).


The exterior, sealed-sheathing, air-barrier approach is a rigid and durable strategy for a wood-frame MURB that meets the five requirements for an air-barrier system.

Prescriptive and general requirements for air barriers within wood-frame MURBs are included within Canadian and U.S. building codes, energy codes, and standards, such as the 2011 BECB and the 2012 IECC. In Canada, general air-barrier performance criteria for enclosure materials and components, rather than criteria for the entire building, are specified. This is primarily because, for large MURBs, it is seen as more difficult and costly to determine air-leakage rates for the entire building (although it is becoming common in jurisdictions such as Washington State). Also, condensation due to excessive air leakage is usually related to specific components, materials and joints rather than being an issue related to the entire building. See Chapter 2 for detailed airtightness requirements.

Testing of wood-frame MURBs in Washington State, where airtightness testing is now required, is showing that it is possible to construct wood-frame MURBs with overall air-leakage rates of less than 0.40 cfm/ft^2 of enclosure area at 75 Pa. Testing has also shown air-leakage rates for wood-frame buildings being consistently lower than 0.25 cfm/ft^2 at 75 Pa, the U.S. Army Corps of Engineers' (USACE) new air-tightness testing standard.

When properly detailed and supported during construction and in-services, the exterior, sealed sheathing membrane, air-barrier approach can be a successful strategy for air-flow control in a MURB.

Efforts to achieve a satisfactory barrier to air movement in wood-frame construction in the early 1980's focused on the use of polyethylene sheet membranes in Canada and the northern United States. This film was structurally supported by the wood framing, insulation, and interior sheathing, and also functioned as a primary vapour-retarder material within the assembly. This approach is still commonly and successfully employed in low-rise wood-frame buildings though not recommended in taller buildings subject to higher air pressures.

Alternative approaches to achieving control of air leakage are to seal the joints between the rigid sheet materials that are used in construction with tapes, sealants, or gaskets. Most materials used in construction have a low permeability to air leakage. Not only the material, but also their joints, must be capable of staying airtight under applicable wind loads.

The air barrier may be placed on the exterior of the majority of the insulation. When it is located on the exterior of the wall in a heating-dominated climate, it must be permeable to water vapour or have enough insulation outside surfaces where condensation could occur to keep the air barrier above condensing temperature for most of the time. In a heating climate, defects or holes in an exterior air barrier are particularly vulnerable to condensation because the materials at the location of the hole are at the coldest part of the assembly. One may also wish to avoid the use of external air-barrier systems made of materials with low water-vapour permeability because they inhibit drying. Building codes place restrictions on the use air-barrier materials with a water-vapour permeance of <1 US perm (<57.4 ng/Pa·s·m^2), rounded to <60 ng/Pa·s·m^2 in Canadian building codes, or a Class I or II Vapour Barrier.

Energy Conservation

The control of air leakage through the building enclosure is important in order to conserve space heat and reduce air-conditioning loads. Air leakage in a MURB occurs through unintentional defects, joints, and interfaces in the building enclosure, but also through open windows and mechanical penetrations. While a window is an obvious and intentional opening in the enclosure, windows are often left open while the building is being heated thus allowing warm air to flow out of the building and subsequently increase the building's heating demand. In MURBs, air leakage may account for up to half of the space-heat loss, depending on the air-leakage rate, building height and wind exposure, occupant behaviour, mechanical penetrations, and several other factors including the effective enclosure thermal performance. Air leakage in MURBs is typically higher than in smaller single-family dwellings due to the increased wind exposure, the stack effect, and the mechanical systems, all of which contribute to higher and more sustained differential pressures across the building enclosure.

An exterior air-barrier approach can be utilized to either seal the joints in the exterior sheathing (gypsum in this MURB) or seal the exterior sheathing membrane (SBPO in this MURB). Selection of which component to seal will depend on cladding type, MURB height, and the contractor's familiarity with the approach.

Not to be confused with air leakage, ventilation is typically provided by mechanical means within suites of MURBs by means of central or individual continuous-supply exhaust systems and individual intermittent exhaust systems. While ventilation is beneficial and required for health, comfort, and moisture control, the duct work and penetrations through the enclosure are also sources of unintentional air leakage. Minimum mechanical ventilation air requirements are outlined in ASHRAE Standard 62 and in local building codes.

Air-Barrier Systems

Air barriers are generally located on either the interior or the exterior side of the wood-frame portion of the wall assembly. In general, in hot and humid climates, the air barrier is installed on the exterior side of the wall to limit air infiltration and wind washing from the exterior, and to prevent warm moist air from contacting cold interior surfaces. In mixed climates the air barrier may be installed on the interior or exterior of the wall, or both, to limit air movement from both the interior and exterior. In cold climates the air barrier is generally installed on the interior to limit air exfiltration into the assembly and convective looping within fibrous insulations, and to prevent moist indoor air from contacting cold exterior surfaces. In cold climates an air-barrier material may also be installed on the exterior side of the wall to prevent wind washing. Unlike vapour barriers, there is little to no downside of redundancy in the air barrier provided that the materials used for the air barrier do not negatively affect vapour flow.

The air-barrier system in building-enclosure assemblies must accommodate the imposed wind load and transfer it to the building structure. In many cases, it is a combination of materials that comprise the air-barrier system; however, there are usually one or two materials that play a dominant role within any particular air-barrier strategy. For example, sheet polyethylene and butyl sealant are the dominant materials in a sealed polyethylene approach to achieving airtightness. Vapour permeable sheathing membranes and tapes are often the key material in an exterior air-barrier strategy, while the exterior sheathing or interior gypsum boards are the key materials in more rigid air-barrier systems. All of these systems tend to perform acceptably (within the limitations of each system) when the wind load acts to cause the primary air-barrier material to bear against the supporting structure. They are generally less able to accommodate the imposed wind load when the wind acts to pull air-barrier materials away from the supporting structure. The systems that are presented have been extensively used and tested and found to perform well under sustained wind loads and gust loads for three- and four-storey wood-frame buildings. However, air-barrier strategies for five- and six-storey buildings must be able to resist higher wind loads. Some of the strategies may not be suitable for these increased exposure conditions, such as where the air-barrier material is not adequately supported or is incapable of handling the higher wind pressures. Regardless of which system or combination of systems is used, continuity must be maintained at interfaces and penetrations, and good workmanship is critical to achieving this. Allowance must also be made to compensate for movement in framing members due to seasonal variations in moisture content or initial drying.

Five different air-barrier strategies are presented for discussion here:

- Sealed polyethylene approach
- Airtight drywall approach
- Spray foam in stud cavity
- Sealed-sheathing approach
- Sealed-sheathing membrane approach
    - Unsupported sheet membranes
    - Supported sheet membranes with vertical strapping
    - Sandwiched membranes behind exterior insulation
    - Self-adhered and liquid-applied membranes

Sealed Polyethylene Approach

The sealed polyethylene air-barrier approach is common in low-rise single-family house construction in heating-dominated climates. In this approach, the polyethylene sheet (typically a minimum of 6 mil) is sealed at the top and bottom plates to form the wall air barrier. All joints in the polyethylene are sealed and clamped between the framing and gypsum board. The wind load is transferred to the gypsum board in the inward direction and to the framing in the outward direction. The polyethylene must be supported by both the outboard insulation and the drywall on the interior. Locations where interior finishes are not normally provided, such as at drop ceiling spaces and below the rim of bathtubs, require specific measures to ensure support of the polyethylene.

This approach does not address wind washing and is not suitable in hot-humid climates due to the vapour impermeability of the polyethylene.

The sealed polyethylene approach uses acoustic sealant and red tape for details and transitions, such as in this wall around the window and light switch. Because the industry is familiar with this approach and the combined vapour barrier function, many designers will elect to use this approach in designs.

Airtight Drywall Approach

The interior gypsum board and framing members provide the air barrier in the airtight drywall approach. Continuity between different materials is created with sealant or gaskets. Special attention has to be paid to sealing the penetrations of the gypsum board at electrical fixtures and other services, as well to sealing as the intersection of partition walls with exterior walls and the ceiling. An advantage of this system is that the gypsum board is exposed for inspection and maintenance at all times. Nail pops, cracks, and other damage can be repaired over the life of the building.

The airtight drywall approach can be used with most of the wall assemblies discussed later within this guide, i.e., as an alternative to the sealed polyethylene approach. Similar to the sealed polyethylene, this interior approach does not address wind washing.

Spray Foam (interior of sheathing)

The use of either ½ pcf (lb/ft^3) open-cell or 2 pcf closed-cell polyurethane spray foam applied within the joist spaces of wood-frame walls and roofs can make up the primary air-barrier material. Joints, cracks, and gaps that are too small to be effectively sealed with spray foam (such as between the wood bottom plate and floor, or between top plates or at other small gaps) need to be air sealed with other sealants and adhesives as part of this approach.

Polyurethane spray foam is used as a transition air-barrier material to seal and insulate the space between roof and floor framing. The use of spray foam to fill small to large gaps in conjunction with other air-barrier strategies is common.

Spray foam can also be sprayed onto the exterior of the sheathing in an exterior air-barrier approach; however, extra care must be taken to properly seal transitions.

The use of spray foam is also often utilized within other air-barrier approaches to air seal transition areas (such as between floor joists).

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.

Exterior Approaches

There are several possible exterior approaches for achieving airtightness in wood-frame MURBs. Exterior approaches are divided into two primary categories, depending on whether the exterior sheathing (e.g., gypsum, plywood, or OSB, etc.) is sealed or whether the water-resistive barrier outside of the sheathing is sealed (e.g., spun-bonded polyolefin housewraps, self-adhered membranes, liquid-applied membranes).

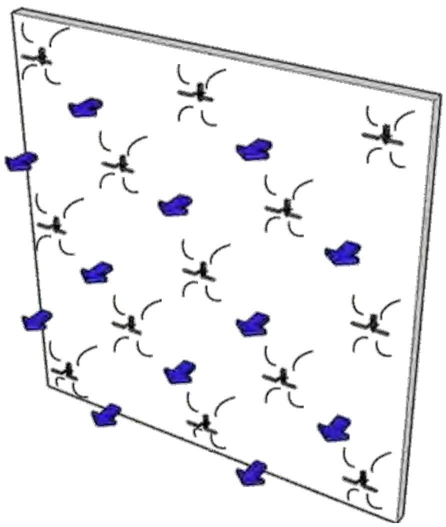
- Sealed-sheathing approach
- Sealed-sheathing membrane approach
  - Unsupported sheet membranes
  - Supported sheet membranes with vertical strapping
  - Sandwiched membranes behind exterior insulation
  - Self-adhered and liquid-applied membranes

Notice the use of tapes to seal the sheathing membrane for this 4-storey MURB. Rigidity and support of the membrane will be added in the form of vertical wood strapping to create the cavity for the rainscreen wall assembly.

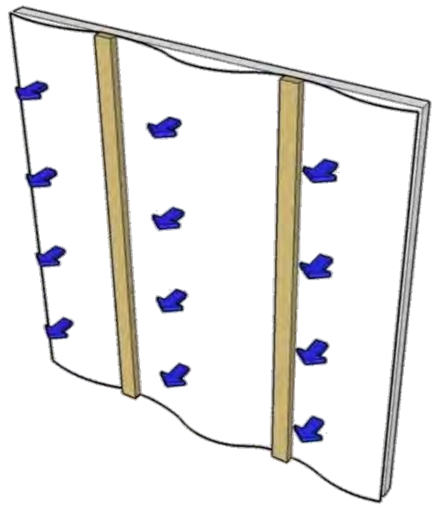
The key advantage of exterior approaches is that penetrations of the interior wall finish for electrical outlets and disruptions such as stairs, plumbing fixtures, and partitions, do not affect the continuity of the air barrier. However, often an alternative strategy must be used at the ceiling and roof details. The details in Chapter 5 present solutions for addressing continuity between wall and roof assemblies.

One exterior approach utilizes the sheathing (with sealed joints) as the primary air-barrier element. A variation of this approach utilizes the exterior sheathing together with strips of membrane to create a continuous air barrier. This approach has been quite successful in demonstrating low air-leakage rates for wood-frame MURBs. In several buildings, which were tested by the authors using this air-barrier approach, the overall enclosure airtightness was less than 0.40 cfm/ft^2 at 75Pa. Experience has shown that it is often much more difficult to achieve the same level of airtightness using unsupported membranes.

Another approach utilizes a vapour-permeable sheathing membrane (often also functioning as the water-resistive barrier) as the primary air-barrier element. The exterior vapour-permeable sheathing membrane is made airtight utilizing sealant and tape. This approach can be used successfully in tall MURBs if the membrane is properly supported and protected from tearing at sharp penetrations (such as at brick ties). The use of vertical wood strapping or metal girts can be used to improve the support for the air-barrier membrane when this approach is used. This is demonstrated in Fig. 3.1.7.



Exterior, sheet, air-barrier membrane with concentrated loads at metal ties.



Exterior, sheet, air-barrier membrane with vertical wood strapping or metal girts, more evenly distributed loads, and deflection of the membrane.

The use of cladding, such as masonry veneer, that relies on localized penetrations of the sheathing membrane by metal ties will increase the potential for tearing of air-barrier materials. The use of self-adhered membranes at brick ties helps reinforce these locations.

There is very little test data available to allow for a more analytical or even empirical approach to determining the structural adequacy of sheet-membrane barrier systems. Precautionary measures could include tightly spaced strapping to secure the membrane, and selection of more robust membranes (i.e., in terms of strength and tear resistance). The use of self-adhered and liquid-applied membranes basically makes the sheathing and membrane an integral, rigid, air-barrier material.

Fig. 3.1.7 Structural support for an exterior sheathing membrane: what to consider when selecting a strategy.

At this 3-storey wood-frame recreational building, self-adhered vapour-permeable membrane is applied directly over plywood to form the air-barrier system. Self-adhered membranes may improve detailing and provide a more rigid and durable air-barrier system than sheet applied and taped membranes.

A variation on the sealed sheathing membrane approach utilizes the vapour-permeable sheathing membrane as the primary element, but additional insulation is placed to the exterior side of the membrane. This effectively sandwiches the air-barrier sheathing membrane between the exterior insulation and the sheathing and provide additional support.

Alternatively, in either approach, an adhered or liquid vapour-permeable membrane could be used. Self-adhered vapour-permeable membranes and liquid vapour-permeable membranes are becoming more common and their use is suggested in many applications because of their improved robustness, some self-sealing characteristics, and rigidity.

In hot and humid climates, the use of an exterior air-barrier approach is preferred. In cold climates, assemblies become more sensitive to exfiltration air leakage when the air barrier is located on the exterior side of the insulation. That is, condensation is more likely to occur because cold surfaces are readily available at any discontinuities in the air barrier. The sealing of the interior drywall or the polyethylene in addition to an exterior approach in cold climates is suggested for some thermally efficient assemblies (e.g., double stud) for this reason. For other thermally efficient assemblies, such as split insulation, the air-barrier is sandwiched between the insulation layers and the risk of condensation occurring due to air leakage within the assembly is minimized.

Other Approaches

A common air-barrier approach used in wood-frame construction in Passivhaus construction in Europe and in some places in North America is the use of thick (2x10 or larger), prefabricated, insulated, wood-frame walls with taped and sealed wood sheathing at the interior surface as the air-barrier and interior vapour-control layers. Many of these wall assemblies are also pre-fabricated and assembled on site are similar to structurally insulated panels (SIPs). Special pressure-sensitive adhesive tapes are used to tape the joints in the interior plywood or OSB layer and between elements to create a continuous air-barrier. (Exterior plywood/OSB may also be taped.) Care must be taken at transitions between floors and roofs, but the rigidity and visibility of this approach generally results in very airtight buildings and it is a potential solution for mass-timber and other prefabricated walls.

A rigid, interior, air-barrier approach using taped plywood sheathing at the inside of the wall assembly is common in Europe and many Passivhaus designs with highly insulated wood-frame walls (pre-fabricated and site built).

Another benefit of this approach is that services are run within a stud wall built to the interior of the prefabricated panel, so that the air barrier is not disrupted or damaged by electrical and plumbing penetrations. This assembly is similar to the double-stud wall assembly discussed in Chapter 4; however, it utilizes a rigid, interior, air-barrier approach.

Table 3.1.2 Air-barrier strategies: benefits and limitations.

Air-barrier strategy	Benefits	Limitations
Sealed polyethylene	• Common; therefore trades are familiar with this approach in most heating-dominated climate zones. • Also functions as vapour barrier (in climates where needed). • Relatively inexpensive.	• Unable to accommodate high pressures and is therefore limited to low-rise buildings. Not recommended for taller MURBs. • Easily damaged during construction. • Difficult to transition between floors levels and past interior details. • Also functions as a vapour barrier (unintended in some climate zones where not needed). • Does not prevent windwashing.
Airtight drywall (ADA)	• Trades are familiar with this approach in many climate zones. • Relatively cost effective, does not require additional materials (other than some sealants and gaskets). • Rigid support is able to accommodate higher pressures. • Visible and easy to repair.	• Some difficulty in penetration detailing. • Transition details where drywall not used (e.g., partition walls, drop ceilings, etc.) can be difficult to make airtight unless properly pre-planned. • Need for additional vapour barrier in some climate zones. • Does not prevent windwashing.
Spray foam (interior of sheathing)	• Seals center of wall well. • Performs insulation and air-barrier functions. • Provides insulation in addition to being an air barrier.	• Does not address details and small cracks, gaps, and transitions that require additional materials (sealants, tapes, etc.). • Costly and does not provide whole-system airtightness. • May be better used as a transitional strategy, as part of other air-barrier approaches.
Sealed exterior sheathing	• Visible, and easy to install on exterior of building. • Minimal detailing needed (sealants or tapes at all joints). • Provides rigid support.	• Transition detailing between exterior and interior air-barrier approaches (e.g., at ceilings) can be difficult without pre-planning. • Weather can delay application of sealants and tapes on exterior sheathing. • Must accommodate shrinkage and movement of wood framing. • Water-resistive barrier is still required to exterior.
Sealed exterior membrane approaches		
• **Unsupported sealed sheet membrane**	• Visible and easy to install on exterior. • Minimal detailing. • Cost effective as also performs water-resistive barrier function.	• Unable to accommodate high pressures (limited to low-rise MURBs). • Can be easily damaged during construction from wind (blow off, tear). • Easily torn around sharp penetrations (e.g., brick ties) and flashings.
• **Sealed sheet membrane supported by vertical strapping**	• Visible and easy to install on exterior of building. • Minimal detailing (sealants or tapes at all sheet laps and interfaces). • Improved rigidity over unsupported. • Cost effective as also performs water-resistive barrier function.	• Requires strapping for support. • Can accommodate higher wind pressures, but not recommended for high-rise applications.
• **Sealed sheet and adhered membranes sandwiched between sheathing and exterior insulation**	• Visible and easy to install on exterior of building. • Minimal detailing. • Rigid support between sheathing and exterior insulation. • Cost effective as also performs water-resistive barrier function.	• Air-barrier detailing must be largely complete prior to installation of exterior insulation. • Screws through insulation may damage some membranes leading to decreased airtightness (suggest using adhered membranes to counter this).
• **Sealed membranes adhered to sheathing (self-adhered, cementitious, and liquids)**	• Visible and easy to install on exterior of building • Minimal detailing. • Single material. • Rigid support (integral support of membrane and sheathing). • Can also act as water-resistive barrier and vapour retarder.	• Membranes/liquids may be more expensive than some other options. • Some membranes are weather sensitive.

3.1.9 Controlling Condensation

Vapour condensation can lead to damage of finishes, structural components, and other materials of the building enclosure, and it may affect indoor air quality and occupant comfort if not effectively controlled. Condensation becomes more critically important for highly insulated building-enclosure assemblies. In heating-dominated climates, condensation control is generally achieved by controlling indoor relative humidity, controlling air flow (air barrier), keeping potential condensing surfaces warm, and controlling vapour diffusion.

Condensation involves changing water from the vapour form as it is present in air, to a liquid form. The variables that impact condensation potential include the temperature of surfaces, air temperature, and the amount of vapour in the air. Warmer air can hold more moisture, and the dew point is a measure of the temperature at which the air can hold no additional moisture. Condensation occurs on surfaces that are colder than the dew point temperature of the air to which they are exposed. Three conditions are required for the accumulation of condensation:

- a source of humidity (see information about interior and exterior moisture sources earlier in this chapter)
- a sufficiently cold surface (at or below the dew point temperature of the air)
- a mechanism(s)—vapour diffusion and/or air movement—to get the humid air to the cold surface

The strategies for the control of condensation therefore involve the management of these three variables.

Controlling Relative Humidity

In cold climates, reducing the amount of moisture in the air is a viable strategy for controlling condensation, particularly with interior air and in association with cold weather conditions. For example, in a cold to temperate climate, it is quite possible for the interior RH to reach 50% in a relatively airtight building that has the typical interior moisture-generation sources. Ventilation can effectively dilute interior air with exterior air to bring the interior RH down to more comfortable levels (30 to 40% RH) in the winter. However, in very cold climates, too much ventilation can reduce the indoor RH levels down to 10 to 20%, which can be uncomfortable for occupants. With lower RH levels, the condensation potential on interior surfaces such as windows, as well as interstitial condensation (inside surface of exterior sheathing for example), will be reduced because the dew point temperature of the interior air will be lower. Note that this ventilation strategy will not reduce interior RH during the warmer humid weather conditions. However, the differences between interior and exterior environments are usually relatively small and all surfaces are usually sufficiently warm during these cooling periods of the year such that condensation potential is minimal.

Keeping Surfaces Warm

In a heated insulated building, condensation can occur on inside surfaces of building-enclosure materials or components of low thermal resistance, such as windows, or where there are strong thermal bridges in the wall or roof framing. This occurs when indoor humidity condenses on cooler surfaces that are isolated from indoor heat by the insulation. Note that insulation can include unintentional insulation provided by furniture such as couches and shelves, and closets filled with clothes.

Keeping surfaces warm is a function of the thermal conductivity of materials within the assemblies and of the temperature of the adjacent air. Windows are the most visible demonstration of this principle. Window frames with high thermal resistance (wood, fibreglass, or vinyl) and good edge spacers prevent condensation and save energy. The circulation of warm air at the surface of the window also increases its temperature, and helps to ensure that air with a lower dew point temperature is present at the window surface.

Condensation within walls or other building assemblies can be reduced by placing insulation outside the building frame and sheathing, thereby reducing thermal bridging. This keeps the inside sheathing surfaces warmer, which will reduce or eliminate condensation. A more detailed discussion of insulation within assemblies can be found in Chapter 4.

The presence of thermal bridges such as metal flashings or other un-insulated solid elements, which pass completely from the interior to the exterior, can result in colder interior surfaces and create a greater potential for condensation.

Controlling Air Movement

Moisture transfer to and through the enclosure from the building interior in the form of water vapour can occur due to air movement or water vapour diffusion. In most cases, air movement is the dominant interior moisture transfer mechanism. The amount of water that condenses within a wall assembly due to air leakage will depend on the length of its path of travel, and on indoor RH. If the air goes directly and quickly through the wall assembly (for example, from a crack below the base plate), a relatively small amount of condensation will occur. However, if the exit path is much longer (for example, from an electrical outlet at the bottom of the wall to the interior and up to a hole in the top of the wall at the exterior), there will be much more time for the warm air to cool and deposit condensation in the assembly. Condensation can also occur on cold surfaces within exterior wall assemblies due to the leakage of air into and out of wall cavities and by convective looping through low-density fibrous insulation. In cold climates, it is the outward flow of air (exfiltration) bringing indoor humidity to cold surfaces that leads to condensation. Inward flow of air (infiltration) does not normally create condensation, except during the summer if the interior is air conditioned (or in hot humid climates during the cooling season). Specific air-barrier strategies are discussed in the previous section.

Controlling Vapour Diffusion

The flow of vapour diffusion through building-enclosure assemblies is traditionally controlled using low-vapour-permeance materials. To avoid condensation inside an assembly due to vapour diffusion in a heating climate, the vapour permeability of surfaces to the interior side of the insulation should be lower than the vapour permeability of surfaces to the outside of the insulation (i.e., use of vapour barrier at interior and vapour-open exterior sheathing membranes). In normal building practices, and as mandated by Canadian building codes and many U.S. state building codes, this is accomplished by placing a low-permeability material, i.e., the vapour retarder, on the warm side of the insulation. This is generally true for Climate Zones 4C and 5 through 8. In Climate Zones 1 to 3 and 4A/4B, the use of interior vapour barriers is not required (IRC 2007). The use of sheet membrane—such as polyethylene on the interior of the wood framing, or vapour barrier paint on drywall—typically serves the function of an interior vapour retard in heating climates. Vapour barrier-based paints, asphalt-saturated kraft paper, and other plastic membranes are also commonly used.

Many U.S. state building codes that reference the IRC define vapour retarders under three classes:

Class I: 0.1 US perm or less
(e.g., sheet polyethylene, non-perforated aluminium foil)

Class II: 0.1 US perm ≤1.0 perm
(e.g., kraft faced fibreglass batts, vapour barrier paint, XPS, concrete)

Class III: US 1.0 perm ≤10 perm
(e.g., Latex or enamel paint, plywood/OSB at low RH)

As a rule of thumb, the materials that are located outboard of the vapour-retarder layer should be at least three to five times more vapour permeable than the vapour retarder. In addition, there should never be two or more layers of materials with low vapour permeance used in an assembly, the exception being the provision for back venting behind impermeable claddings such as metal panels. Selection of an appropriate vapour-retarder material and location should therefore be done on the basis of the permeability of other materials in the assembly. Within

Canada, vapour-retarder material requirements for small MURBs are provided in Section 9.25 of the NB;, Section 5.5 of the NBC and provincial codes provide less prescriptive requirements for larger buildings. Because the climate zones in Canada are heating dominated, vapour-diffusion control is fairly straightforward. In the United States, because climate zones vary from heating to cooling-dominated, building codes are less clear on vapour-retarder requirements and vary by state.

While these requirements seem simple, it can get complicated because materials used to keep water vapour from moving into an assembly can also restrict water vapour from moving out. This is a problem in situations where some drying is necessary to facilitate initial drying of wet building materials (such as wet wood or concrete), or because of changes in the direction of the moisture drive (for example, inward drive due to heated moisture in absorptive claddings). For example, exterior foam insulation (XPS, EPS, or polyiso) in wood-frame assemblies should not be installed over wet sheathing, nor should water be allowed to penetrate behind the insulation during construction or in service. Vapour permeance of materials in assemblies must therefore be carefully selected in the context of the permeability of the other layers within the assembly and the given climate zone. The control of vapour diffusion is particularly important in highly thermally efficient assemblies. Guidance on the control of vapour diffusion for different climate zones is covered with the specific wall and roof assemblies discussed in Chapter 4. The water-vapour permeance of many materials may be found in the *2009 ASHRAE Handbook—Fundamentals*.

3.1.10 Managing Construction Moisture

It is important to limit the amount of wetting that wood-frame assemblies receive through the shipping, on-site storage, and construction stages, to the stage that the building is closed in or at least protected from rain. This becomes even more critical where engineered wood products such as parallel strand lumber, laminated strand lumber (LSL), laminated veneer lumber (LVL), CLT, and glulam are used because these massive wood elements may absorb and store more moisture than dimensional lumber when exposed to liquid water sources, but they tend to dry slowly. Moreover, it is difficult for highly insulated wood-frame assemblies to dry out after the insulation is installed.

Taking steps to properly protect wood during construction is important. Appropriate preventative measures should be used, such as installing temporary or permanent, horizontal, water-resistant barriers on walls and roofing/waterproofing on horizontal surfaces as soon as wood framing is built. Such measures will go a long way in reducing construction delays, and costs associated with drying out wet wood during construction in wet environments (unlike the building in this photo).

Where wood becomes wet during construction, it is important to avoid closing in assemblies at elevated moisture levels, which could create ideal conditions for mould and decay to start growing. Strategies to limit on-site wetting and built-in moisture may include:

- ordering dry wood products (such as kiln-dried lumber)
- protecting wood from rain during shipping, using covered pallets and/or covered trucks
- scheduling of material deliveries to minimize on-site storage time
- leaving the product wraps on until use
- supporting and covering stored wood products to protect them from standing water, rain, or snow
- improving construction efficiency and reducing exposure time during construction

- protection wood framing immediately after erection by use of temporary or permanent rainwater protection elements (e.g., roofing, temporary tarping, water-resistive barriers, or temporary/permanent shelters such as roofs and overhangs)
- taking into consideration the changing season (dry season) for construction (where possible)
- using preservative treatment where wetting will occur and cannot be adequately managed in a reasonable time (e.g., large, low-slope, wood-frame roofs and CLT roof panels)
- using water-repellent coatings for engineered wood products such as PSL, LVL, LSL, glulam, and CLT, etc.
- avoiding use of wood materials that swell irreversibly when exposed to moisture

Because decay is governed by moisture content, time, and temperature, the moisture tolerance of a building assembly's wood elements depends both on the assembly's tendency to absorb water and the speed at which it can dry. Impervious exterior surfaces or membranes that can reduce wetting from exterior sources may actually increase the probability of decay because they slow the drying process. An example of this phenomenon is the use of a vapour-impermeable membrane over an entire wall surface or large area at a detail such as the water-resistive barrier. While this membrane, once in service, can form part of an assembly that is arguably one of the most durable and high-performing wall assemblies, the presence of the vapour-impermeable membrane eliminates drying of the wood sheathing and framing to the exterior. Therefore, if wetting does occur during construction, it may be necessary to take precautions to encourage drying, such as ventilating to the interior prior to the installation of any interior finishes. The use of a higher permeance vapour-retarder layer that adequately controls vapour diffusion will also permit some drying to the interior once the gypsum board is installed (provided that relatively vapour-permeable interior finishes are used). Even when the use of vapour-impermeable membranes is more limited, such as restricting its use to key details, it is possible to retard drying on a localized basis to the point where an elevated moisture content persists long enough to initiate decay. The use of vapour-impermeable membranes at details should therefore be minimized, and it should be fully adhered to the wood in small areas only. In particular, applications that create a pocket restricting downward migration of moisture, such as at window head locations, should be avoided.

Excessive and improper use of vapour-impermeable, self-adhered membrane (blue) around windows and other penetrations of a wood-frame building in Climate Zone 5.

Minimal and proper use of impermeable, self-adhered membrane (blue) at window sills, with vapour-permeable membrane used at the jambs and head of the windows of a wood-frame MURB in Climate Zone 4. Window detailing is covered in further detail in Chapter 6, complete with build-slides that show sequencing of this detail.

3.1.11 Moisture Thresholds of Wood

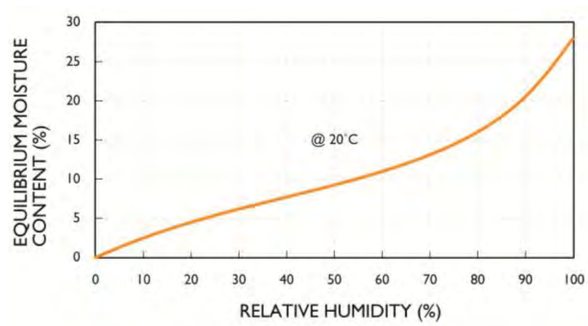
Wood-frame structures have generally withstood the test of time in all North American climates. When built properly, most of these structures remain free of decay during their service life. However, under certain conditions, decay will occur and can cause damage to the building structure. The growth of decay fungi requires suitable moisture conditions, suitable temperature, suitable food (non-durable wood), favourable competition over other microorganisms, and the presence of oxygen. Among these conditions moisture content is the most practically important. Generally, the growth and progress of decay fungi in wood requires the presence of free water inside wood. Free water is the liquid water or vapour in cell lumina and other cavities of wood. Research has shown that decay fungi can colonize kiln-dried wood products if the moisture content rises above a threshold of 26%, which can be considered as the low end of fibre saturation; it then takes months for detectable structural damage to occur under such marginal conditions. However, when there is free water readily available with moisture content ranging from 40 to 80%, strength loss can happen rapidly (in weeks). Preventing extended exposure to excessive moisture is the key to preventing decay during the service life of buildings. Compared with decay, mould growth occurs on surfaces and is more associated with the relative humidity of the environment and the surface relative humidity of building components. It does not affect wood strength. Infestation by insects may also require certain moisture conditions.

The NBC and provincial building codes in Canada state that "Moisture content of lumber shall be not more than 19% at the time of installation" for Part 9 buildings (houses and small MURBs). While this requirement is not explicitly stated for Part 3 buildings (larger MURBs), it is generally accepted as best practice.

Wood species vary widely in natural durability. Sapwood of all wood species has low natural durability. Heartwood is generally more durable than sapwood. The heartwood of SPF and hem-fir is not durable. Douglas-fir and western larch heartwood are moderately durable. The heartwoods of species such as western redcedar, California redwood (old growth), and yellow-cedar have high natural resistance to decay. When the wood is not naturally durable enough to prevent attack by decay fungi or insects in building service, it can be treated with preservatives to improve long-term durability. Wood-based composites such as plywood, OSB, PSL, LVL, LSL, glulam, and CLT have the same level of durability as the wood from which they were made, unless a preservative and/or water repellent has been added during the manufacturing process. More information related to wood durability can be found at www.durable-wood.com.

3.1.12 Controlling Wood-Frame Shrinkage

The shrinkage of wood framing needs to be considered in the design of building-enclosure assemblies. Wood shrinkage becomes more apparent and critical in taller wood-frame buildings due to the potential shrinkage amounts being greater. Wood shrinkage occurs because, over time, framed lumber generally attains a lower moisture content than it had at the time of construction. The moisture content at the time of construction will generally <20%, however could be >30% if it is wetted by rainfall while being built or if it was initially wet. In-service, seasonal, moisture contents between 5 and 20% may be expected depending on the climate and equilibrium RH at the wood component. Wood therefore shrinks after initial construction is completed and then shrinks and expands in service depending on the seasonal RH. Plywood and other engineered wood products generally have a lower moisture content at the time of manufacture, so initially they may gain moisture from construction.



Generic Sorption Isotherm for Wood - The moisture content of wood (if absent from wetting caused by liquid water) mostly depends on the RH in the surrounding environment. This can range from 10 to 20% indoors during the winter in cold climates or during the summer in dry climates, and up to 80 to 95% in wet and humid climates.

When moisture-content changes occur in wood, differential movement will occur when the wood is used in combination with other materials such as steel, concrete, and masonry, or with wood that has varying amounts of cross grain wood in the load path.

Shrinkage across the width and thickness (tangentially and radially across the grain) of lumber is expected, while longitudinal shrinkage is negligible. Light, wood-frame, platform construction practices are susceptible to shrinkage of solid wood elements, i.e., primarily those located at the floor levels (floor joists, headers, sill and top plates). In a structure of several storeys, each of the wall plates and joists will contribute to an overall shrinkage that can be significant. For most S-DRY softwood lumber, average shrinkage is 0.25% for each 1% drop in moisture content. Differential movement can create severe problems for connections, plumbing stacks, elevator shafts, and other services that are relatively rigid. Good design of these systems, and of their interface with the wood-frame structure, are necessary to ensure that the movement can be accommodated.

The use of engineered floor joists and LVL/LSL headers reduce shrinkage at floor levels. Likewise, balloon framing practices or use of mass timber (CLT, LVL/LSL) also reduce shrinkage.

Portions of the structure supported on masonry or steel will remain at a constant elevation while portions supported solely on wood-bearing walls will drop due to wood shrinkage. A floor supported by masonry or steel at one end and a wood-bearing wall on the other end, and level at the time of construction, may eventually slope significantly.

Even within the wood structural assembly, care is necessary to minimize differential movement. For example, differential shrinkage may be noticeable across floors that are supported at one end on conventional platform framed walls (studs with plates and bearing joists) and at the other end on wood columns.

Whenever adjacent load paths are comprised of wood having different combinations of shrinkage properties, differential shrinkage may result. Attention should be paid to shrinkage differences due to mixes in the amounts of wood loaded parallel and perpendicular to the grain, and mixes of dimensional lumber and engineered wood products. In addition, differential shrinkage may be experienced when the materials have varying moisture contents at the time of installation.

3.2 Controlling Heat Flow and Insulation

Of all the energy used in North America it is estimated that 30 to 40% is consumed within buildings. In both single-family and multi-family residential buildings, the largest component of this energy consumption is space-conditioning (heating in the north and cooling in the south) which typically accounts for 30 to 60% of a building's total energy consumption. Therefore, buildings play a critical role as part of global initiatives and programs for conserving energy and reducing greenhouse gas emissions.

Reducing space-heating energy use is a primary function of the building enclosure. While heat flow through the building enclosure cannot be prevented, it can be controlled in order to reduce the total energy consumption and improve comfort. This is achieved by constructing a thermally insulated and airtight building enclosure, which is a fundamental strategy towards achieving an energy-efficient building, and of course in being a code-compliant building.

3.2.1 Mechanisms of Heat Flow

There are three principal mechanisms of heat transfer through the materials, components, and assemblies that make up the building enclosure: conduction, radiation, and convection. The control of all three mechanisms is critical in thermally efficient building-enclosure assemblies.

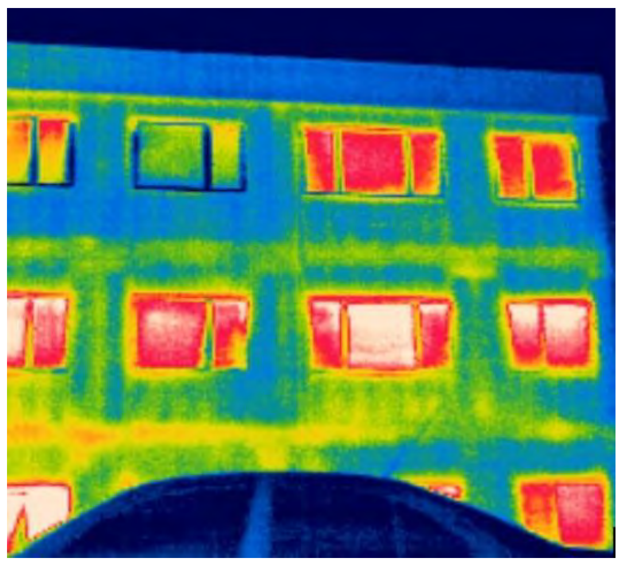
Conduction

Conduction is the transfer of energy at the molecular level through a material, or between materials that are in direct contact. The rate of energy flow depends on the conductivity (k) of the material. The term conductance (C) is simply the conductivity divided by the thickness of the material. The inverse of a material's conductance is its thermal resistance or R-value (IP), or RSI-value (metric). Thermal properties for materials are provided by numerous sources including the 2009 *ASHRAE Handbook - Fundamentals*, and are available directly from product manufacturers.

A range of low-conductivity materials are commonly used as thermal insulation. Resistance values (inverse of conductivity) typically range from R-3 to R-6/inch (RSI-0.52 to 1.0/25.4 mm). Structural low-conductivity materials such as wood, fibreglass, and plastics are also relatively poor conductors of heat. However, when placed within thermal insulation layers they do result in some thermal bridging (for example, wood studs within an insulated wall).

Structural high-conductivity materials such as steel, aluminum, or even concrete readily conduct heat and act as large thermal bridges within buildings. Buildings constructed of steel and concrete typically have greater degrees of thermal bridging than wood-frame construction, making wood-frame buildings generally more thermally efficient.

Reducing the number of thermal bridges through building insulation, by design and detailing, and by material and assembly choice, is essential if a building is to have good thermal performance. In wood-frame buildings this typically means the optimization of structural framing and cladding attachments and the use of continuous insulation layers.



Infrared image of an older wood-frame MURB showing thermal bridging through the framing and more predominantly through the window frames and glazing. While thermally efficient wall and roof assemblies are important in achieving an energy-efficient building—windows and consideration for whole-building heat loss are also critical factors. The impacts and thermal balance of walls, windows, and roof enclosures are covered in this chapter.

Radiation

Radiation is the transfer of energy through a gas or a vacuum, in the form of electromagnetic waves. It is the process where a hot surface radiates heat to a colder surface and requires a clear line of sight between the surfaces involved. Both the temperature of the two surfaces and the emissivity of the materials affect the amount of heat loss.

Unlike conduction or convection, it does not depend on an intermediate material as a carrier of energy. Within building assemblies, radiation occurs across the open airspaces within walls and attics, and across the air within sealed insulating glass units.

Night-sky cooling is the process by which warmer objects radiate heat to the cold clear sky, thus lowering the surface temperature and resulting in condensation (dew) or frost on exposed surfaces including roofs and walls.

Convection

Convection is the transfer of energy by the movement of a fluid such as air. Convective heat transfer for building enclosures has two primary mechanisms; convective flow of air within assemblies or spaces, and convective flow through assemblies from interior to exterior or exterior to interior. This latter form of convection is generally referred to as air leakage.

Convection within the airspaces of enclosure assemblies can reduce the effectiveness of low-density insulation by movement of air (i.e., convective loops between hot and cold surfaces). Convection currents can be resisted by installing insulation to completely fill cavities and be in intimate contact with the air barrier.

Convection due to air movement through assemblies, or air leakage, is a significant portion of the heat loss in a building. Depending on the airtightness of a building, up to 50% of the total heat loss could occur by air leakage. Airtight building-enclosure assemblies, components, and details are used to control convection in energy-efficient wood-frame buildings.

3.2.2 Controlling Heat Flow

The control of heat flow for the building enclosures of multi-unit wood-frame buildings incorporates three primary components:

- Use of the site, features of the building, and glazing properties to optimize the effects of solar radiation.
- Minimizing conductive losses through the opaque wall areas through the use of insulating materials, the avoidance of thermal bridging, and the use of thermally efficient window frames and glazing.
- Limiting unintentional air flow through the elements of the building enclosure by the construction of airtight assemblies.

Solar Control

Solar radiation delivers significant radiant heat energy to surfaces of the building enclosure. Heating of the opaque portion of the enclosure can increase surface temperatures considerably, with associated increases in the cooling loads and/or contributions to the thermal-comfort problems within the building. The glazing in windows can allow a large portion of this energy to pass into the building. While this heat gain can help to offset heating loads in the building, it can also lead to overheating and increased cooling loads. The control of solar radiation is a balance between these benefits and detriments.

Exterior shading, either by features of the building or from adjacent plants, can limit solar gains. Interior shading for windows is generally not effective at limiting solar heat gain. With appropriate design, shading can take advantage of the gains during the cooler times of the year and limit gains during the warmer times of the year.

Windows play a significant role in solar control. The solar heat gain coefficient of the glazing, window U-value, thermal mass, climate, and orientation all factor into effective strategies. Guidance on passive solar control strategies for large buildings including MURBs is beyond the scope of this guide, but can be found in numerous architectural textbooks and such publications as the City of Vancouver's Passive Design Toolkit (2009).

Minimizing Conductive Losses

The thermal resistance, or effective insulating value, of building-enclosure assemblies and components determines the magnitude of the conductive heat loss. All enclosure assemblies should be designed to maximize thermal resistance (within practical limits) and minimize thermal bridging. As discussed in Chapter 2, a thermal bridge is a building component with a high thermal conductivity that cuts through the insulation in an assembly. Common thermal bridges include studs and cladding supports, wood floors, balconies, fasteners, concrete slabs, and window frames. Energy standards and codes such as ASHRAE and the NECB require these thermal bridges to be accounted for in the code compliance of wood-frame MURBs.

It is important to remember that thermal bridging can result in greater potential for condensation (because of reduced interior surface temperatures), in addition to decreases in the effective R-value of the insulation. The location of the insulation relative to materials with varying vapour permeability will affect the condensation potential within the wall assembly. Controlling vapour flow and maintaining temperature of surfaces above the dew point temperature in order to limit condensation is a primary function of the building enclosure.

Framing factor refers to the percentage of the wall that is comprised of wood framing members. The framing factor for a specific portion of the building enclosure can be calculated by determining the area of framing relative to insulation. Traditional framing for walls (including plates, sills and headers, and corners) have a framing factor of approximately 25% with studs at 16 inches o.c., or 22% for studs at 24 inches o.c. Framing factors for advanced framing walls can be as low as 16%; however, the use of advanced framing may be limited in taller MURBs and in high seismic zones. Framing factors in excess of 30% have been observed in 6-storey MURBs, because exterior walls of lower floors often require greater amounts of framing for gravity, wind, and seismic loads.

With 5- and 6-storey wood-frame MURBs now being built, their greater height creates a need for more structural framing, particularly at the lower floor levels. The use of stud packs of built-up 2x6 or larger 4x6 stud/columns may be utilized to meet seismic and gravity load-carrying requirements. In these larger buildings, framing factors of 40% or higher are possible, which reduces the maximum potential R-value. In many of these walls, the use of exterior-insulated assemblies may be more efficient than insulating what is left of the stud cavity.

Minimizing Air Leakage

The control of airflow in MURBs was previously covered in this chapter in relation to moisture, but it is as important for heat flow control. Materials and strategies used to provide for a continuous air-barrier system are covered in Chapter 5.

3.2.3 Thermal Insulation Strategies and Materials

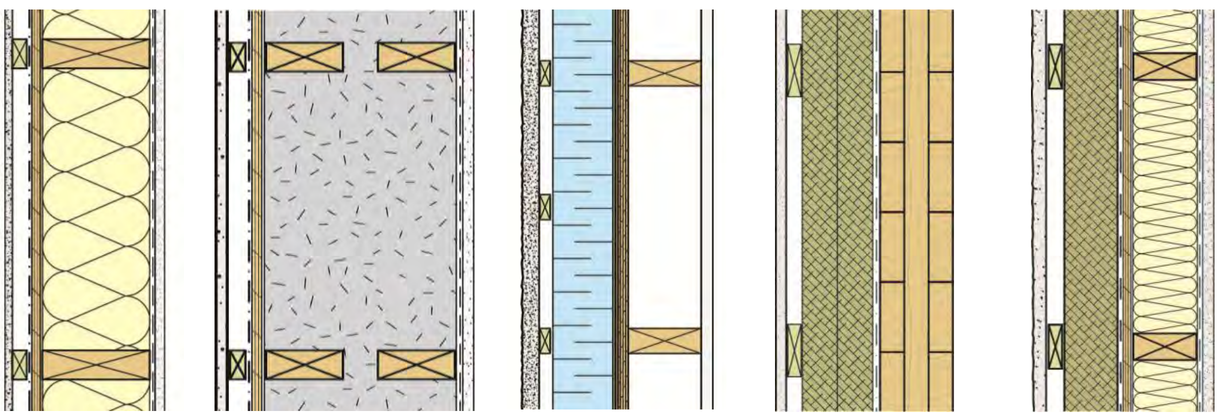
The primary means of controlling heat flow from building enclosures is to use insulation materials. The major energy conservation-related regulations target greater thermal insulation levels in building enclosures as being the key remedy for achieving the energy efficiency of buildings. In order to achieve effective heat flow control, the continuity of thermal insulation should be maintained through assemblies, and details should be provided to reduce thermal bridging. The use of thermal insulation must also be considered, together with the airtightness as well as the vapour permeability of various materials in the assemblies, in order to achieve effective thermal efficiency and good durability performance.

The insulated wall and roof assemblies shown in this guide have insulation placed at several alternative locations within the assembly (Fig. 3.2.1, Fig. 3.2.2, and Fig. 3.2.3 show insulation placement within wall assemblies, below-grade wall assemblies, and roof assemblies). The location of the insulation has been used as a differentiator for these assemblies as follows:

Interior Insulated: Insulating layer is located to the interior side of the water-resistive barrier. For walls, this typically means that the insulation is located within the stud space. For roofs, the interior insulation may be located above the sheathing but under the roof membrane, or alternatively below the sheathing within the roof framing—both are considered to be 'interior insulated'.

Exterior-insulated: Insulating layer is located to the exterior of the water-resistive barrier, i.e., the likely wet zone. For walls, this means that the insulation is located within the drained cavity space, while for roofs it means that the insulation is located above the membrane (i.e., an inverted roof or protected membrane assembly). For mass timber such as CLT walls, this is the preferred insulation strategy to protect the wood from moisture accumulation. Exterior insulation materials must be resistant to the effects of moisture.

Split Insulation: More than one insulating layer is provided, typically with one layer to the interior and one layer to the exterior of the water-resistive barrier. The selection of appropriate insulation in split-insulation assemblies is covered in further detail in Chapter 4.



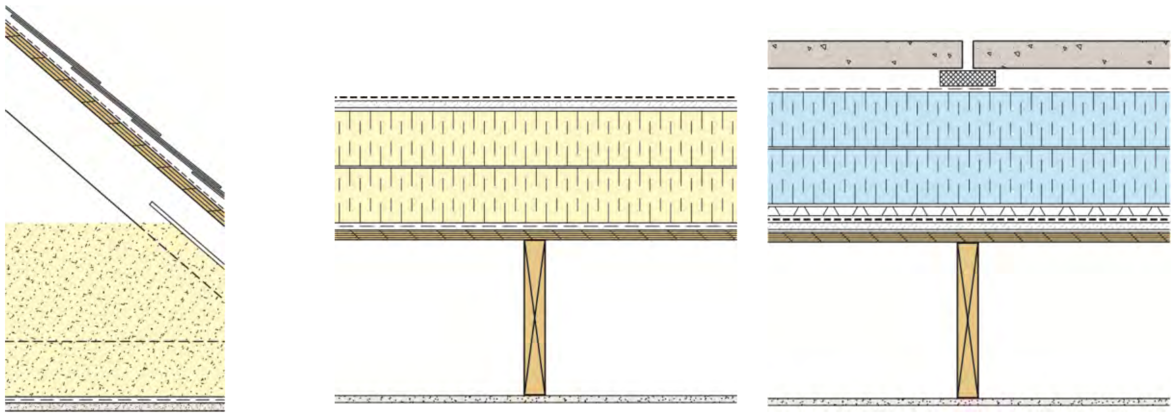
2x6 stud wall | **Double-stud wall** | **2x4 (or 2x6) stud wall** | **CLT/mass timber** | **2x4 (or 2x6) stud wall**

Interior-insulated wall assemblies | **Exterior-insulated wall assemblies** | **Split-insulated wall assembly**

Fig. 3.2.1 Options for placement of insulation within thermally efficient above-grade wood-frame wall assemblies.

Interior-insulated wall | **Exterior-insulated wall** | **Interior- and exterior-insulated wall**

Fig. 3.2.2 Options for placement of insulation within thermally efficient below-grade wood-frame wall assemblies.



Interior-insulated pitched roof **Low-slope roof: conventionally insulated** **Low-slope roof: inverted**

Fig. 3.2.3 Options for placement of insulation within selected thermally efficient roof and roof deck assemblies.

The primary means of controlling heat flow from wood-frame buildings has historically been to place fibreglass batt insulation within stud cavities and attics. In some cases rigid and semi-rigid insulation boards are placed just to the exterior of the sheathing (exterior-insulated), or both are placed in the stud cavity and to the exterior of the sheathing (split insulation). Rigid insulation boards are also used below grade and in roofing applications. The use of spray-in-place polyurethane foams (both ½ pcf and 2 pcf) has also become more common in construction during the past decade.

The selection of insulation type is based on a variety of factors including cost, availability, thermal performance, moisture retention and transmission performance, fire, and acoustics. There are numerous types of insulation and manufacturers to choose from. Each manufacturer will be able to provide technical data for their proprietary formulation, density, thermal performance, and insulation installation.

Fibreglass is the most common insulating material, with several large manufactures in North America. Because of code requirements and variations in fibre density, it is common to see 3½-inch fibreglass batts sold with R-values ranging from R-12 (RSI-2.1) through R-15 (RSI-2.6), and 5½-inch fibreglass batts ranging from R-19 (RSI-3.3) through R-24 (RSI-4.2). Loose-fill and batt insulation must be installed at the manufacturer's recommended thickness and must not be compressed if they are to retain the published R-values.

Table 3.2.1 provides a list of the most commonly used insulation types in wood-frame construction, including a range of typical R-values along with vapour and air permeability (from low to high). Those products that have low vapour permeability can be considered vapour barriers in typical thicknesses, and those with low air permeability can be considered suitable as an air-barrier material.

For foamed insulation products such as polyisocyanurate (Polyiso), polystyrene, or polyurethane spray foam, only the aged long-term thermal resistance, LTTR (per Standard CAN/ULC S770) values should be used for making energy calculations of buildings. Initial insulation R-values will typically be higher and are advertised up to R-7.5/inch (RSI-1.3/25.4 mm), but these will degrade over the first few years after installation as blowing gases escape from the foam.

Table 3.2.1 Typical types of insulation products: R-value range, vapour permeability, and air permeability.

Insulation type	Typical use	R-value/inch [R-value (RSI)]	Vapour Permeability	Air Permeability
Fibreglass				
Batts	Stud cavities, between attic trusses	R-3.0 to 4.2 (0.53 to 0.75)	High	High
Blown fibres	Blown into stud cavities, attic loose-fill	R-2.5 to 3.7 (0.44 to 0.65)	High	High
Dense pack	Sprayed into stud cavities	R-3.5 to 4.0 (0.62 to 0.70)	High	High
Semi-rigid board	Exterior cavities exposed to dampness, window spandrel panels	R-3.5 to 4.2 (0.62 to 0.75)	High	High
Mineral or rock fibre				
Batts	Stud cavities	R-3.0 to 4.2 (0.53 to 0.75)	High	High
Rigid and semi-rigid board	Exterior cavities exposed to dampness, window spandrel panels, fire-stopping	R-3.5 to 4.3 (0.62 to 0.76)	High	High
Cellulose				
Blown fibres	Stud cavities, attic loose-fill	R-3.0 to 3.8 (0.53 to 0.67)	High	High
Dense pack	Sprayed into stud cavities	R-3.5 to R-3.8 (0.62 to 0.67)	High	Medium
Extruded polystyrene (XPS): rigid board	Sheathing, roofing (where exposed to water), below grade, below slab, cavities exposed to dampness	R-5.0 to 5.6 - R-5.0 typical (0.88 to 1.0)	Low	Low
Expanded polystyrene (EPS): rigid board	Sheathing, roofing (where protected from water), below grade, cavities, EIFS, insulated concrete forms (ICFs)	R-3.7 to 4.3 (0.65 to 0.76)	Low	Low
Polyisocyanurate: rigid board, foil, or fibreglass faced	Roofing, sheathing, and wall cavities (where protected from water)	R-5.0 to 6.0 aged (0.88 to 1.06)	Low	Low
Spray polyurethane foam				
½-pound, low-density, open-cell	Stud cavities, attics below sheathing	R-3.6 to 3.8 (0.63 to 0.67)	High	Low
2-pound, high-density, closed-cell	Exterior of sheathing, attics below sheathing, below-grade, air ceiling floor/roof joists ,and other difficult-to-insulate/seal locations	R-5.0 to 6.0 aged (0.88 to 1.06)	Low	Low

3.2.4 Impacts of Thermal Bridging Caused by Framing

As described in Chapter 2, it is becoming common to use effective R-values to rate thermal performance by taking into consideration thermal bridging, and some building codes provide detailed requirements for calculating effective R-values. The effective R-values for insulated wood-frame wall and roof assemblies can be determined by a number of methods including simple manual calculations (i.e., the isothermal planes method or the parallel path method), use of 2D and 3D thermal simulation, or laboratory testing using a guarded hot box. Basic manual calculations can be adequate for simple assemblies where thermal bridging is minimal (e.g., exterior-insulated roofs and wood-stud assemblies).

Measured R-values from guarded hot-box measurements have only been performed for a limited number of wood-frame assemblies and in research applications. While these data are useful for calibrating 2D and 3D thermal models (e.g., THERM and HEAT3), there has not been enough testing performed to assess all possible insulation and framing configurations. The use of computer simulations to assess effective R-values of wood-frame assemblies and details is relatively straightforward. Wood-frame models tend to be relatively easy to set up and require little calibration for contact resistances and material properties, which tends to be necessary for steel-frame assemblies and connections. Computer simulations also make it convenient to make assessments of the thermal impacts of discrete fasteners and various cladding attachments that are not possible using manual calculation methods, although this may not be required by all energy and/or building codes.

Construction of a 6-storey MURB with non-combustible gypsum sheathing. Framing factors at lower floors are higher than at upper floors in order to accommodate structural loads. The effective R-value of these walls will be affected by this wood-framing factor and the chosen insulation strategy.

Published R-value tables within ASHRAE Standard 90.1 and guarded hot-box data for standard wood-frame wall assemblies provide a source of useful, effective insulation data for which 2D and 3D thermal models can be checked and calibrated against. Effective R-values for each of the assemblies presented within this guide have been calculated using 3D thermal-simulation software (HEAT 3) based on models calibrated to ASHRAE Standard 90.1's published wood-frame data or on Oak Ridge National Laboratory and other's published results of guarded hot-box testing.

Compared with concrete and steel, wood-based building-enclosure systems have very low thermal bridging; however, the studs and built-up wood framing elements around windows and at corners in assemblies still cause a considerable amount of thermal bridging compared with insulation materials. In taller MURBs, the use of heavy timber columns and built-up stud packs within walls also results in greater thermal bridging, which affects overall R-values and the ability for some assemblies to meet code compliance. For example, the difference in effective R-value for a 2x6 wall with R-22 insulation between a 25% framing factor and a 35% framing factor is R-1.8, which is a reduction from R-16.3 to R-14.5, or 10.9%. R-1.8 may not seem that large; however, in many jurisdictions, the minimum prescriptive R-value within ASHRAE Standard 90.1 for a wood-frame assembly in some climate zones is R-15.6, meaning that the assembly with a 35% framing factor wall may require additional exterior insulation. Confirming or correcting an energy analysis to account or the actual framing factor in construction is the responsibility of the registered professional signing off on the energy code compliance.

Two examples are presented to demonstrate the effect of framing factor on effective R-values of insulated wood-frame wall assemblies. In the first example (Figure 3.2.4) the impact of framing factor on insulated 2x4 and 2x6 frame walls is demonstrated in a plot, which compares framing factor with nominal stud insulation R-value. The framing factor has a fairly large impact on the effective R-values of wood-frame assemblies. Comparing the nominal assembly R-value (accounting for insulation, other materials, and air films) with no framing (a framing factor of 0%) to a framing factor of 25% reveals a thermal reduction of between 26% for R-12 batts and up to 33% for R-22 batts is shown. Likewise, the improvements that can be made as a result of switching from conventional framing practices (typically with a framing factor of 25%) to advanced framing techniques (i.e., as low as a 16% framing factor) can improve the effective R-value over standard framing by 9 to 11%. Efforts are required to ensure the structural performance when advanced framing is used, particularly for MURBs. More information about advanced wood framing can be found in the *Advanced Framing Construction Guide* (APA the Engineered Wood Association 2012). One way of offsetting part of the thermal losses from walls with higher framing factors is to use higher R-value insulation. For example, an effective R-11 requirement can be met by using R-12 batts within a wall with a framing factor of 20%, or R-14 batts within a wall with a framing factor of 26%.

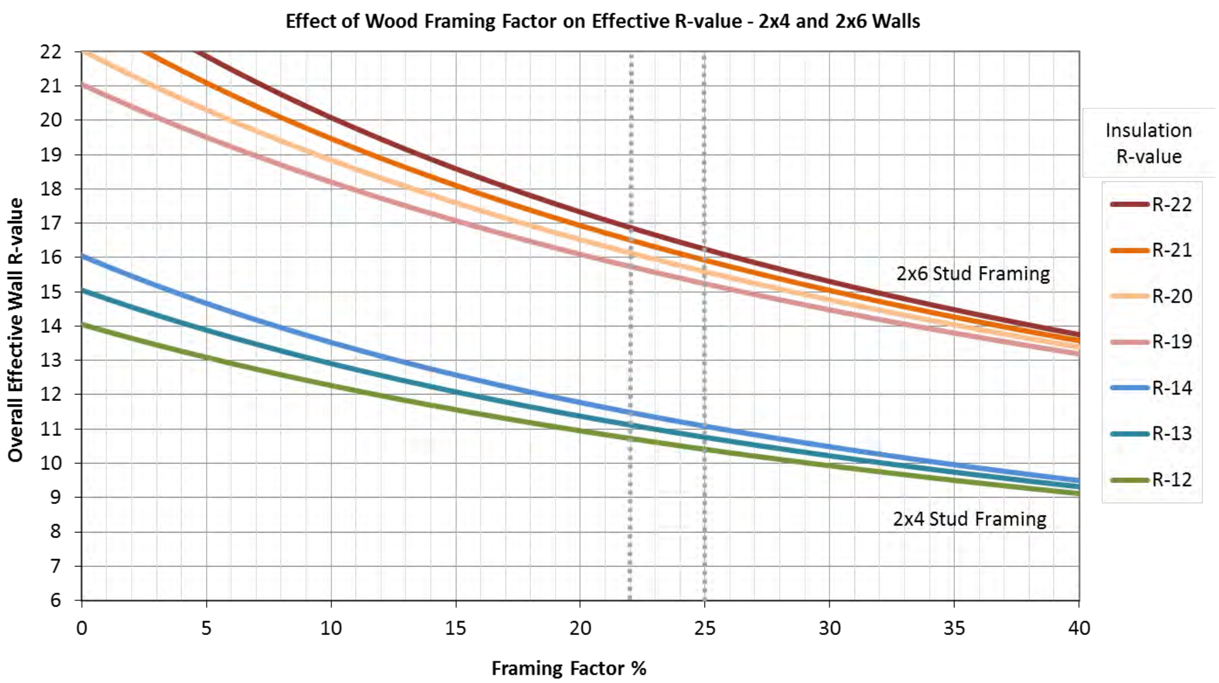


Fig. 3.2.4 Impacts of framing factor on a wall's overall effective R-value, for 2x4 and 2x6 wood-frame walls with batt insulation.

In the second example (Figure 3.2.5), the impact of the framing factor on a more highly insulated split-insulation wall (R-14 batts with exterior insulation from R-4 to R-12) is demonstrated. The framing factor affects only the R-14 stud insulation, and the exterior insulation is added incrementally to this value. The effective exterior insulation R-4 in the plot accounts for the cladding attachment (i.e., R-5 nominal insulation reduced here by 20% to account for metal clips). This exterior insulation reduction depends on the cladding-attachment strategy and is often determined by thermal modelling. Some energy codes do not always require this reduction to be included in energy code compliance (assuming some level of reduction); however, when assessing actual heat loss and sizing mechanical equipment, it is an important aspect to consider.

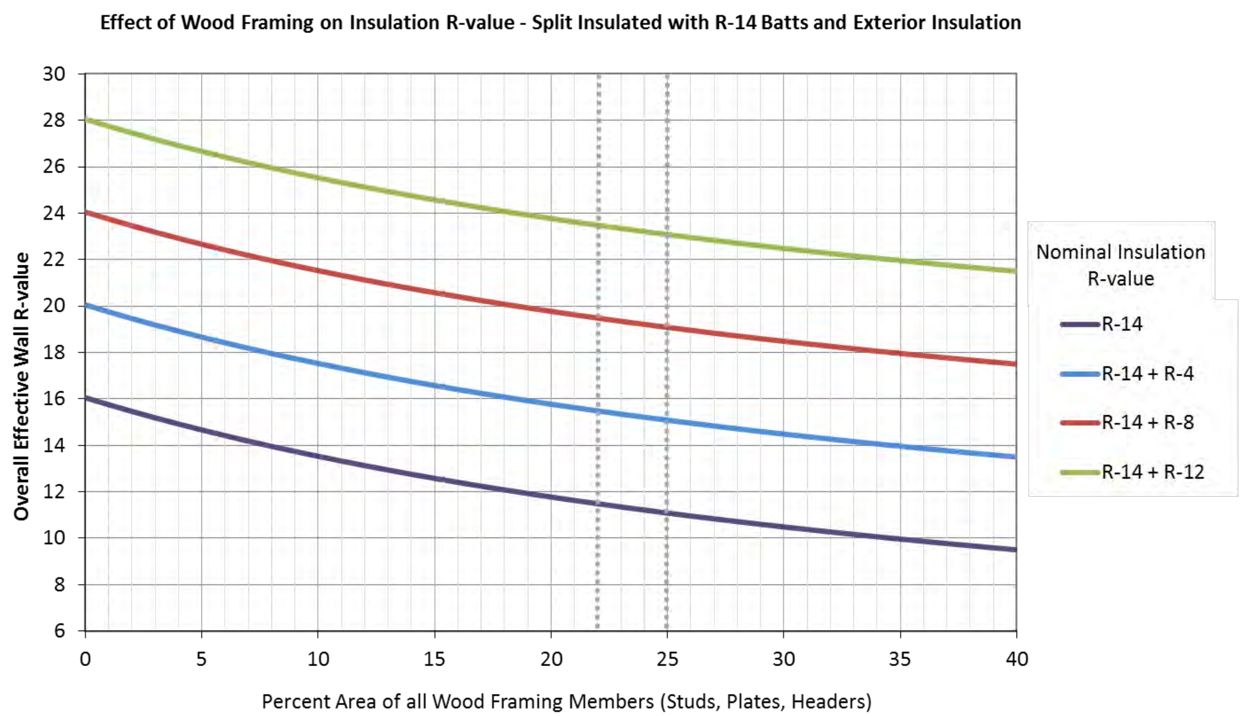
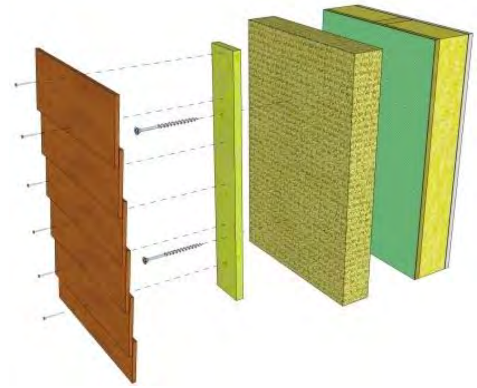


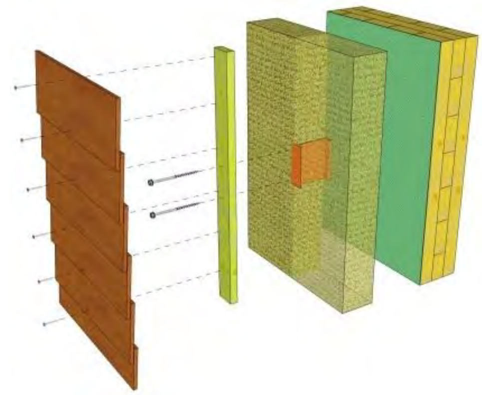
Fig. 3.2.5 Impacts of framing factor on a wall's overall effective R-value, for a split-insulation 2x4 wall with R-14 batts and exterior insulation (R-4 to R-12).

3.2.5 Thermally Efficient Cladding-Attachment Strategies, through the Exterior Insulation

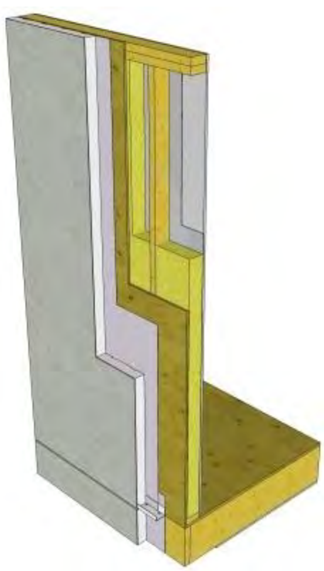
The cladding attachment can be a source of significant thermal bridging in exterior and split-insulation wood-frame wall assemblies. Optimizing structural cladding attachments is important for improving the thermal efficiency of wall assemblies, while minimizing exterior insulation and overall wall thicknesses. It is also critically important to adequately consider the gravity and wind and seismic loads so that the claddings will perform in service without deflecting excessively, cracking, or detaching from the structure. Many strategies, products, and techniques, some of which have proved to work structurally and thermally, have been developed over the years to meet this challenge.



Long screws through rigid mineral-fibre insulation attach vertical strapping to the load-bearing wall. Cladding is attached to the vertical strapping, thereby transferring loads back to the structure. Structural loads and deflection are not a concern with most lightweight claddings, and can be accommodated for heavier claddings such as stucco and stone veneer. In cases where loads or deflection are a concern, alternative low-conductivity, cladding-support systems can be used, such as the fibreglass clips shown below.



The following cladding-attachment strategies are covered here in the context of thermal performance. Structural guidance can be provided from product manufacturers' test data (e.g., for brick ties and thermal spacers), or by applying fundamental structural analysis (e.g., for long screws or continuous framing elements). While the minimization of thermal bridging is a key strategy in a thermally efficient assembly, the selection of the best cladding-attachment strategy for an exterior or split-insulation wood-frame wall will depend on a number of other factors. Not all options presented here are suitable for all cladding types and loads.



EIFS (exterior insulated finish system) is an exterior insulated or split insulated system with continuous expanded polystyrene insulation, which is glued or mechanically fastened to the substrate.

Structural Adhesives: EIFS

Structural adhesives used to attach insulated cladding systems such as EIFS to wood-frame walls result in almost no thermal bridging (except at metal flashings and open insulation joints). Insulated metal panels can also be attached using adhesives in a similar manner. Adhesive requirements are provided by product manufacturers. In some applications, intermittent mechanical fasteners may also be required.

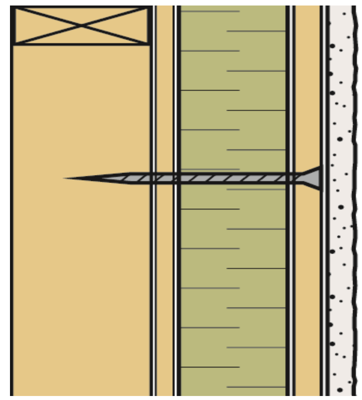
Adhered insulation claddings are common for some building types, and are often used on MURBs. Aside from the limited aesthetic options, there have been severe moisture-control issues, resulting mainly from a reliance on using a face seal approach as a strategy for water penetration control. Many building-enclosure failures have been attributed to failed EIFS joints and details. As a result, drained and vented EIFS and metal panel products are available with improved water-shedding characteristics (drained and vented rainscreen type assemblies) that are more suitable for wet climate zones. In these applications, however, the thermal performance may be slightly degraded by the exterior vented airspace behind the insulation in the drainage and vent space. Research is underway to determine the effective thermal reduction from this vented airspace behind insulated claddings.

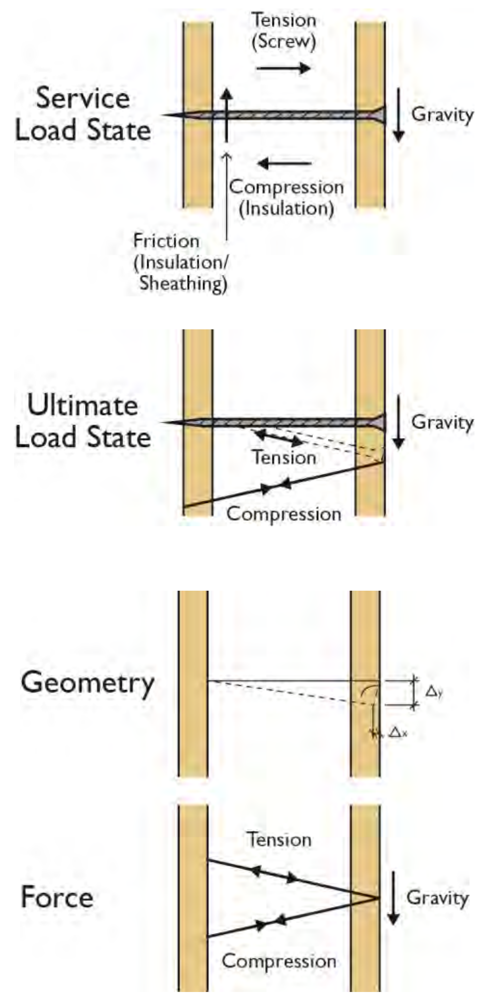
Long Screws through Exterior Insulation

Attaching different cladding types through rigid exterior insulation can be performed by attaching a rigid fastening base on the exterior of the insulation so that long fasteners are not required for each piece of cladding. The use of vertical strapping (i.e., 1x3 and 1x4), screwed directly through the insulation with long screws spaced as required (often every 12 to 24 inches), provides this cladding with structural support and a fastening base. The vertical strapping also creates a drainage space, capillary break, and ventilation cavity (i.e., rainscreen) between the cladding and exterior insulation. This is an effective moisture-management strategy in wet climate zones and also serves to improve the durability of the cladding. This is also the most thermally efficient cladding-attachment strategy presented here and it can support the widest range of cladding options. Thermal reductions for screws through the insulation in wood framing are generally in the order of 5%. Three-dimensional thermal modelling can be used to simulate the impact of discrete fasteners on exterior-insulated effective R-values where needed.

The structural system of screws through insulation relies on compression of the vertical strapping against the insulation, and the creation of a structural truss that accommodates loads and deflection. In addition, friction between the insulation and the sheathed wall—created by the normal force applied by tension in the screws when drilled into the sheathing or studs—provides additional support in the service load state. Screws drilled upwards at a slight angle through the insulation create this truss without the initial deflection, in order to reduce deflection and increase the strength of the system (screw is in tension instead of bending). Insulation deemed rigid enough to be used in this manner includes XPS, EPS, Polyiso, rigid mineral fibre (>8 pcf), and some rigid fibreglass products. Lower density rigid and semi-rigid mineral or glass fibre may not be rigid enough and would compress excessively under the vertical strapping. This structural system does not work if vertical strapping is not provided (i.e., attaching cladding with long fasteners through the insulation). Upwardly drilled screws may also prevent moisture from migrating through the insulation to the sheathing.

This is a relatively new method of cladding attachment, driven by exterior-insulated assemblies. Therefore, the design communities do not necessarily have a good understanding of it yet, and there

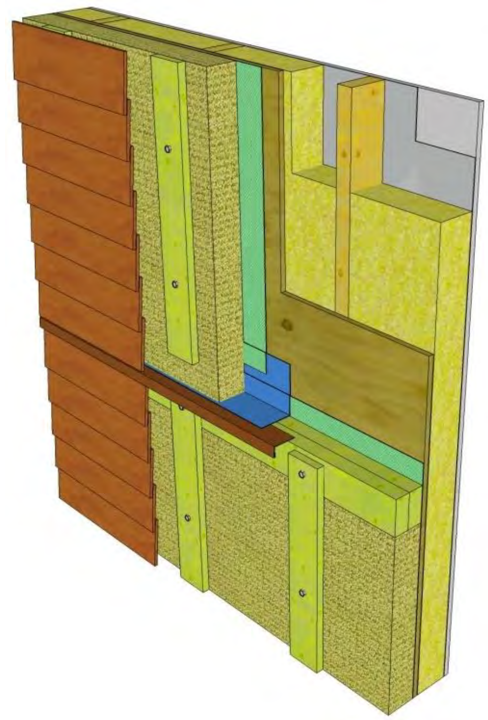




Service load state and ultimate load state: structural analogy used to assess the support of cladding attached to vertical strapping that is attached through exterior insulation.

may still be hesitation about using this strategy. Testing has been performed by several research organizations and manufacturers, and this thermally efficient cladding-attachment technique has been used successfully in many buildings across North America. The following is a list of recent publications on the topic of fastening through exterior insulation:

- *REMOTE, A Manual* (Cold Climate Housing Research Center in Alaska, revised 2009) provides guidance on attaching thick exterior insulation (6 to 12 inches of EPS) using long screws. See cchrc.org/docs/best_practices/REMOTE_Manual.pdf.
- Foam Sheathing Coalition – Deflection and load testing of siding through various foam insulation products as insulated sheathing (2010). foamsheathing.org/tech_info.php
- *Roxul – ComfortBoard Insulating Sheathing (IS) Deflection Testing* (Building Science Consulting Inc. 2011). See roxul.com/residential/products/roxul+comfortboard+is



Continuous wood framing (using preservative treated wood in wet climates) can be added as a shear block to provide additional strength to the screws through insulation cladding attachment method. The wood framing is cut to depth of the insulation and is used to effectively hang the strapping from the top, with the lower fasteners providing lateral support. Screws are still installed through the insulation, but the shear blocking carries a significant portion of the load and limits deflection. Some thermal bridging results through the wood framing however can be accommodated in the design. The blocking is placed at the cross cavity flashing location, so that lower conductivity self-adhered membrane flashing can be used instead of conductive aluminum or steel, thereby improving overall thermal performance.

Testing has shown that common residential claddings, including vinyl siding (<1 lb/ft^2), wood siding (<1.5 lbs/ft^2), and even heavier fibre cement and panelized claddings (4 to 5 lbs/ft^2), can be easily attached using this method with any type of foam insulation such as EPS, XPS and Polyiso, and rigid mineral fibre. Stucco cladding (10 to 15 lbs/ft^2) and adhered stone veneers/cultured stone (17 to 25 lbs/ft^2) can also be effectively attached using this method, provided that any long-term deflections from these large claddings are accommodated in the design.

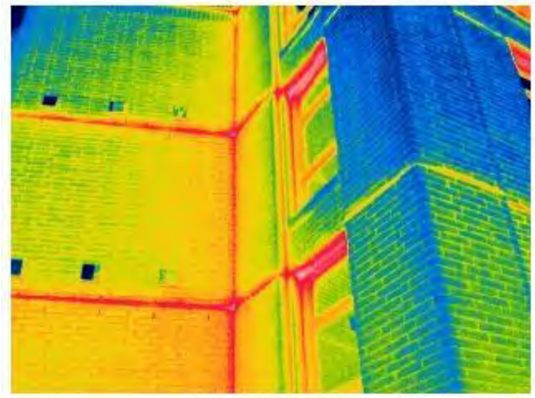
Some designers using this approach may opt for the use of shear blocking installed at the top of the strapping by means of the exterior-insulated cladding-attachment method. The shear blocking carries the majority of the load and can limit deflection with some heavier claddings such as thick stucco or adhered stone veneer.

Metal Clips

The structural attachment of heavier claddings (e.g., stone panels) and some proprietary cladding-attachment systems use intermittent metal clips (e.g., L-brackets, C-channels, Z-girts etc.) and exterior vertical girts to support claddings in wood-frame MURBs. Cladding is attached to vertical or horizontal girts that are attached to the metal clips which in turn are then attached to the studs in the backup wall. The clips are designed based on structural requirements for the cladding. The thermal reduction of the insulation will depend on the clip gauge, length, spacing, and even the type of metal used (i.e., galvanized versus stainless). A reduction in thermal insulation of between 15 to 25% can be expected for lightly to heavily spaced metal clips, which may require greater thicknesses of exterior insulation to reach project R-value targets. Three-dimensional thermal modelling can be used to simulate the impact of metal clips on the effective R-values of exterior insulation where needed.

Masonry Ties and Shelf Angles

Brick masonry cladding in wood-frame construction is typically supported at floor level using steel shelf angles, and at grade on brick ledges or shelf angles attached to the foundation. Brick ties are used for lateral load provisions throughout the wall area and are typically spaced no more than 24x16 inches. These brick ties result in some loss in effective R-value of the exterior insulation, typically in the order of 10 to 20% attached to wood framing, depending on spacing, gauge, and metal type; however, these are not the largest sources of heat loss and thermal bridging in exterior-insulated masonry walls. The metal shelf angles at each floor typically result in the greatest amount of thermal bridging and can reduce effective R-values of exterior-insulated assemblies in the order of 30% to greater than 50%.



Infrared image of brick masonry cladding showing heat loss at non-thermally broken shelf angles. This heat loss can degrade the thermal performance of the exterior insulation within entire wall assembly by 30 to greater than 50%

Strategies in concrete- and steel-framed buildings address this issue by thermally isolating the shelf angle from the backup wall with intermittent standoff supports (such as clips, plates, or proprietary systems), which are welded or bolted to the edge of the concrete or steel floor. In wood-frame construction this becomes more complicated as the floor framing and joist header/blocking are not able to support discrete load at each standoff. In wood-framed buildings, it is more common to support the brick at grade on the foundation (using either corbels or shelf angles) and provide only lateral load resistance using brick ties up to the height of the building (up to 4 to 6 storeys, depending on local structural requirements). This approach, however, requires special consideration for differential movement of the wood frames compared to the masonry, and can become difficult to achieve effectively in taller wood-frame buildings. Of course, brick shelf angles could still be bolted to the wood-frame without standoff supports for stud insulated assemblies or in split-insulation walls, which would however de-rate the exterior insulation significantly.

Intermittent Thermal Spacers

To attach cladding to vertical girts outside of the exterior insulation, low-conductivity spacers in conjunction with long screws can be used as a more thermally efficient strategy than using intermittent metal clips as rigid connections. There are various clip/spacer arrangements to distribute the gravity, lateral, and wind loads to the underlying structure using spacers with screws capable of handling all range of claddings. The use of low-conductivity materials, such as proprietary fibreglass spacers or wood blocks and screws, results in thermally efficient exterior insulation R-values. Reductions in effective R-value for the exterior insulation in the range of 5 to 15% with this type of cladding-attachment strategy are typical, but are only slightly higher than the values for just the screws through the exterior insulation. Effective R-values can be calculated using three-dimensional thermal-simulation software where needed. A sketch of this cladding-attachment strategy is shown for an exterior-insulated CLT panel wall assembly in Figure 3.2.6.

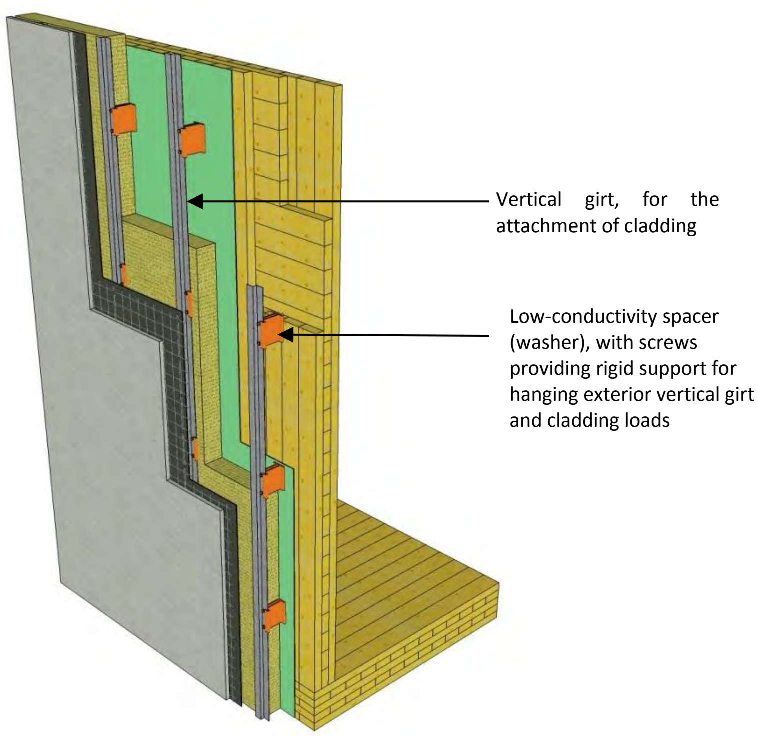


Fig. 3.2.6 Thermally efficient cladding attachment using low-conductivity thermal spacers and screws, rather than metal clips, to reduce thermal bridging through the exterior insulation.

Continuous Wood Framing

While often not as thermally efficient as many of the options presented previously, continuous wood framing through the exterior insulation can be used for cladding support. Wood members that bridge the entire depth (i.e., stud-sized strapping) or part of the depth could be used; however, all wood components outside the weather barrier need to be preservative treated in wet climates (coloured green in Fig. 3.2.7). Continuous wood framing through exterior insulation results in a reduction of the effective R-value of the exterior insulation layer in the order of 20 to 25% for exterior insulation thicknesses of 2 to 4 inches; the thicker the insulation layers the greater the reduction. To overcome these thermal losses, additional depths of insulation will be required in order to meet thermal insulation targets. Effective R-values for this cladding-attachment strategy can be determined using 2D and 3D thermal-simulation software where needed. While continuous wood framing results in a manageable amount of thermal bridging, the use of continuous steel Z-girts is not recommended because they can result in losses in the range of 50 to 60%, depending on spacing and insulation depth (they do not meet the continuous insulation requirements of ASRAE 90.1).

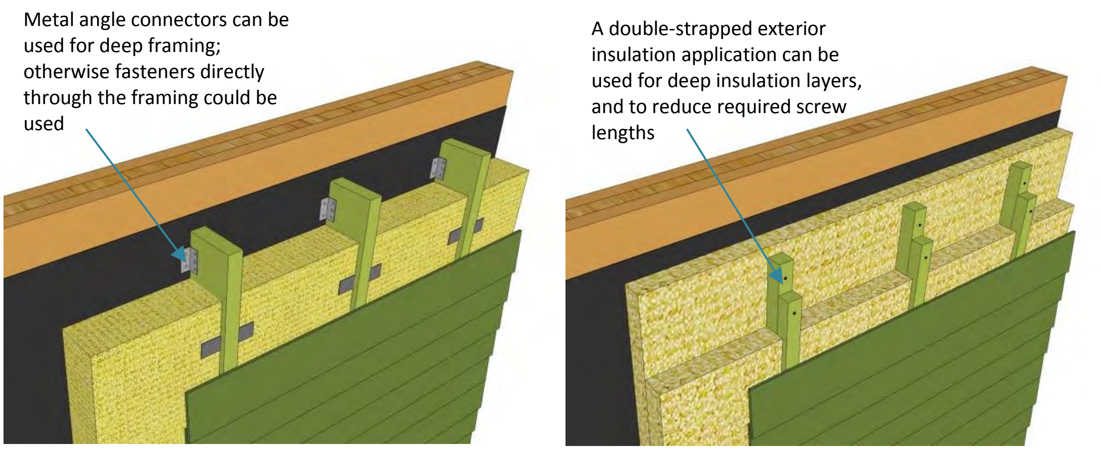
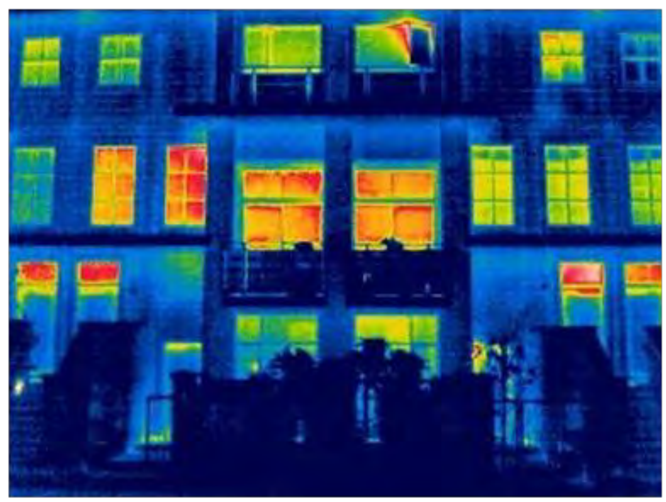


Fig. 3.2.7 Continuous-framing cladding attachment, installed through exterior insulation.

3.2.6 Whole-Building Energy Efficiency and the Impacts of Fenestration

Whole-building energy efficiency takes into consideration the thermal loss through all of the building-enclosure components. This includes the above-grade and below-grade walls, roofs, decks, balconies, floors, windows, doors, skylights, and all the interfaces and details between.

Windows have perhaps the largest thermal impact on the overall effective R-value of the building enclosure, i.e., through heat loss and gain. Window components, because of their relatively large proportion of the total wall area and their relatively low thermal resistance compared to insulated walls and roofs, can be considered as large thermal bridges within the building enclosure. This becomes apparent when looking at infrared images of wood-frame buildings with relatively thermally efficient wall assemblies and standard window assemblies, such as that shown to the right.



Infrared image of typically insulated, wood-frame walls (effective R-value 16.9). The windows (R-2.85), which are minimally code compliant in this jurisdiction, occupy a large percentage of the building enclosure and comprise the largest component of conductive heat loss.
Standard window-to-wall ratios are, on average, between 15 and 20% for single-family houses but are much higher for MURBs. Window-to-wall ratios in the range of 30 to 50% are common for wood-frame MURBs.

The "thermal weight" concept can be demonstrated using a simple chart that plots the overall effective R-value of the vertical enclosure (combined wall and window area) on the y-axis, and which is based on a combination of the wall R-value, the window R-value, and window-to-wall ratio on the x axis. This only accounts for conductive heat flow (no air leakage) and does not account for any solar heat gain and daylighting impacts of the windows.

The impact of the wall R-value alone, i.e., the effective vertical enclosure R-value with R-4 windows and three different R-10, R-20, and R-30 walls, are plotted against window-to-wall ratios (Fig. 3.2.8). For low window-to-wall ratios up to 20 to 30%, an increase in wall R-value plays a large impact on the overall effective R-value. However, the window R-value dominates with large glazing ratios.

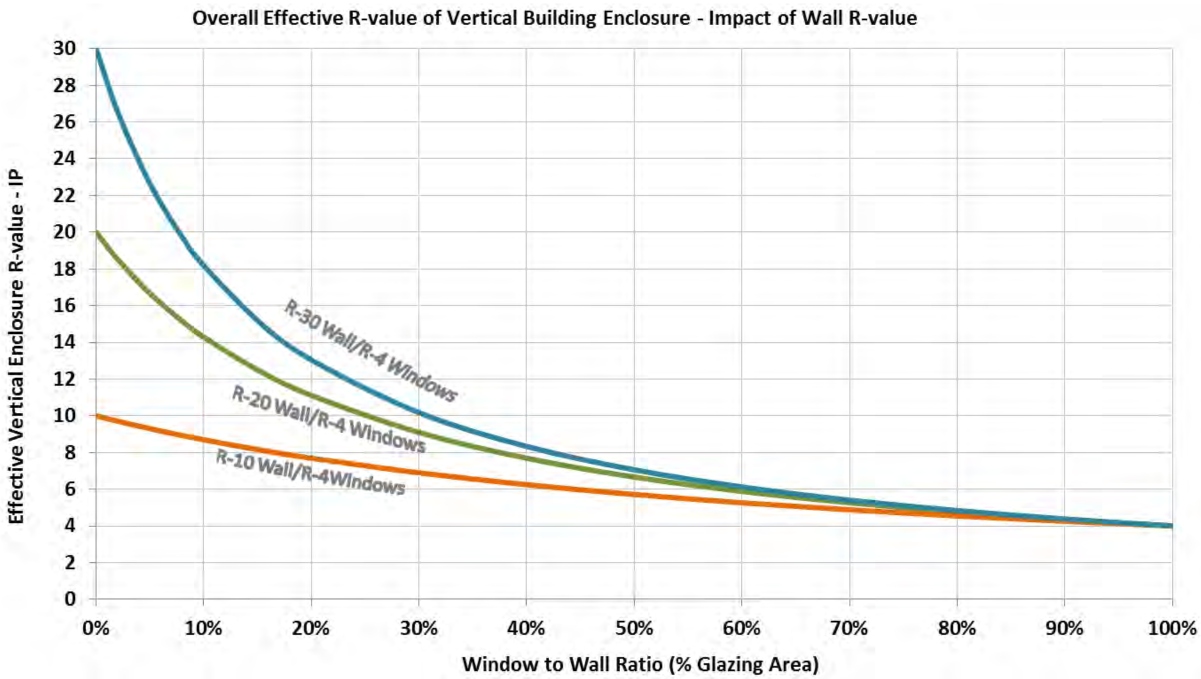


Fig. 3.2.8 Overall effective R-value of vertical building enclosure versus window-to-wall ratio, for R-4 windows with R-10, R-20, and R-30 walls.

Figure Fig. 3.2.9 shows the impact of the windows alone, with R-30 walls and R-2, R-4, and R-6 windows. Significant improvement can be achieved by increasing the R-value of windows, and the benefits of higher effective R-values for walls are only seen when high R-value windows are used. In Fig. 3.2.10, a range of typical wall and window R-values are plotted to provide an indication of the limitations or potentials for the performance of a MURB's building enclosure. While the insulated wall assemblies are important in an energy-efficient building, the windows can have a very large and often overpowering effect. Poor window performance can very quickly erode the benefits of highly insulated walls. Take for example the point where the R-30 wall/R-2 window crosses the line at around 22% window-to-wall ratio with the R-10 wall/R-4 window. Beyond this point the R-10 wall/R-4 window would outperform the R-30 wall/R-2 window.

This simple analysis forms the backbone of the energy code compliance and ASHRAE's Building Envelope Trade-off Option. Analysis can be performed at the design phase of a project to assess realistic wall and window targets. Roof and skylight thermal performance could also be assessed in a similar manner.

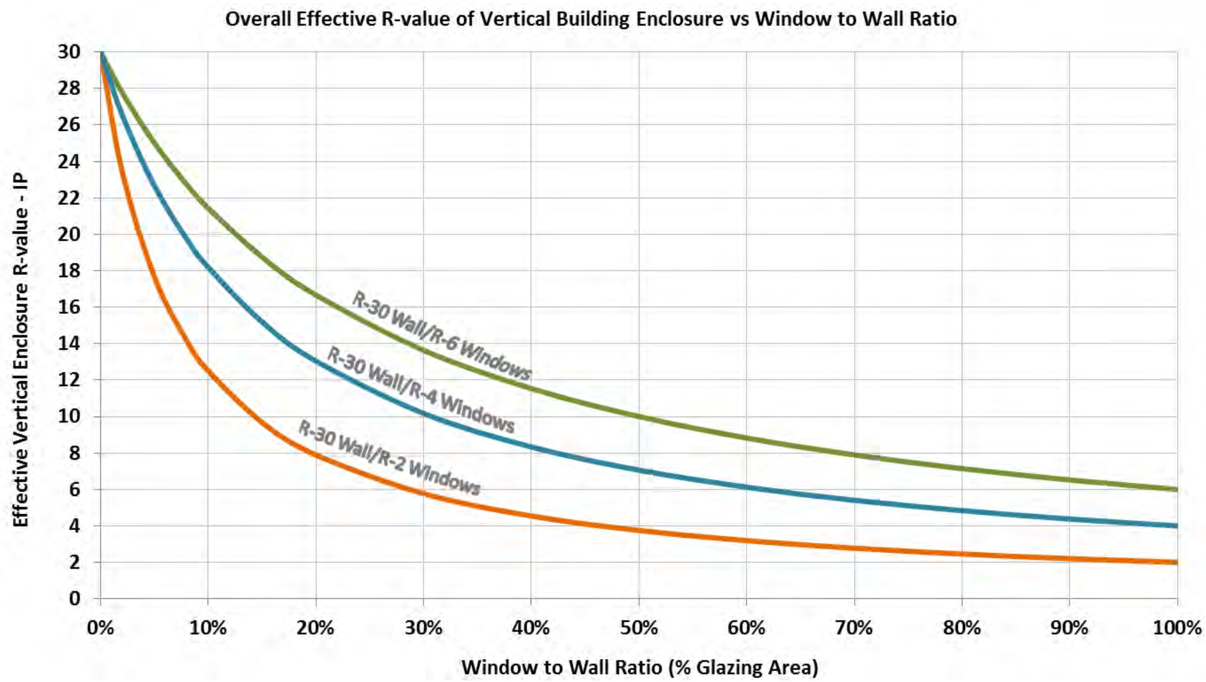


Fig. 3.2.9 Overall effective R-value of building enclosure versus window-to-wall ratio, for R-30 walls and R-2, R-4, and R-6 windows.

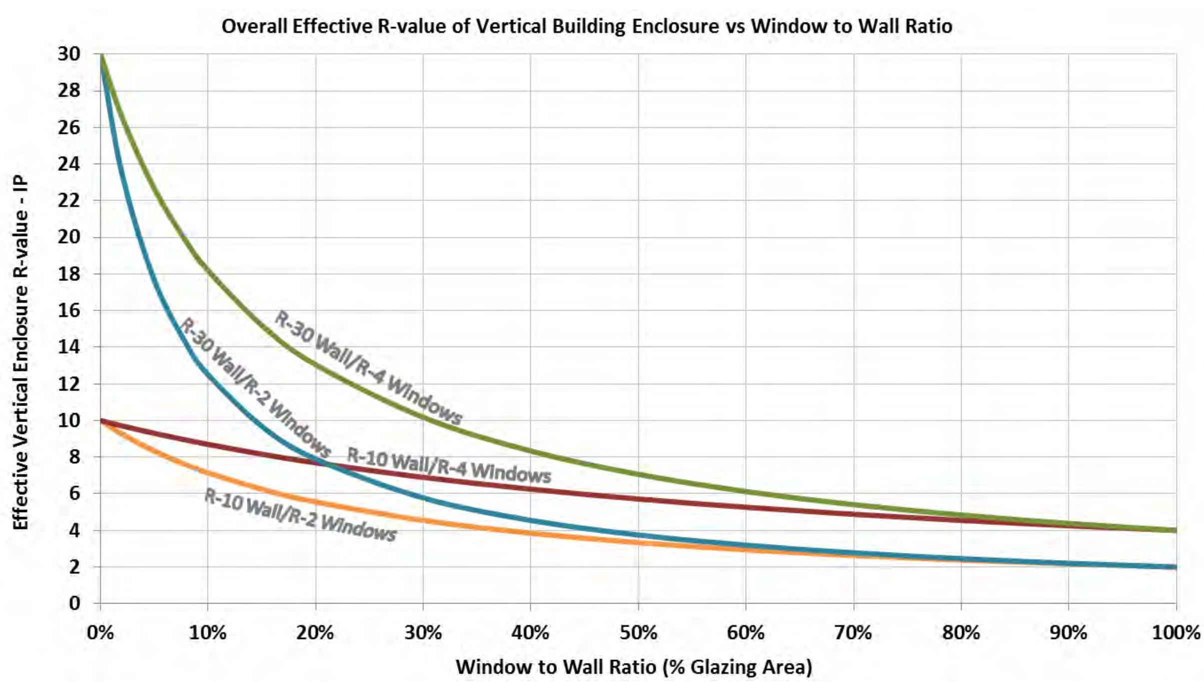


Fig. 3.2.10 Overall effective R-value of building enclosure versus window-to-wall ratio, for R-10 to R-30 walls and R-2 to R-4 windows.

Example: Calculation of Whole-Building Conductive Heat Loss

Consider a hypothetical, four-storey, 60-unit, wood-frame MURB:

- Walls are constructed using 2x6 standard wood framing and R-21 insulation with an effective R-16.9 (U-0.059).
- Windows/sliding doors are vinyl-framed, low-e, argon filled, R-2.85 (U-0.35), and comprise 30% of the vertical building-enclosure elements (wall + window area).

The overall effective R-value for the overall vertical building-enclosure elements is calculated using an area-weighted U-value calculation. U-values (inverse of R-value) must be used in all energy calculations because energy flow is directly related to the U-value.

$$U_{overall} = U_{wall} \cdot \%Area_{wall} + U_{window} \cdot \%Area_{window}$$

$$U_{overall} = 0.059 \cdot 0.70 + 0.35 \cdot 0.30$$
$$U_{overall} = 0.0414 + 0.105$$
$$U_{overall} = 0.147$$
$$R_{overall} = 6.82$$

As shown, the effective overall R-value for the overall vertical building-enclosure elements is R-6.82, with 72% of the energy flowing through the windows (which comprise only 30% of the overall area). This simple calculation, which can be performed during the conceptual stage of a building design, highlights the importance of window performance on the energy performance of the building enclosure, and illustrates building-enclosure trade-off potential. Graphically, this is demonstrated in Fig. 3.2.11 for an R-16.9 wall with R-2.85 windows, with a window area that varies from 0 to 100%. As windows are added, the overall effective R-value rapidly decreases.

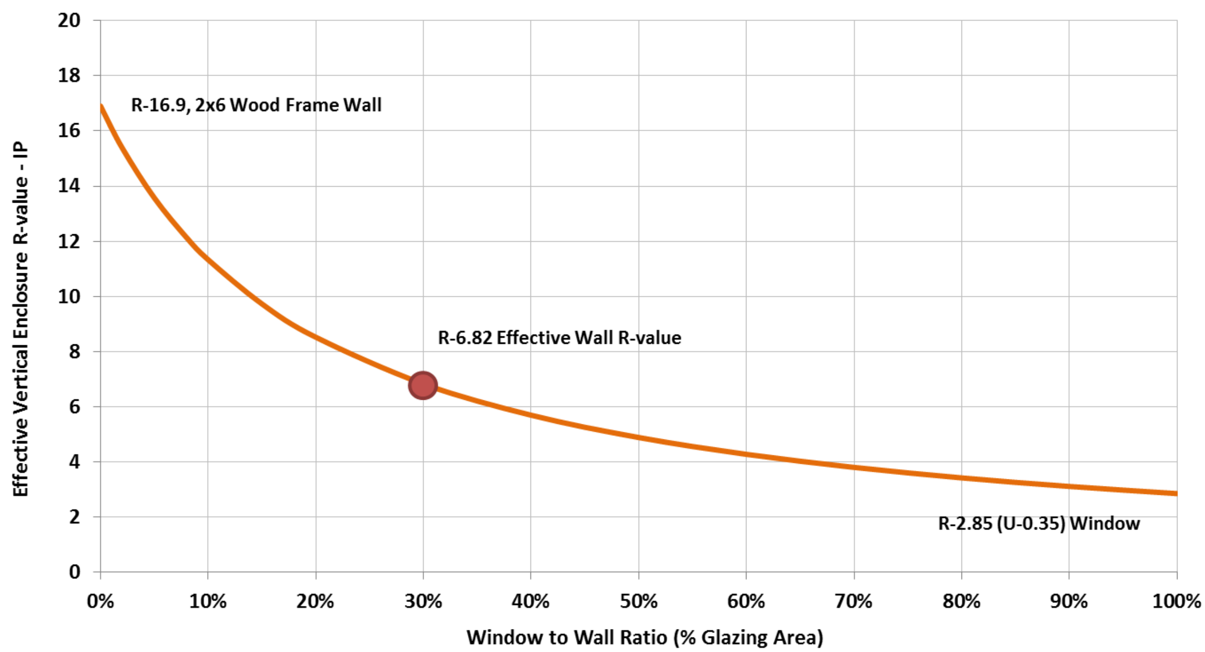


Fig. 3.2.11 Overall combined R-value of wall and window enclosure, for R-2.85 windows and R-16.9 walls.

Opportunities to Improve the R-Values of Building Enclosures

On the other hand, the relatively poor thermal performance of windows also presents an opportunity for significant improvement in overall enclosure performance. The building-enclosure trade-off compliance path in

ASHRAE 90.1 highlights the imbalances in thermal performance (for example, R-2.85 windows within R-16.9 walls with an R-40 roof). Understanding how the weaker performing thermal elements such as windows (or other large thermal bridges) affect the whole-building thermal performance will help to decide where to best allocate resources when designing energy-efficient or even energy code-compliant buildings. Such exercises can also help to achieve LEED credits or other credits where needed.

A simple trade-off calculation can be performed by determining the weighted U-value and area-weighted UxA factors for a building. Remember that R-values cannot be used in these area-weighted calculations. An example is shown in Table 3.2.2. Windows carry a weight of approximately 76% in the thermal calculations. The impacts of adding insulation to the walls or attic can be explored but will have a minimal influence on overall performance, i.e., until the window performance is improved. For example, improving the attic insulation to R-80, would only increase the overall R-value of the enclosure to R-7.7, a 2.8% improvement.

In the proposed building example below (see Table 3.2.3), the windows are modified to triple glazed IGUs within low-conductivity frames with an overall U-value of 0.17 (R-5.9). Such an upgrade in window performance from R-2.85 to R-5.9 triple-glazed windows (an increase of R-3.05) improves the R-value of the whole building by 63% (reduces the heat flow or U-value by 39%) over the baseline. The weighting of the energy use of components also changes, with a shift of thermal weight onto the wood-frame walls.

Further improvements could now be more effectively made to components such as the attic or walls. For example, the final building design includes R-40 effective walls with R-5.9 windows and an R-50 effective attic by utilizing the strategies presented within this guide (Table 3.2.4). The improvement of windows, walls, and attic insulation improves the R-value of the whole building by 104% (reduces the heat flow or U-value by 51%) over the baseline. As shown, highly insulated opaque assemblies can have a significant impact on the building enclosure's overall R-value as long as thermally efficient windows are also used.

Table 3.2.2 Sample, area-weighted, U-value calculation for a baseline building that is ASHRAE Standard 90.1 compliant.

Component	Area (ft^2)	U-value (BTU/ ft^2·F·h)	U x A factor	Thermal weight (%)
Walls, R-16.9 effective	12 000	0.059	708	**19.1**
Windows, R-2.85 effective	8 000	0.35	2 800	**75.5**
Attic, R-40	8 000	0.025	200	**5.4**
	Total sum (ΣU·A)		3 708	
	Overall U-value – BTU/ ft^2 F h (ΣU·A)/A_{TOT}		0.132	
	Overall R-value - ft^2 F h/BTU		**7.55**	

Table 3.2.3 Sample, area-weighted, U-value calculation for a building with thermally improved windows: incremental improvement over the baseline building.

Component	Area (ft^2)	U-value ($BTU/ft^2 \cdot F \cdot h$)	U x A factor	Thermal weight (%)
Walls, R-16.9 effective	12 000	0.059	708	**31.2**
Windows, R-5-9 effective	8 000	***0.17***	1 360	**60.0**
Attic, R-40	8 000	0.025	200	**8.8**
	Total sum ($\Sigma U \cdot A$)		2 268	
	Overall U-value – BTU/ ft^2 F h ($\Sigma U \cdot A)/A_{TOT}$		0.081	**39% reduction in heat flow**
	Overall R-value - ft^2 F h/BTU		**12.3**	**63% improvement**

Table 3.2.4 Sample, area-weighted, U-value calculation for a proposed very energy-efficient building enclosure with thermal insulation and window upgrades: estimated incremental improvement over the baseline building.

Component	Area (ft^2)	U-value ($BTU/ ft^2 \cdot F \cdot h$)	U x A factor	Thermal weight (%)
Walls, R-40 effective	12 000	0.025	300	**16.5**
Windows, R-5-9 effective	8 000	0.17	1 360	**74.7**
Attic, R-50 effective	8 000	0.02	160	**8.8**
	Total sum ($\Sigma U \cdot A$)		1 820	
	Overall U-value – BTU/ ft^2 F h ($\Sigma U \cdot A)/A_{TOT}$		0.065	**51% reduction in heat flow**
	Overall R-value - ft^2 F h/BTU		**15.4**	**104% improvement over baseline**

3.2.7 Thermal Mass Effects of Heavy Timber Framing

The thermal mass of the building-enclosure elements, as well as that of the interior floors and walls, can act to improve the energy efficiency of buildings by storing solar heat energy during the day and releasing it at night. This acts to reduce peak utility loads by shifting the time and intensity at which they occur, reduce the building's overall energy use, and improve occupant comfort. The actual benefits of thermal mass within a building will vary with climate and solar radiation, building type and internal heat gains, building geometry and orientation, and the actual amount and location of thermal mass used, but it is a common strategy in energy-efficient buildings. Thermal mass is typically associated with concrete or masonry buildings; however, heavy timber framing, such as CLT panels, do have considerable thermal mass which will have whole-building energy-efficiency benefits.

To demonstrate the benefit of thermal mass an hourly simulation of building energy was performed to look at space-conditioning energy savings associated with using CLT wall and floor construction versus traditional wood framing in a 4-storey, 40-unit (31,000-ft^2) MURB in nine U.S. cities covering ASHRAE Climate Zones 1 to 8. In order to isolate the effect of just the thermal mass of the CLT, identical effective enclosure R-values (as per ASHRAE Standard 90.1-2007 minimums by climate zone) were used for each of the wall and roof enclosure assemblies, with the only variable being the thermal mass of the wood within the assemblies. Other building-enclosure and system factors, including HVAC systems, windows, airtightness, etc., were also kept the same.

Fig. 3.2.12 presents the percentage energy savings for a CLT structure relative to the light wood-frame baseline on an annual basis. Savings are separated into heating energy, cooling energy, and energy use for fans (heating and cooling combined). The figure shows that the CLT thermal mass has some benefit in all locations but the greatest benefit is seen in Climate Zones 1 to 3. Energy savings for CLT thermal mass are greater during the times of year when the outdoor temperatures fluctuate above and below indoor temperature. The reductions in peak heating and cooling load are also shown in Fig. 3.2.13, and demonstrate consistent energy savings for peak cooling (electrical load) of 10 to 16%, but less consistent heat savings. In Chicago and Minneapolis, the additional thermal mass of the CLT slightly increases the peak load due the greater amount of energy required to heat the wood structure. Related information can be found in Chapter 10 of the *Cross-Laminated Timber Handbook* (US Edition) published by FPInnovations and Binational Softwood Lumber Council in 2013.

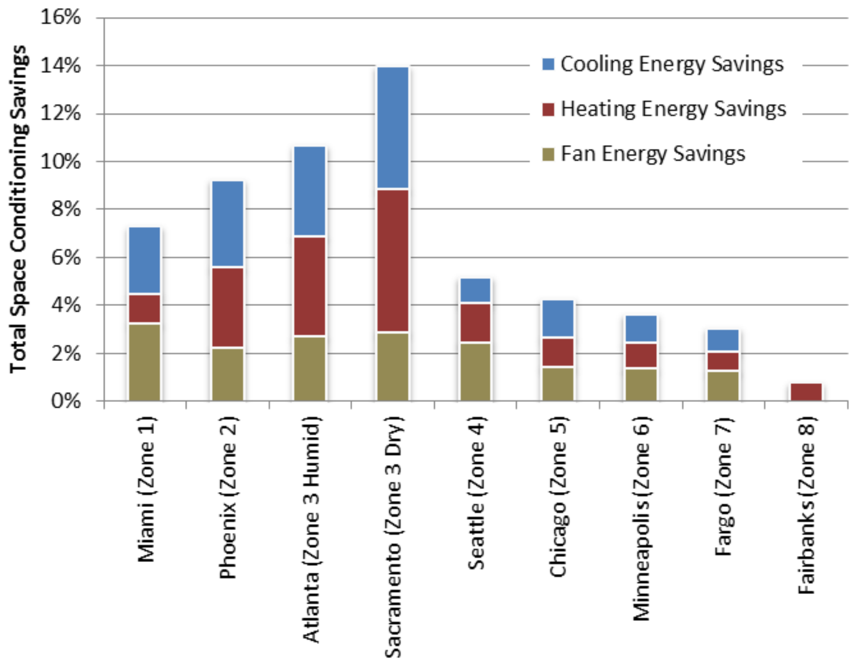


Fig. 3.2.12 Savings associated with space conditioning of a 4-storey MURB, for a CLT thermal mass versus a wood-frame baseline, for representative U.S. cities.

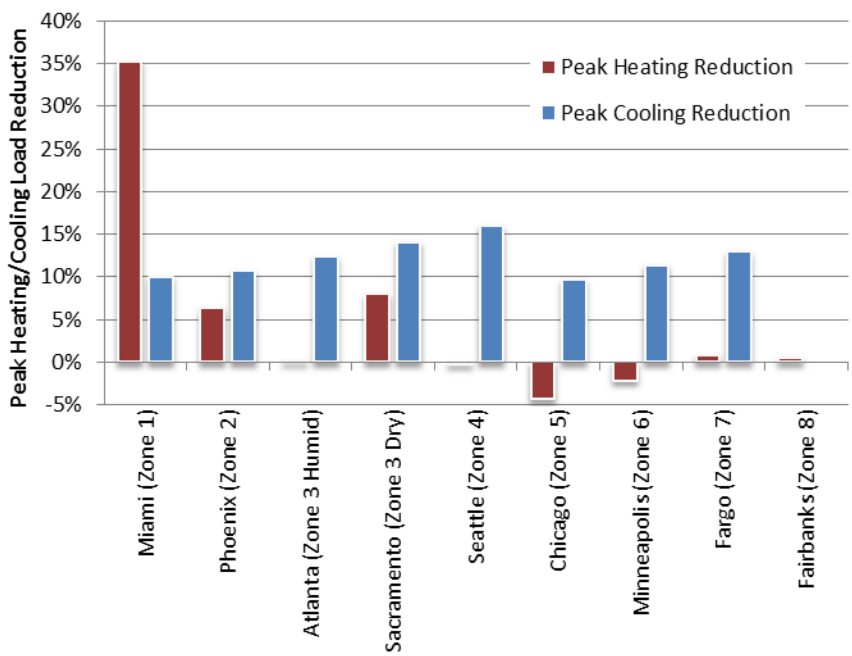


Fig. 3.2.13 Energy savings associated with peak-load cooling and heating of a 4-storey MURB, CLT thermal mass versus wood-frame baseline, for representative U.S. cities.

3.3 Computer Simulation: Thermal and Hygrothermal Performance during Building Enclosure Design

Just as the design process for structural engineering often includes the use of computer software, the building-enclosure design process can also utilize computer tools to assist in making design decisions for climate- and building-appropriate enclosure assemblies. However, unlike structural design, where the material inputs and boundary conditions are relatively well known and predictable, the boundary conditions, environmental loads, and even material properties in building-enclosure design are relatively poorly known. Therefore the term "enclosure design software" is used loosely and models—hygrothermal models in particular—are used more as tool to look at relative performance impacts to aid the designer in decision making rather than to evaluate the absolute results of a simulation. Such tools should also be used only as a design aid and only by professionals who are trained and experienced in the use of the model, material properties, and boundary conditions, and in the interpretation of the results. Regarding material properties alone, more efforts are needed to generate appropriate data for wood products as well as for other products used in building enclosures. A summary of hygrothermal properties of wood is provided in the building enclosure chapter (Chapter 10) of the *Cross-Laminated Timber Handbook* (U.S. Edition, FPInnovations and Binational Softwood Lumber Council, 2013).

There are two main types of computer simulations that may be performed to assist in the design of building enclosures: thermal simulation and hygrothermal simulation.

3.3.1 Thermal Simulation

Thermal simulation is the modelling of heat flow through building-enclosure assemblies, components, and details. Thermal-simulation software utilizes calculations of 2D and 3D finite element heat flow to determine R-values/U-values, as well as thermal profiles and surface temperatures, of drawn details and assemblies. Programs such as HEAT3 (Blocon, buildingphysics.com) and THERM (LBNL, windows.lbl.gov/software/therm/therm.html) are examples of commonly used thermal-simulation software for this purpose. These software packages have been validated with laboratory testing data; however, the results are only as accurate as the inputs and user interpretation. Published laboratory testing data can be used for validation of results. Training in the use of these software packages is recommended.

The U-values and R-values of building-enclosure assemblies and details are often calculated using software to assess prescriptive or trade-off energy code compliance (e.g., ASHRAE Standard 90.1 Prescriptive Option or Building Envelope Trade-Off Option, using ENVSTD). They can then be input to whole-building energy models to assess energy-code compliance (e.g., ASHRAE Standard 90.1 Energy Cost Budget). Research using other advanced, 3D, time-transient, heat-transfer models has also been conducted by ASHRAE and other organizations to specifically assess thermal bridging and effective thermal performance of various building-enclosure assemblies.

Many whole-building energy models may also have some 1D and 2D thermal calculation capabilities for input of building-enclosure assemblies (e.g., EQuest, DesignBuilder, Hot2000, etc.). These are typically adequate for simple assemblies and details as long as they take into account thermal bridging through framing to determine effective R-values. Models that only use nominal R-values would not be accurate in assessing energy flow through the building enclosure.

3.3.2 Hygrothermal Simulation

Hygrothermal modelling is the computer-assisted simulation of heat, air, and moisture flow through building-enclosure assemblies that are exposed to indoor and outdoor environmental loads (e.g., walls, roofs, floors, below-grade walls, etc.). It is the process of simulating the performance of assemblies so that the future durability and risk associated with different assembly designs, materials, and climate or exposure can be evaluated and assessed. For example, the risk of condensation occurring within an assembly could be analyzed in terms of increased insulation, different vapour-retarder properties, or different insulation materials. The hygrothermal model outputs temperature, humidity, and moisture-content data at materials and interfaces throughout the assembly so that the risk of condensation, moisture entrapment, fungal growth, and even material degradation can be assessed.

Hygrothermal-simulation software utilizes 1D or 2D finite element simultaneous heat and moisture calculations to determine heat and moisture flows through assemblies and details. Condensation, moisture accumulation, thermal profiles, and likely deterioration over a period of time (typically a minimum of 2 to 3 years) can be judged based on the output. Some software packages can model the impacts of wind-driven rain and air leaks.

The WUFI Pro software package from the Fraunhofer Institute for Building Physics in Germany (wufi.de) is one of the most widely used hygrothermal models in the building science community. The National Research Council of Canada has also developed similar models (hygIRC series, archive.nrc-cnrc.gc.ca/eng/projects/irc/hygirc.html) for assessing hygrothermal performance. This type of software is best suited for forensic or research purposes; however, it can also be used for the design of new assemblies to estimate the likely performance in service. It is, however, not recommended to rely on any hygrothermal simulation to determine whether a design will work or not work in a certain climate because of the number of unknown variables involved. Modelling always has a level of uncertainty. The results are only as accurate as the user inputs, assumptions, and interpretations of results. Moreover, building-enclosure performance relies heavily on the quality of construction, but workmanship-related water and air leaks cannot be confidently predicted by models.

The best use of hygrothermal simulation in a design scenario is to compare the performance of one assembly versus another in terms of relative performance, to assess material selection and placement (e.g., insulation, vapour placement, etc.), or to assess the sensitivity of assemblies to climatic variables (e.g., indoor RH, outdoor driving rain, and solar radiation, etc.).

When assessing wood-frame wall assemblies, the following procedure is recommended for assessing the relative performance and risk of moisture accumulation for new assembly designs as compared to baseline designs with known performance. This process allows the designer to determine the relative risk of a proposed assembly and potentially make changes to the design to mitigate this risk. For example, if a proposed wall is more susceptible to air-leakage condensation, then a more robust air-barrier strategy could be used.

1. Model the performance of a baseline assembly of which you are familiar with the performance, or for which you have data for a certain climate zone. A common wood-frame baseline wall assembly would be a 2x6 framed wall with fibreglass insulation and a common cladding type. Calibrate the model as necessary with respect to boundary conditions.
2. Model the performance of the proposed wall assembly (e.g., a split-insulation wall with some type of exterior insulation) using the exact same inputs (i.e., cladding, wetting, orientation, etc.) as the baseline wall. Compare performances to assess the relative performance of the proposed assembly. The proposed wall assembly could include a number of similar assemblies—for example, a number of different exterior insulation types or thicknesses—and be modelled simultaneously.
3. Model the baseline wall but with <u>initially wet wood sheathing</u> (i.e., 30% moisture content) and determine the time it takes for this wall to dry out during different times of the year. This will help to understand the importance of dry wood at the time of closing in, and the relative ability for the wall to dry.

4. Model the proposed wall assembly(s) with the same initially wet wood sheathing used for the baseline wall and determine the time it takes for this wall to dry out compared to the baseline wall. Assess whether this drying time is acceptable or if there is risk for decay to occur.
5. Model the baseline wall with a driving rain leak which wets a portion of the wall that could get wet in service (e.g., the exterior surface of the exterior sheathing below a window). Determine the maximum size of rainwater leak that could be tolerated in service (i.e., incur up to 30% moisture content for 2 weeks but dry out) and still allow the wall to dry out.
6. Apply this exact same sized leak to the proposed wall assembly(s) and simulate. Plot and compare the moisture content and RH levels within the proposed and baseline assemblies. Assess the relative performance implications and risk of this leak in the proposed versus the baseline assembly and determine whether the proposed wall assembly is more or less sensitive to rainwater leaks. This will help to understand the importance of preventing wetting and will assist with detailing. If the risk is intolerable, a re-design may be necessary.
7. Model the baseline wall with an air leak which could wet a portion of the wall that could get wet in service (e.g., the inside of the exterior sheathing). Determine the air-leakage rate that could be tolerated in service (i.e., incur up to 30% moisture content for 2 weeks but dry out) and still allow the wall to dry out.
8. Apply this exact same size of air leak to the proposed wall assembly(s) and simulate. Plot and compare the moisture content and RH levels within the proposed and baseline assemblies. Assess the relative performance implications and risk of this leak in the proposed versus the baseline assembly. Determine whether the proposed wall assembly is more or less sensitive to air leakage. This will help understand the importance of controlling air flow and assist with detailing. If the risk is intolerable, a re-design may be necessary.

An example output from this analysis is shown in Fig. 3.3.1 in which the moisture content of the plywood sheathing within a highly insulated double-stud wall assembly is compared to that of a baseline 2x6 wall. As shown, when the double-stud wall is exposed to air and rainwater leaks it gets slightly wetter for prolonged periods and is also more sensitive to air leakage. The use of more robust air-barrier systems and detailing to prevent rainwater penetration is essential in a double-stud or highly insulated stud wall assembly, and may result in detailing that is new or unique in some climate zones. These considerations are addressed within the following chapters.

This type of relative comparison analysis also allows for the designer to evaluate the relative risk of the design or the selection of insulation and other materials within alternate wall or roof assemblies. An example of this evaluation is shown in Fig. 3.3.2, where several different highly insulated wall assemblies and insulation options are compared to a baseline 2x6 wall exposed to an air leak. Rainwater leaks would also be simulated and also evaluated (not shown here).

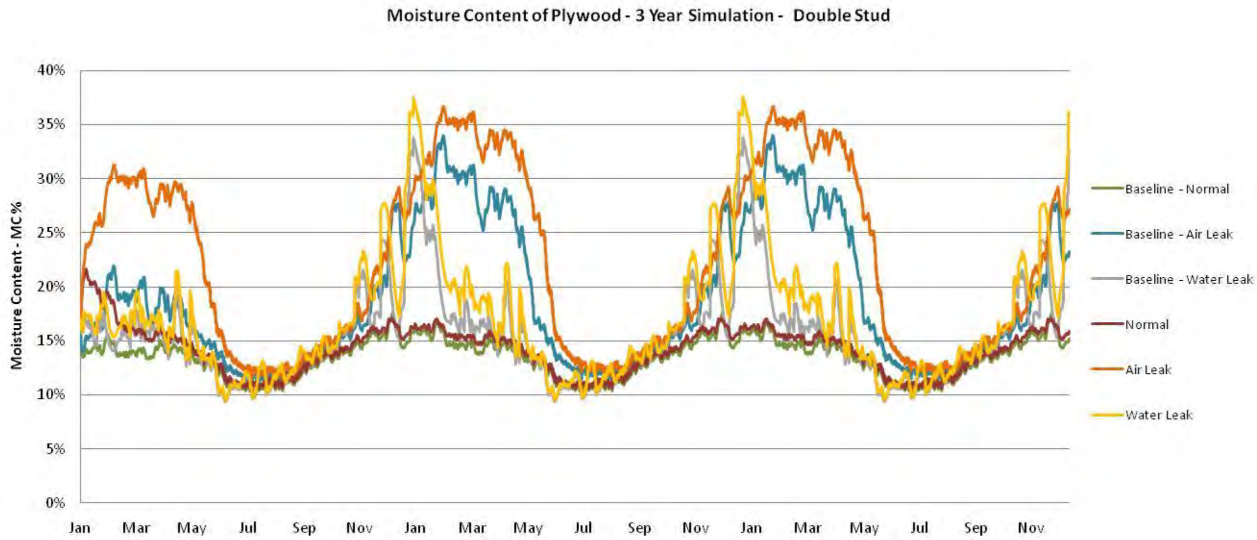


Fig. 3.3.1 An example of output from a 3-year simulated hygrothermal assessment, comparing the moisture content of the plywood sheathing within a highly insulated double-stud wall to a baseline 2x6 wall in Climate Zone 4.

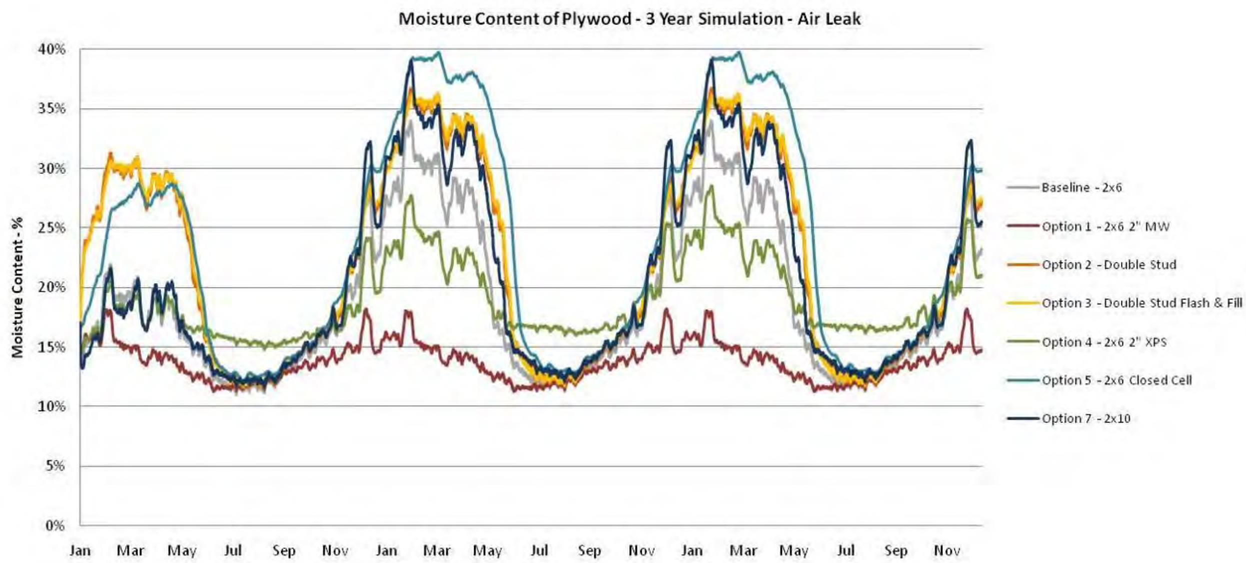


Fig. 3.3.2 An example of output from a 3-year simulated hygrothermal assessment, comparing the moisture content of the plywood sheathing within several wall assemblies when exposed to an air-leak

This method of relative hygrothermal assessment is a useful design tool for assessing the durability of highly insulated and more thermally efficient wall and roof assemblies. It helps designers understand where certain risks may exist and the importance of the control of air leakage, vapour diffusion, and water penetration. Proper application of the fundamentals covered in this chapter, along with that of the recommended assemblies and details covered in the next two chapters, will lead to durable and energy-efficient wood-frame MURBs.

When simulating wood mass assemblies such as CLT walls, more caution is required due to the need for further improving the understanding of their transient behaviour and properties under dynamic hygrothermal conditions, of the variations between wood species and products, and of the lack of long-term field-performance data for benchmarking and validation. Research is underway to address all these needs.

CHAPTER 4: ENERGY-EFFICIENT WALL AND ROOF ASSEMBLIES

Five-storey multi-unit residential building under construction. The selection of thermally efficient assemblies is summarized in this chapter, but the details of integrating these assemblies with penetrations, windows, doors, balconies, etc. is covered in Chapter 5.

Chapter 2 covered the thermal-insulation requirements of building-enclosure assemblies for climate zones and jurisdictions across North America. Chapter 3 covered moisture, air, and heat-flow control and durability principles for enclosure designs. Chapter 4 presents the design strategies for thermally efficient assemblies of wood-frame walls and roofs. It provides the key design considerations for thermal insulation, moisture management and the required critical barriers, material selection, and effective R-values.

Three above-grade, two below-grade, and four roof assemblies have been selected within this guide as being highly thermally efficient, cost-effective, buildable, and durable. Many other wood-frame assemblies may also meet these criteria but are not covered within this version of this guide.

It may be possible to use variations of the assemblies shown (e.g., use alternative materials) as well as other assemblies not presented in this guide. In either case, it is important to ensure that appropriate consideration is given to each of the variables affecting heat, air, and moisture control. Undertaking hygrothermal simulation, as discussed in Chapter 3, or laboratory and field performance testing of new or alternative assemblies are recommended to confirm the performance characteristics of the variables.

This chapter also provides a fact sheet for the major assemblies. The fact sheet includes a concise summary of their attributes, including exterior moisture control, thermal insulation, airflow control, vapour-flow control, applications, and factors limiting performance.

The following assemblies are covered in this guide:

Wall Assemblies

- split-insulation
- double-stud or deep-stud insulated
- exterior-insulated mass timber panel (i.e. CLT)

Traditionally insulated 2x4 and 2x6 assemblies are not covered here even though they would meet the minimum R-value requirements in some climate zones.

In addition to these three main wall assemblies, the use of split-insulated, wood-frame infill walls for concrete-frame buildings and for wood post-and-beam construction is also covered conceptually within this chapter and within a few of the details in Chapter 5.

The proper insulation of concrete foundation walls is an important component of an energy-efficient MURB. The following below-grade concrete wall assemblies have therefore been included for discussion in this guide:

- interior insulated
- exterior insulated

Insulated concrete forms (ICFs), which insulate on both sides of the concrete foundation wall with EPS insulation, while a viable alternative for below-grade walls (and even above-grade walls), are not covered within the scope of this guide.

Roof Assemblies

Most highly insulated wood-frame roof assemblies look and behave very similarly to typical wood-frame roof assemblies except that the former generally have greater thicknesses of insulation. The assemblies are very similar; however, greater thicknesses of insulation may pose challenges with detailing at interfaces (e.g., door thresholds). Three of the most commonly used, highly insulated, wood-frame roof assemblies, as well as a less common sloped roof assembly are included here:

- pitched roof: vented attic, insulated ceiling
- pitched roof: exterior insulated (less common)
- low-slope roof/deck: conventional insulated assembly
- low-slope roof/deck: inverted (protected membrane) insulated assembly

The following roof assemblies are not included within this guide, because they are fairly standard practice and/or cannot be modified substantially enough to be considered highly insulated in the context of this guide. However, many assemblies can meet current energy code targets in most jurisdictions, and, with proper consideration given to assembly design and detailing, can meet the needs for most MURBs.

- pitched roof: vented cathedral ceiling
- pitched roof: unvented cathedral ceiling
- low-slope roof/deck: interior insulation, vented
- low-slope roof/deck: interior insulation, unvented

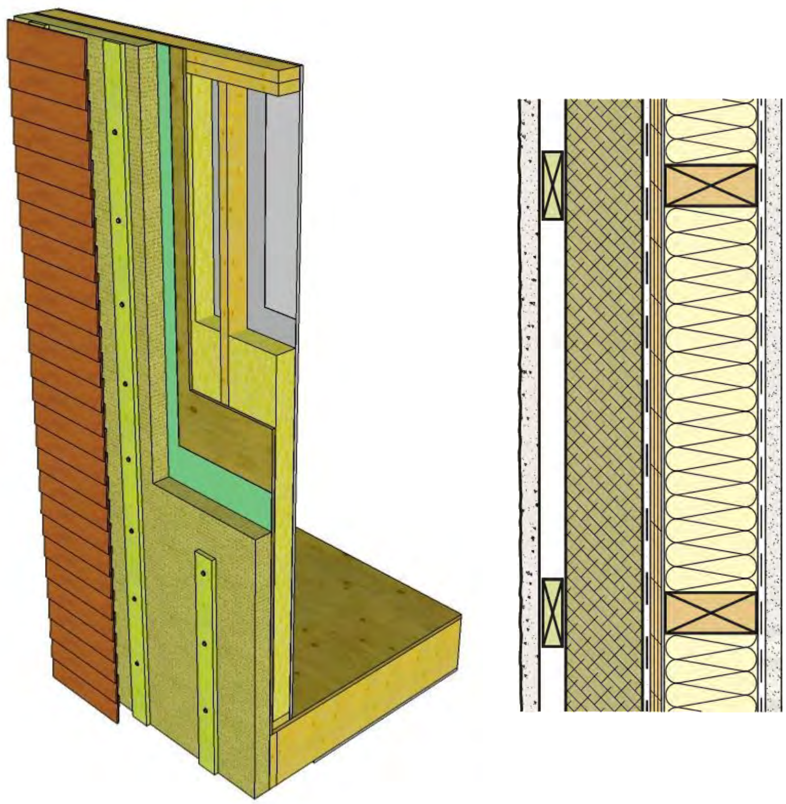
Further guidance on these assemblies can be found within the *Building Enclosure Design Guide: Wood-frame Multi-Unit Residential Buildings (*Homeowner Protection Office, Branch of BC Housing, 2011). Mass timber wall and roofing assemblies utilizing CLT panels can be found in the *Cross-Laminated Timber Handbook* (Canadian Edition, FPInnovations, 2011) and the *Cross-Laminated Timber Handbook* (U.S. Edition, FPInnovations and Binational Softwood Lumber Council, 2013).

For each assembly, three-dimensional sketches are utilized to discuss assemblies and various concepts. Detail drawings of the utilization of each assembly are provided in Chapter 5. For each assembly the critical barriers and control functions as discussed in Chapter 3 are applied. Information regarding the best strategies to control exterior moisture (water-shedding surface, water-resistive barrier), control airflow (air barrier), control vapour flow, and thermal insulation are covered. Effective three-dimensional R-values for each of the wood-frame assemblies in various configurations are also provided to select appropriate insulation levels to meet the requirements of local energy codes or other localized requirements. Alternative cladding-attachment strategies for walls are also covered.

4.1 Split-Insulation Wall Assembly

A split-insulation assembly consists of rigid or semi-rigid insulation placed on the exterior of a conventional, above-grade, insulated, 2x4/2x6, wood-frame wall assembly. High effective R-values of the assembly are achieved by the use of continuous insulation outside of the structural framing and thermally efficient cladding attachments, as well as stud-space insulation. See Fig. 4.1.1.

In cold climates, insulation placed on the exterior of the stud wall increases the temperature of the moisture-sensitive wood sheathing and framing, and reduces the risk that condensation will occur due to air leakage and vapour flow from inside. Such a wall assembly may therefore have improved durability performance over traditional interior-stud-insulated wall assemblies. However, it has unique design characteristics in terms of cladding attachment through the exterior insulation, exterior insulation selection, and vapour control, as discussed in the next section.



EXTERIOR

- Cladding
- Airspace (ventilated)
- 1x3 wood strapping, screwed through Insulation
- Rigid, mineral-fibre insulation (thickness to meet R-value requirement)
- Vapour-permeable sheathing membrane
- Sheathing (plywood or OSB)
- 2x4 or 2x6 wood framing with batt insulation
- Polyethylene film (cold climates only)
- Gypsum board and paint

INTERIOR

Fig. 4.1.1 Split insulation wall assembly with rigid, exterior, mineral-fibre insulation (isometric sketch and plan view detail).

This assembly is similar to an insulated sheathing assembly which is often used in low-rise residential construction in colder climates. The difference is the inclusion of the structural wall sheathing. Plywood and OSB sheathing is typically used in multi-storey MURBs for lateral load and shear wall provisions. MURBs typically have less solid wall area often as a result of increased window to wall ratio, and therefore other bracing methods suitable for one and two storey houses are not suitable for MURBs. Exterior gypsum sheathing (in addition to plywood or OSB) is also required in some jurisdictions for wood-frame MURBs for fire protection. The inclusion of this wood (and gypsum) sheathing introduces a moisture sensitive component between insulation layers, which may not be present in insulated sheathing walls.

4.1.1 Selection of Exterior Insulation

With a split-insulation assembly, numerous potential insulation combinations are possible. The stud insulation may consist of fibreglass; cellulose; mineral fibre; open-cell, 1/2 pcf spray foam; or in some cases closed-cell 2 pcf spray foam with a nominal R-value of between R-12 (RSI 2.1) and R-15 (RSI 2.6) for a 2x4 stud space, and a nominal R-value of between R-19 (RSI 3.3) and R-24 (RSI 4.2) for a 2x6 stud space. On the exterior there are two options: semi-rigid or rigid board products. The amount of exterior insulation required will depend on the stud wall framing (2x4 or 2x6) and the R-value target for the assembly.

Split-insulation wall assembly consisting of rigid mineral fibre on the exterior of the wood sheathing and sheathing membrane. Cladding will be attached to the vertical strapping on the exterior of the insulation, which has been fastened back into the structure using longer screws.

Semi-rigid or rigid mineral or glass fibre and extruded polystyrene (XPS) insulations are recommended for use in exterior rainscreen cavities. Rigid mineral fibre is naturally moisture resistant, and is treated with oils to make it more hydrophobic and moisture tolerant. It is also free draining and will not accumulate moisture, and is therefore suitable for use as exterior cavity insulation. Lower density fibreglass and mineral-fibre batts intended for use in the stud cavity would not be suitable in this application. Foam insulation, including XPS, is moisture resistant and suitable for much wetter uses (such as below grade and inverted roofs), and is therefore suitable for use as exterior cavity insulation. Higher densities of expanded polystyrene (EPS) may also be suitable. Polyisocyanurate (with foil or other moisture-tolerant facing) can also be used, provided that the core is protected from moisture.

Based on industry practices and hygrothermal simulation, the use of semi-rigid or rigid mineral or glass fibre that is vapour open provides for the best durability of the wood-frame assembly and is therefore recommended for this wall type in most situations. Vapour-tight foam insulation (EPS, XPS, or polyiso) can also be used, but it can increase the risk of trapping moisture within the sheathing in the event of rain or air leaks while in service, or of built-in construction moisture, thus reducing durability. In Climate Zones 4 to 8, the use of foam insulation requires an assessment to determine safe split ratios between exterior insulation and stud-cavity insulation in order to adjust the interior vapour-control method. The indoor and outdoor climates are factors in this decision. In general, where exterior foam is used, the more foam that is placed on the exterior of the sheathing, the better the moisture performance. The insulation ratios provided within building codes—including the NBC and IRC—and in some literature may not be conservative enough for more exposed wood-frame MURBs with higher moisture loadings. The use of vapour-open mineral-fibre or glass-fibre insulation alleviates this concern as well as the need to determine a safe insulation ratio.

In hot climate zones (i.e., Zones 1 to 3) where interior vapour control is not typically needed, XPS will provide more vapour control than rigid mineral fibre or glass fibre on the exterior and may result in improved durability performance because the predominant vapour drive is inward. However, the considerations for combustibility of the exterior insulation, particularly for taller MURBs, may prevent the use of foam plastic insulation in some jurisdictions, thus prompting the use of non-combustible mineral fibre.

The construction and detailing of a ventilated cavity outside of the insulation is recommended in all climate zones. This is strongly recommended where vapour-open exterior insulations are used in conjunction with absorptive claddings and in warmer climates where the predominant vapour flow is inwards. The benefits of ventilation also include reduced cladding temperatures in warm climates, which helps reduce heat gain. The creation of this cavity is formed by the use of standard cladding attachments, typically using exterior vertical strapping, as discussed in Chapter 3.

4.1.2 Cladding Attachment and Support

Any type of cladding can be used with this wall assembly. The strategy to attach the cladding will depend on the weight and support requirements for the cladding. Most claddings can be attached directly to the vertical strapping, which itself is attached directly through the insulation to the primary structure.

The compressive strength of the exterior insulation will determine the potential cladding-attachment strategies. With rigid insulation (rigid mineral fibre, XPS, EPS, Polyiso), the simplest strategy is to attach the cladding to 1x3 strapping that is screwed directly through the exterior insulation by using long screws into the plywood sheathing or studs. The use of 1x3 strapping cut from plywood (typically pre-treated with preservative) rather than lumber will reduce splitting and provide a more robust nail base for cladding attachment.

Semi-rigid mineral-fibre or glass fibre insulation may also be used; however, the density of this insulation is insufficient to attach the cladding by using only screws through the insulation. Instead, the use of exterior framing or discrete clip cladding supports, such as those presented earlier in this chapter, is needed.

4.1.3 Controlling Exterior Moisture

Water-Shedding Surface

This rainscreen wall assembly anticipates control of the majority of exterior moisture at the exterior cladding while recognizing that some incidental moisture will likely migrate behind the exterior cladding (to varying degrees depending on type). Any moisture that does penetrate the cladding is allowed to drain through the rainscreen cavity and out of the assembly at cross-cavity flashing locations. Further drying of the cavity is facilitated by evaporation and by ventilation of the cavity, which also removes any moisture that is driven inwards from absorptive claddings that are subject to solar heating.

Water-Resistive Barrier

The water-resistive barrier is the vapour-permeable sheathing membrane behind the exterior insulation. There are a variety of sheet products (loose and self-adhered) that could be used as well as some liquid-applied products. The sheathing membrane needs to be vapour permeable to allow for some outward migration of vapour, thereby minimizing condensation within the wall assembly. The mineral-fibre insulation placed outboard of the sheathing membrane will also create a drainage surface so that very minimal moisture is likely to reach the sheathing. Where foam insulation is used, the joints should be taped and sealed so that water does not penetrate through the insulation and potentially become trapped.

The assembly can accommodate several air-barrier strategies; however, the simplest approach is to use the vapour-permeable sheathing membrane/WRB (weather-resistant barrier) as the air-barrier membrane. The sheathing membrane is taped/sealed and sandwiched between the sheathing and the exterior insulation in this assembly, which addresses structural support. Applying a self-adhered or a liquid-applied vapour-permeable membrane to the sheathing would have comparable performance. Alternatively, a sealed-sheathing air-barrier strategy could be used. Continuity of this air-barrier membrane through details and interfaces is critical in terms of whole-building airtightness.

4.1.4 Vapour Barrier

Adding insulation to the exterior of the sheathing increases the temperature of the moisture-sensitive sheathing and framing and effectively shifts the dewpoint outside of the stud cavity. Mineral-fibre or glass fibre insulation is vapour-permeable and therefore does not affect placement of the interior vapour barrier in heating-dominated climates.

In heating climates, polyethylene provides the primary vapour-retarder layer in this assembly. Vapour-retarder paint may also provide an adequate vapour-flow-control layer if it is properly applied. As greater thicknesses of exterior insulation are added, the permeance of this vapour control layer can be increased, and latex paint could be sufficient in some assemblies.

If XPS is used as exterior insulation in heating climates, then the interior vapour-control-layer should be removed (no dual vapour barrier). In this case, greater care must be taken to control the indoor RH and minimize the amount of exterior moisture that reaches the sheathing membrane because the foam will restrict drying. Applying additional insulation on the exterior (i.e., to achieve a higher exterior-to-stud insulation ratio) would also serve to improve the performance.

In cooling-dominated climates (Zones 1 to 3) no interior vapour control is needed. The use of XPS as exterior insulation would control inward vapour flow in cooling-dominated climates.

4.1.5 Effective R-Values

Tables 4.1.1 to Table 4.1.4 summarize, for different exterior insulation and attachment methods based on three-dimensional thermal modelling, the effective R-values for 2x4 and 2x6 split-insulation walls with R-4 (RSI 0.7) and up to R-30 (RSI 5.3) of exterior insulation. These effective R-values account for a stud-wall framing factor of 25% (studs at 16 inches o.c., sill plates, double top plate, window headers, corners, built-up studs at windows, etc.).

The R-values provided include the screws through the insulation (assumed to be a maximum of #12 screws at 12-inch vertical spacing and 16-inch horizontal spacing) through the exterior insulation (Table 4.1.1 and Table 4.1.2), exterior insulation adhered without screws (Table 4.1.3), and exterior insulation fastened with intermittent thermal girt spacers (Table 4.1.4). Cladding-attachment methods are discussed in section 3.3.3 of Chapter 3. The use of #8 or #10 screws and greater spacing will result in less thermal bridging and slightly higher R-values; however, the corresponding tables are not provided here.

Table 4.1.1 Effective R-values for assembly of wood-frame walls with R-4/inch exterior split insulation (rigid-mineral fibre or EPS) and screw fasteners (#12 at 12x16 inches o.c.) though the insulation, by thickness of insulation. Stud wall consists of standard framing at 16 inches o.c. (25% framing factor) with insulation as shown.

Wood framing	**Nominal stud-space insulation [R-value (RSI)]**	**Exterior insulation**						
		None [R-value (RSI)]	**R-4 (1 inch)** [R-value (RSI)]	**R-8 (2 inches)** [R-value (RSI)]	**R-12 (3 inches)** [R-value (RSI)]	**R-16 (4 inches)** [R-value (RSI)]	**R-20 (5 inches)** [R-value (RSI)]	**R-24 (6 inches)** [R-value (RSI)]
2x4	**R-12 (2.1)**	10.7 (1.9)	15.0 (2.6)	18.8 (3.3)	22.5 (4.0)	26.2 (4.6)	29.7 (5.2)	33.2 (5.8)
	R-14 (2.5)	11.5 (2.0)	15.8 (2.8)	19.6 (3.4)	23.2 (4.1)	27.0 (4.8)	30.5 (5.4)	34.0 (6.0)
2x6	**R-19 (3.3)**	15.5 (2.7)	19.8 (3.5)	23.7 (4.2)	27.3 (4.8)	31.0 (5.5)	34.5 (6.1)	38.0 (6.7)
	R-22 (3.9)	16.6 (2.9)	21.0 (3.7)	24.8 (4.4)	28.5 (5.0)	32.2 (5.7)	35.7 (6.3)	39.2 (6.9)

Table 4.1.2 Effective R-values for assembly of wood-frame walls with R-5/inch exterior split insulation (rigid XPS) and screw fasteners (#12 at 12x16 inches o.c.) though the insulation, by thickness of insulation. Stud wall consists of standard framing at 16 inches o.c. (25% framing factor) with insulation as shown.

Wood framing	**Nominal stud-space insulation [R-value (RSI]**	**Exterior insulation**						
		None [R-value (RSI)]	**R-5 (1 inch)** [R-value (RSI)]	**R-10 (2 inches)** [R-value (RSI)]	**R-15 (3 inches)** [R-value (RSI)]	**R-20 (4 inches)** [R-value (RSI)]	**R-25 (5 inches)** [R-value (RSI)]	**R-30 (6 inches)** [R-value (RSI)]
2x4	**R-12 (2.1)**	10.7 (1.9)	15.9 (2.8)	20.6 (3.6)	25.1 (4.4)	29.6 (5.2)	33.9 (6.0)	38.1 (6.7)
	R-14 (2.5)	11.5 (2.0)	16.7 (2.9)	21.4 (3.8)	25.9 (4.6)	30.4 (5.4)	34.7 (6.1)	38.9 (6.9)
2x6	**R-19 (3.3)**	15.5 (2.7)	20.7 (3.6)	25.5 (4.5)	29.9 (5.3)	34.4 (6.1)	38.7 (6.8)	43.0 (7.6)
	R-22 (3.9)	16.6 (2.9)	21.9 (3.9)	26.6 (4.7)	31.1 (5.5)	35.6 (6.3)	39.9 (7.0)	44.1 (7.8)

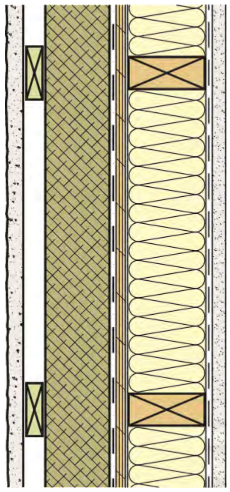
Table 4.1.3 Effective R-values for assembly of wood-frame walls with R-4/inch exterior insulation (rigid EPS with EIFS) adhered to the wall and no fasteners, by thickness of insulation. Stud wall consists of standard framing at 16 inches o.c. (25% framing factor) with insulation as shown.

Wood framing	**Nominal stud-space insulation [R-value (RSI]**	**Exterior insulation**						
		None [R-value (RSI)]	**R-4 (1 inch)** [R-value (RSI)]	**R-8 (2 inches)** [R-value (RSI)]	**R-12 (3 inches)** [R-value (RSI)]	**R-16 (4 inches)** [R-value (RSI)]	**R-20 (5 inches)** [R-value (RSI)]	**R-24 (6 inches)** [R-value (RSI)]
2x4	**R-12 (2.1)**	10.7 (1.9)	15.1 (2.7)	19.2 (3.4)	23.1 (4.1)	27.2 (4.8)	31.2 (5.5)	35.1 (6.2)
	R-14 (2.5)	11.5 (2.0)	15.9 (2.8)	20.0 (3.5)	24.0 (4.2)	28.0 (4.9)	32.0 (5.6)	35.9 (6.3)
2x6	**R-19 (3.3)**	15.5 (2.7)	19.9 (3.5)	24.0 (4.2)	28.0 (4.9)	32.0 (5.6)	36.0 (6.3)	39.9 (7.0)
	R-22 (3.9)	16.6 (2.9)	21.1 (3.7)	25.2 (4.4)	29.2 (5.1)	33.3 (5.9)	37.2 (6.6)	41.1 (7.2)

Table 4.1.4 Effective R-values for assembly of wood-frame walls with R-4.2/inch exterior split insulation (semi-rigid mineral fibre) and intermittent, thermal girt spacers spaced at 24 inches o.c. x 16 inches. Stud wall consists of standard framing at 16 inches o.c. (25% framing factor) with insulation as shown. (source: cascadiawindows.com)

Wood framing	**Nominal stud-space insulation [R-value (RSI]**	**Spacer depth for exterior insulation**				
		None [R-value (RSI)]	**3½-inch spacer (R-14.7)** [R-value (RSI)]	**4-inch spacer (R-16.8)** [R-value (RSI)]	**5-inch spacer (R-21.0)** [R-value (RSI)]	**6-inch spacer (R-25.2)** [R-value (RSI)]
2x4	**R-12 (2.1)**	10.7 (1.9)	24.4 (4.3)	26.1 (4.6)	29.3 (5.2)	32.4 (5.7)
2x6	**R-19 (3.3)**	15.5 (2.7)	29.6 (5.2)	31.2 (5.5)	34.4 (6.1)	37.5 (6.6)

SPLIT-INSULATION WALL ASSEMBLY: SUMMARY



PLAN VIEW

EXTERIOR

- Cladding
- Airspace (ventilated)
- 1x3 treated wood strapping, screwed through insulation
- Rigid mineral-fibre insulation or other suitable insulation (thickness to suit R-value requirement)
- Vapour-permeable sheathing membrane
- Sheathing (plywood or OSB)
- 2x4 or 2x6 wood framing with batt insulation
- Polyethylene film (cold climates only; removed where exterior foam insulation is used)
- Gypsum board and paint

INTERIOR

CONTROLLING EXTERIOR MOISTURE

This rainscreen wall assembly anticipates control of the majority of exterior moisture at the exterior cladding while recognizing that a small amount of incidental moisture will likely migrate behind the exterior cladding. Any moisture that does penetrate the cladding is allowed to drain through the rainscreen cavity that is behind the exterior cladding, and out of the assembly at cross-cavity flashing locations. Further drying of the cavity is facilitated by evaporation and by ventilation of the cavity.

Cladding (Water-Shedding Surface, First Plane of Protection)

Any type of cladding can be used with this wall assembly. The strategy for attaching the cladding will depend on the weight and support requirements for the cladding. With rigid insulation (rigid mineral fibre, 8 pcf and greater; XPS), the cladding can be attached to strapping that is screwed directly through the exterior insulation using long screws into the plywood sheathing or studs. Semi-rigid mineral or glass fibre insulation may also be used; however, the density of this insulation is insufficient to attach screws through the insulation. This approach requires the use of additional framing or discrete clip cladding supports.

Water-Resistive Barrier (Second Plane of Protection)

The water-resistive barrier is the vapour-permeable sheathing membrane. There are a variety of sheet products that could be used as well as some liquid-applied products. Where foam insulation is used, it is more critical that water does not penetrate through the insulation and potentially become trapped against the sheathing membrane.

CONTROLLING AIR FLOW: AIR BARRIER

The assembly can accommodate several air-barrier strategies; however, the simplest approach may be to use the vapour-permeable sheathing membrane (taped and sealed) as the primary air-barrier material. The sheathing membrane is sandwiched between the sheathing and the exterior insulation in this assembly and is therefore adequately supported. A sealed-sheathing or interior air-barrier strategy could also be used. Continuity of this air-barrier membrane through details and interfaces is critical in terms of whole-building airtightness.

CONTROLLING HEAT FLOW

Exterior Insulation

The amount of exterior insulation required will depend on stud wall framing (2x4 or 2x6), the framing factor, method of cladding attachment, and the R-value target for the assembly. Mineral-fibre or XPS insulation are appropriate.

Interior/Stud Insulation

Fibreglass, mineral-fibre insulation, or open-cell 1/2 pcf spray foam are appropriate insulation types. Closed-cell spray foam (2 pcf) may also be used, but tends to be more expensive than other options.

CONTROLLING VAPOUR FLOW: VAPOUR RETARDER

In heating climates, polyethylene provides the primary vapour-retarder layer in this assembly. Vapour-retarder paint may also be used. Mineral-fibre insulation is vapour permeable and therefore does not affect the placement of the interior vapour barrier in heating-dominated climates. If XPS is used then the interior vapour-control layer should be removed. The use of XPS requires an assessment of the safe split ratios, depending on the climate.

In cooling-dominated climates no interior vapour control should be provided. The use of XPS or polyiso as exterior insulation will provide adequate vapour-flow control because the dominant vapour drive is inward.

DETAILING

The detailing of split-insulation wall assemblies requires some simple modifications to standard wood-frame construction practices.

Continuity of the water-shedding surface is more critical in wall assemblies that utilize XPS insulation. Window sub-sill drainage should direct water to the exterior side of the XPS insulation.

Exterior gypsum sheathing may be required to meet the fire-protection code in some jurisdictions.

APPLICATION

This assembly as shown will perform well in all climate zones for all MURB exposure levels.

Pressure moderation may be considered for taller wood-frame buildings in exposed locations in wet climates in order to control rainwater penetration and reduce moisture loading within the rainscreen cavity.

In areas with low rain-water exposure, the need for a drained and ventilated rainscreen cavity becomes less critical and a concealed barrier approach may be suitable.

FACTORS LIMITING PERFORMANCE

The detailing of the cladding and flashing is important in order to restrict the amount of water that penetrates the water-shedding surface, and to allow open airflow at the top and bottom of the wall cavities in order for ventilation to occur.

The use of alternative insulation types to those mentioned above may negatively affect hygrothermal performance and must be carefully considered in the design of a split-insulation assembly.

The cladding attachment must be carefully considered. The support of lightweight claddings on vertical strapping attached through the insulation is acceptable in most cases. The support of heavier claddings may require intermittent clips, wood framing, or shear blocking (treated wood in wet areas).

The use of continuous metal flashing or other elements that bridge the exterior insulation will significantly reduce thermal effectiveness of the exterior insulation and would not be recommended. Details within Chapter 5 address many of these considerations.

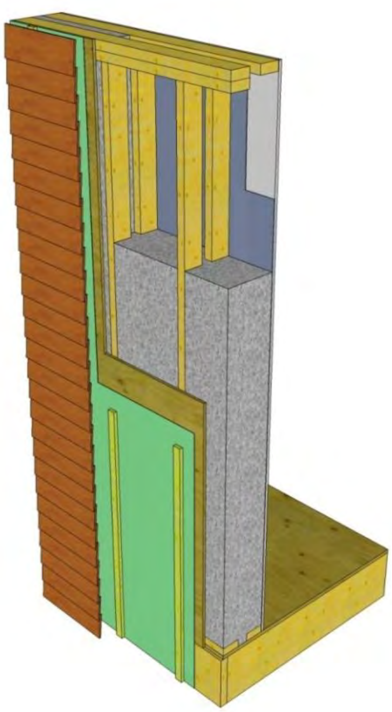
4.2 Double-Stud (or Deep Single-Stud) Insulated Wall Assembly

This above-grade wall assembly consists of a deeper stud cavity created by a double-stud (dual 2x4 or 2x6 framed walls with or without a gap between the two) or 2x8 or 2x10 framing filled with insulation. This generally results in thicker walls and could use site-built or pre-fabricated wall assembly. A wide variety of insulation products can be used, ranging from fibreglass or mineral-fibre batts or blown-in dense-pack fibrous-fill (fibreglass, mineral fibre, cellulose) to spray-foam insulation. See Fig. 4.2.1.

Very high effective R-values can be achieved with the construction of a 2x4 double-stud assembly by simply varying the gap between the two stud walls. Where lower effective R-values are needed, the use of 2x8 and 2x10s can be used. Deeper framing can also be achieved by using products such as I-joists and wall trusses.

The additional insulation R-value placed within the stud space results in slightly cooler sheathing temperatures compared to typical 2x6 framing, and may therefore lead to a slightly increased potential for moisture accumulation within this wall assembly. Continuity of the water-shedding surface, water-resistive barrier, and detailing at interfaces to address water infiltration are key factors in the success of this assembly. The use of treated plywood may be recommended in some climate zones to improve durability. The control of air flow through (infiltration/exfiltration) and within (convective looping) this assembly are both important for achieving insulation and moisture management. An effective air barrier at both sides of the cavity and proper insulation placement are therefore key focal points during construction.

Cladding is attached directly to the wall through vertical strapping (furring) using standard rainscreen detailing. Because this wall assembly contains more insulation and is more moisture sensitive, the use of rainscreen cladding is recommended in all climate zones to control rainwater penetration and inward vapour drive, and improve cladding durability.



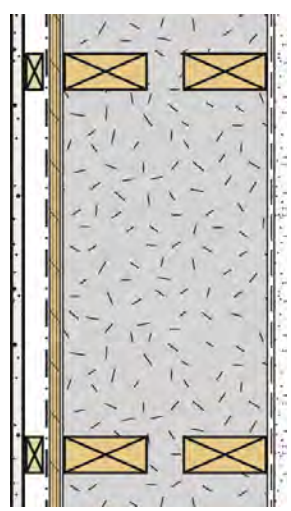


Fig. 4.2.1 Double-stud insulation wall assembly with dense-pack cellulose insulation (isometric sketch and plan view detail).

4.2.1 Controlling Heat Flow: Insulation Selection

Double-stud insulation consists of fibrous-fill insulation between the studs. A wide variety of insulation products can be used, ranging from fibreglass or mineral-fibre batts or densely packed blown-in fibrous fill (fibreglass, mineral fibre, cellulose), to open-cell spray foam. With fibrous-fill insulations, high-density blown-in products with integral binders are used to prevent settlement within the deep wall cavity. Protecting the insulation from fungal infection is also recommended. For blown-in cellulose this will mean using borate-treated products with installed densities equal to or greater than 4pcf. A cost-effective combination of open-cell spray foam and fibrous fill in a flash-and-fill application could also be considered in order to improve airtightness of the assembly and also reduce convective looping within the insulation. In this scenario the spray foam can be detailed as the airtight element, with the use of sealants and membranes to tie the centre of wall to other interfaces and details.

Pre-fabricated double-stud wall assembly. *Photo courtesy: Winton Global Homes*

4.2.2 Controlling Exterior Moisture

Water-Shedding Surface

This rainscreen wall assembly anticipates control of the majority of exterior moisture at the exterior cladding while recognizing that some incidental moisture will likely migrate behind the exterior cladding (to varying degrees, depending on type). Any moisture that does penetrate the cladding is allowed to drain through the rainscreen cavity between the exterior cladding, and out of the assembly at cross-cavity flashing locations. Further drying of the cavity is facilitated by evaporation, and by ventilation of the cavity, which also removes any moisture that is driven inwards from absorptive claddings that are subject to solar heating.

Water-Resistive Barrier

The water-resistive barrier is the vapour-permeable sheathing membrane. There are a variety of sheet products (loose and self-adhered) that could be used as well as some liquid-applied products. The sheathing membrane needs to be vapour permeable to allow for some outward migration of vapour, thereby minimizing condensation within the wall assembly.

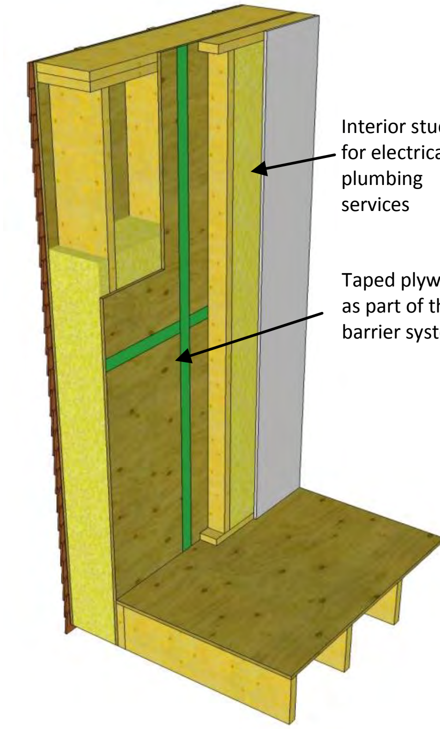
4.2.3 Air Barrier

The assembly can accommodate several air-barrier strategies; however, in all climate zones, the simplest approach is to use the vapour-permeable sheathing membrane as the air-barrier membrane at the exterior. The sheathing membrane is supported between the sheathing and the vertical strapping in this assembly, which addresses structural support. Applying self-adhered or liquid-applied vapour-permeable membrane to the sheathing would have comparable performance. Alternatively, a sealed-sheathing air-barrier strategy could be used. Continuity of this air-barrier membrane through details and interfaces is critical in terms of whole-building airtightness.

The polyethylene sheet at the interior should also be detailed to be airtight as a secondary air-barrier membrane in heating climates in order to prevent the flow of air into the insulated cavity from the interior and thus reduce the likelihood of convective looping. Where polyethylene is not required for vapour control, the drywall should be detailed airtight, along with electrical and other penetrations and interfaces.

An alternative air-barrier approach for deep- or double-stud insulated wood-frame walls is to use plywood or OSB at the interior of the stud wall as the air barrier. This approach is common in Europe and with pre-fabricated highly insulated walls. The plywood (or OSB) is sealed and joints are taped with special tapes designed for adhering to wood and to maintain adhesion and structure for the life of the building. The plywood (or OSB) also acts as the vapour retarder in this assembly, removing the need for polyethylene. An interior 2x4 stud wall is often constructed to the interior of the deep-stud wall in order to run electrical and plumbing services and thus avoiding any need to penetrate the plywood air barrier.

The same tapes could also be used on the exterior layer of plywood behind the water-resistant barrier, i.e., for airtightness of the exterior plywood as well.



Common Passivhaus wall assembly utilizing a deep, insulated, 2x10 or 2x12 stud wall (often pre-fabricated and balloon framed); taped and sealed plywood (or OSB) at the interior of the stud wall is the air barrier. Durability of the tapes is essential for air-barrier performance, and therefore specially developed tapes (often from Europe) are used for this approach.

4.2.4 Vapour Barrier

In heating-dominated climates, polyethylene provides the primary vapour-retarder layer in this assembly. Vapour-retarder paint may also provide an adequate vapour-flow-control layer provided it is properly applied.

If this wall were constructed in a cooling-dominated climate (Climate Zones 1 to 3), no vapour control would be needed in this assembly. Vapour-impermeable interior finishes should not be used in cooling-dominated climates with this assembly. The use of a ventilated cavity on the exterior will reduce inward vapour drive. In these climate zones the installation of 1 inch of XPS on the exterior of this assembly (i.e., a combination of a split-insulation wall and double-stud wall) could provide vapour control where necessary.

4.2.5 Effective R-Values

The effective R-values for double-stud, 2x8, and 2x10 stud cases are shown in Table 4.2.1 and Table 4.2.2. These effective R-values were determined using three-dimensional thermal modelling based on ASHRAE's published values and they account for a stud-wall framing factor of 25% (studs at 16 inches o.c., sill plates, double top plate, window headers, corners, built-up studs at windows, etc.). As shown, slight thermal improvements can be made with studs spaced at 24 inches o.c. (a framing factor of 22%) where structurally adequate; however, in taller MURBs, higher framing factors could be expected.

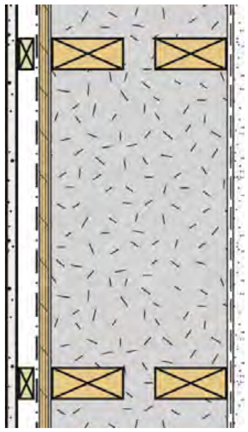
Table 4.2.1 Effective R-values, including losses due to thermal bridging, for double-stud walls with varying gap width between 2x4 stud walls, by gap width.

Wood framing	Nominal fill insulation [R-value/inch (RSI/cm)]	Gap width between stud walls						
		No gap [R-value (RSI)]	1-inch [R-value (RSI)]	2-inches [R-value (RSI)]	3-inches [R-value (RSI)]	4-inches [R-value (RSI)]	5-inches [R-value (RSI)]	6-inches [R-value (RSI)]
Double-stud 2x4	**R-3.4/inch (0.24/cm)**	19.1 (3.4)	22.9 (4.0)	26.5 (4.7)	30.0 (5.3)	33.4 (5.9)	36.9 (6.5)	40.3 (7.1)
	R-4.0/inch (0.28/cm)	20.5 (3.6)	25.1 (4.4)	29.4 (5.2)	33.4 (5.9)	37.4 (6.6)	41.5 (7.3)	45.4 (8.0)

Table 4.2.2 Effective R-values for 2x4, 2x6, 2x8, and 2x10 stud walls, by framing factor.

Wood framing	Nominal fill insulation [R-value/inch (RSI/cm)]	Framing factor	
		25% (16 inches o.c.) [R-value (RSI)]	22% (24 inches o.c.) [R-value (RSI)]
2x4	**R-3.4/inch [R-12] (0.24/cm [RSI 2.1])**	10.7 (1.9)	11.0 (1.9)
	R-4.0/inch [R-14] (0.28/cm [RSI 2.5])	11.5 (2.0)	11.8 (2.1)
2x6	**R-3.4/inch [R-12] (0.24/cm [RSI 2.1])**	15.5 (2.7)	16.1 (2.8)
	R-4.0/inch [R-14] (0.28/cm [RSI 2.5])	16.6 (2.9)	17.4 (3.1)
2x8	**R-3.4/inch [R-25] (0.24/cm [RSI 4.4])**	19.6 (3.5)	21.1 (3.7)
	R-4.0/inch [R-29] (0.28/cm [RSI 5.1])	21.1 (3.7)	22.8 (4.0)
2x10	**R-3.4/inch [R-25] (0.24/cm [RSI 4.4])**	24.4 (4.3)	25.4 (4.5)
	R-4.0/inch [R-29] (0.28/cm [RSI 5.1])	26.3 (4.6)	27.5 (4.8)

DOUBLE-STUD INSULATED WALL ASSEMBLY: SUMMARY



PLAN VIEW

EXTERIOR

- Cladding
- Airspace
- Treated wood strapping
- Vapour permeable sheathing membrane
- Sheathing (plywood or OSB)
- 2x4 double-stud framing with fibrous-fill or spray-foam insulation
- Polyethylene film (where necessary for vapour control)
- Gypsum board

INTERIOR

CONTROLLING EXTERIOR MOISTURE

This rainscreen wall assembly anticipates control of the majority of exterior moisture at the exterior cladding while recognizing that a small amount of incidental moisture will likely migrate behind the exterior cladding. Any moisture that does penetrate the cladding is allowed to drain through the rainscreen cavity behind the exterior cladding, and out of the assembly at cross-cavity flashing locations. Further evaporative drying of the cavity is facilitated by ventilation.

Cladding (Water-Shedding Surface, First Plane of Protection)

Any type of cladding can be used with this wall assembly; attachment strategies will be similar to those used on 2x4/2x6 framed walls.

Water-Resistive Barrier (Second Plane of Protection)

The water-resistive barrier is the vapour-permeable sheathing membrane. There are a variety of sheet products (loose and self-adhered) that could be used, as well as some liquid-applied products. In heating-dominated climates, the sheathing membrane needs to be vapour permeable to allow for outward migration of vapour, thereby minimizing condensation within the wall assembly.

CONTROLLING AIR FLOW: AIR BARRIER

The assembly can accommodate several air-barrier strategies; however, the simplest approach is to use the vapour-permeable sheathing membrane as the primary air-barrier material. The sheathing membrane is supported between the sheathing and the vertical strapping, which addresses structural support. The application of a self-adhered or liquid-applied vapour-permeable membrane to the sheathing could also be used and would have comparable performance. Alternatively, a sealed-sheathing air-barrier strategy could be used. Continuity of this air-barrier membrane through details and interfaces is critical in terms of whole-building airtightness.

In heating climates, the polyethylene sheet at the interior should also be detailed to be airtight as a secondary air-barrier membrane in order to prevent the flow of air into the insulated cavity from the interior and thereby reduce the potential for convective looping (i.e., act as a convection suppressor). Where polyethylene is not required for vapour control, the drywall should be detailed airtight, along with electrical penetration and other interfaces, to perform a similar function.

CONTROLLING HEAT FLOW

The double-stud insulation consists of fibrous-fill insulation between the studs of the double-stud assembly. A wide variety of insulation products can be used, from fibreglass or mineral-fibre batts or densely packed blown-in fibrous fill (fibreglass, mineral fibre, cellulose), to open or closed-cell spray foam. With fibrous-fill insulations, high-density blown-in products with integral binders are used to prevent settlement within the deep wall cavity. A cost-effective combination of spray foam and fibrous fill in a flash-and-fill application could also be considered to improve airtightness of the assembly and to reduce convective looping within the insulation. In this scenario the spray foam can be detailed as the airtight element, with sealants and membranes to tie the centre of wall to other interfaces and details.

CONTROLLING VAPOUR FLOW: VAPOUR RETARDER

In heating-dominated climates, the polyethylene provides the primary vapour-retarder layer in this wall assembly. Vapour-retarder paint may also provide an adequate vapour-flow-control layer provided it is properly applied.

In cooling-dominated climates, no interior vapour control would be needed in this assembly. In addition, vapour-impermeable interior finishes should not be used in cooling-dominated climates with this assembly. The use of a ventilated cavity on the exterior will reduce inward vapour drive. In cooling climate zones the installation of 1 inch of foam insulation on the exterior of this assembly (i.e., a combination of a split-insulation and double-stud wall) could provide vapour control if necessary.

DETAILING

The detailing of the critical barriers (air, water-resistive barrier, vapour) within double-stud or deep-stud wall assemblies is similar to a 2x4 or 2x6 framed wall with the added wall depth. Window placement within the deeper wall cavity may be a factor for performance and aesthetics.

Exterior gypsum sheathing may be required to meet the fire-protection code in some jurisdictions, i.e., in addition to wood sheathing, which is required for lateral load provisions. The water-resistant barrier would be installed on the exterior side to protect the gypsum sheathing from wetting. In a sealed-sheathing air-barrier strategy, the exterior gypsum sheathing would be sealed instead of the plywood/OSB. Gypsum is vapour permeable but has a low moisture storage capacity compared to wood, and therefore the recommendations provided here for the control of moisture would be more critical in this assembly.

APPLICATION

This assembly as shown will perform well in all climate zones and for all MURB exposure levels. Structural sheathing with higher vapour permeability is preferred to improve the drying potential. In addition, the use of treated plywood or OSB as the exterior sheathing may be recommended in some climate zones to improve durability and reduce the risk of fungal growth.

In exposed locations in wet climates, cladding pressure moderation may be considered for taller wood-frame buildings to control rainwater penetration and reduce moisture loading within the rainscreen cavity.

FACTORS LIMITING PERFORMANCE

Detailing of the cladding and flashing are important in order to restrict the amount of water that penetrates the water-shedding surface and to allow open airflow at the top and bottom of the wall cavities for ventilation.

The additional insulation placed within the stud space results in slightly cooler sheathing temperatures compared to those in typical 2x6 framing, thus slightly increasing the potential for moisture accumulation within this wall assembly.

Control of air flow through and within this assembly (i.e., by convective looping) is important for achieving effective insulation and moisture-management performance. Therefore an effective air barrier on both sides of the insulation and proper insulation placement are key focal points during construction. Placing spray foam within the cavity would also address this concern but it may be a more expensive option.

Cladding is attached directly to the wall through vertical strapping (furring) using standard rainscreen detailing. As this wall assembly contains more insulation and is more moisture sensitive, the use of rainscreen claddings are recommended in all climate zones to control rainwater penetration and vapour drive, and improve cladding durability.

4.3 Exterior-Insulated Mass Timber Panel

This above-grade wall assembly uses mass timber panels (i.e., CLT) as the structure. This assembly achieves high effective R-values by the use of continuous rigid or semi-rigid insulation installed outside of the panels and by the use of thermally efficient cladding attachments. See Fig. 4.3.1.

See the *Cross-Laminated Timber Handbook* (Canadian Edition) and *Cross-Laminated Timber Handbook* (U.S. Edition) for additional information on thermal insulation and moisture management of CLT building-enclosure assemblies.

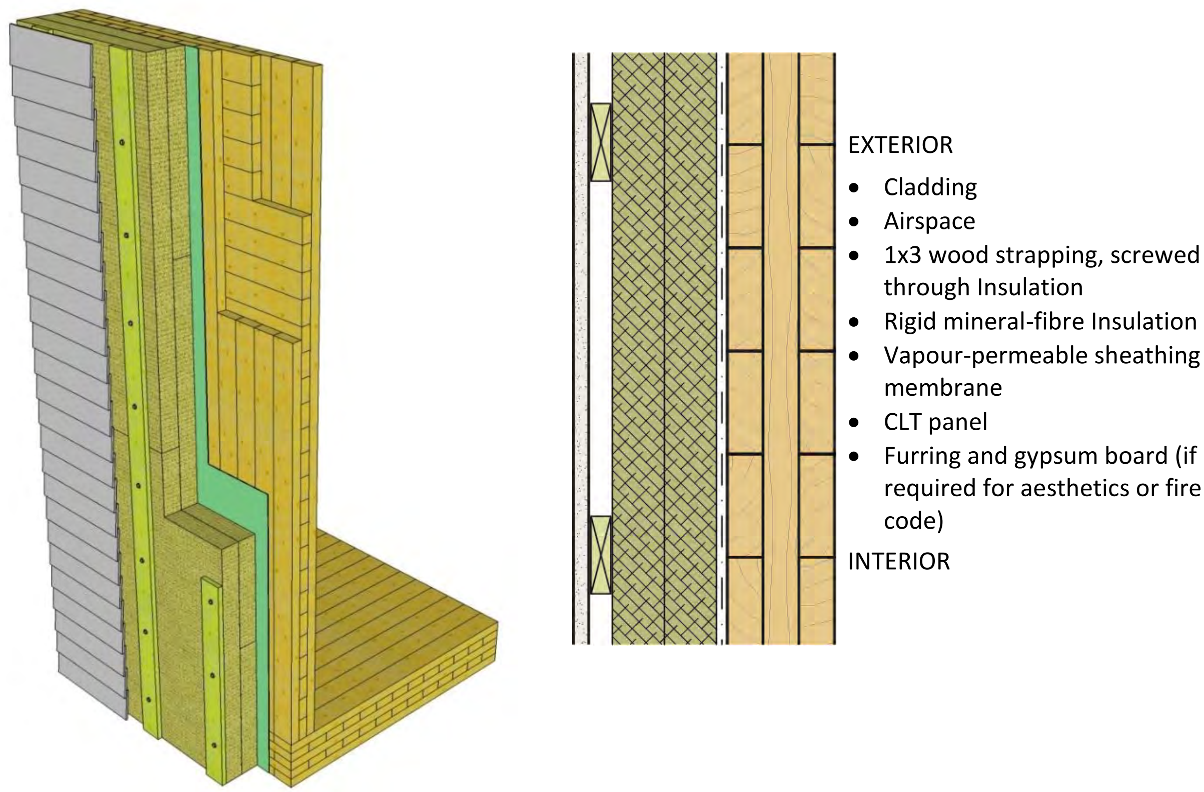


Fig. 4.3.1 Exterior-insulated mass timber panel assembly (isometric sketch and plan view detail).

4.3.1 Insulation Placement

The CLT panel itself has some nominal thermal resistance value (R-1.2/inch), but on its own it is insufficient for achieving a thermally efficient building, let alone minimum code compliance. Additional insulation should be placed on the exterior of the CLT panels in an exterior-insulated assembly as shown. Exterior insulation increases the temperature of the moisture-sensitive wood panels and reduces the risk for wetting from air leakage and vapour flow from inside in cold climates. Warmer wood temperatures also mean that drying is faster with vapour-permeable exterior insulation should the panels become wet from rain or condensation.

There may be a desire to place additional insulation on the interior side of this CLT panel (i.e. for providing space for servicing). This will reduce the temperature of the CLT panel and may result in decreased durability in some climate zones. If insulation is placed on the interior side, it should be done only in conjunction within exterior insulation. No more than one-third of the total nominal insulation R-value should be placed to the interior of the CLT panel (i.e., two-thirds of R-value outside to one-third of R-value inside). The interior insulation should be vapour-permeable mineral or glass fibre to allow drying, because the CLT is a vapour retarder (or barrier) itself.

Large CLT wall panels make up most of the structure of the building and provide a substrate for the water resistive barrier and exterior insulation.

4.3.2 Selection of Exterior Insulation

Semi-rigid or rigid mineral-fibre or glass fibre and extruded polystyrene (XPS) insulations are recommended for use in exterior rainscreen cavity applications. Rigid mineral fibre / glass fibre is naturally moisture resistant, but is treated with oils to make it more hydrophobic and moisture tolerant. It is also free draining, and will not accumulate moisture, which makes it suitable for exterior cavity insulation. The use of lower density fibreglass and mineral-fibre batts intended for stud-cavity use would not be suitable in this application. Foam insulation, including XPS, is moisture resistant and suitable for much wetter uses (such as below grade and inverted roofs), and is therefore suitable for the cavity insulation. Higher densities of expanded polystyrene (EPS) may also be suitable. Polyisocyanurate (faced) can also be used, provided that the core is protected from moisture.

The use of vapour-open semi-rigid or rigid mineral fibre / glass fibre provides for the best durability of the wood-frame assembly and best hygrothermal performance in most climate zones. The use of vapour-tight foam insulation (EPS, XPS, or polyiso) may be considered in some climates to control inward vapour flow when non-ventilated absorptive cladding systems are used. Fire codes are evolving regarding the use of mass timber construction for MURBs, and the use of non-combustible insulation such as rigid mineral fibre may be required in some jurisdictions versus combustible foam insulations.

The construction and detailing of a ventilated cavity outside of the insulation is recommended in all climate zones. Benefits of cladding ventilation include control of inward vapour drive that can wet the CLT panels through the vapour-open exterior insulation, and reduced cladding temperatures in warm climates, which serves to reduce heat gain. The creation of this cavity is formed by standard cladding attachment using exterior vertical strapping and thus requires little additional detailing effort.

4.3.3 Cladding Support

Any type of cladding can be used with this wall assembly. The strategy for attaching the cladding will depend on the weight and support requirements for the cladding. Most claddings can be attached directly to the vertical strapping, which itself is attached directly through the insulation to the primary structure.

The compressive strength of the exterior insulation will determine the potential cladding-attachment strategies. With rigid insulation (rigid mineral fibre / glass fibre, XPS, EPS, Polyiso), the simplest strategy is to attach the cladding to 1x3 strapping that is screwed directly through the exterior insulation using long screws into the panels.

The use of 1x3 strapping cut from plywood (i.e. pre-treated with preservative) rather than lumber will reduce splitting and provide a more robust nail base for cladding attachment.

Semi-rigid mineral or glass-fibre insulation may also be used; however the density of this insulation is insufficient for cladding attachments that require screws through the insulation. This approach requires the use of exterior framing or discrete clip cladding supports such as those presented earlier in this chapter. With CLT panels, clip attachments may be placed anywhere within the panel, unlike many other strategies which may need to align with the structural studs.

4.3.4 Controlling Exterior Moisture

Water-Shedding Surface

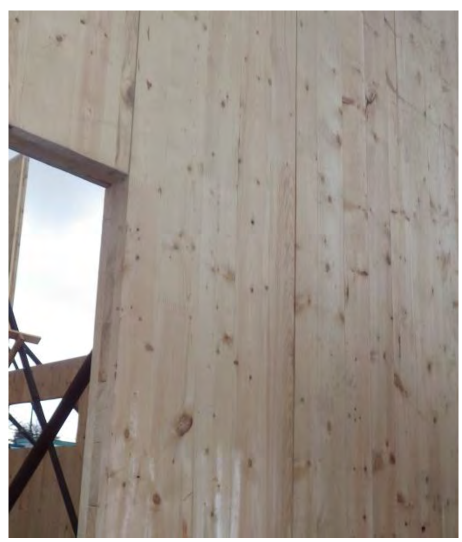
This rainscreen wall assembly anticipates control of the majority of exterior moisture at the exterior cladding while recognizing that some incidental moisture will likely migrate behind the exterior cladding (to varying degrees, depending on type). Any moisture that does penetrate the cladding is allowed to drain through the rainscreen cavity, and out of the assembly at cross-cavity flashing locations. Further drying of the cavity is facilitated by evaporation and by ventilation of the cavity, which also removes any moisture that is driven inwards from absorptive claddings that are subject to solar heating.

Water-Resistive Barrier

The water-resistive barrier is the vapour-permeable sheathing membrane that is attached to the CLT panel behind the exterior insulation. There are a variety of sheet products (loose and self-adhered) that could be used, as well as some liquid-applied products. The sheathing membrane needs to be vapour permeable to allow for some outward migration of vapour, thereby minimizing wetting within the wall assembly. The mineral-fibre insulation placed outboard of the sheathing membrane will also create a drainage surface so that very minimal moisture is likely to reach the sheathing.

4.3.5 Air Barrier

The CLT panels themselves may not be airtight due to wood shrinkage and the gaps between the individual wood pieces that make up the panels. In addition, the continuity between panel joints needs to be addressed. Because a water-resistive barrier is required on the exterior of the panels, the simplest approach is to use this membrane as the air barrier. The sheathing membrane is sandwiched between the CLT and the exterior insulation in this assembly, which addresses structural support. The application of a self-adhered or liquid-applied vapour-permeable membrane to the sheathing would have comparable performance. Continuity of this air-barrier membrane through details and interfaces is critical in terms of whole-building airtightness.



Shrinkage gaps between the wood pieces and panels in service make CLT panels generally difficult to make air tight, therefore a separate air barrier membrane is recommended.

4.3.6 Vapour Barrier

Adding insulation to the exterior of the sheathing increases the temperature of the moisture-sensitive sheathing and framing and effectively shifts the dewpoint outside of the CLT panel. Mineral-fibre insulation is vapour permeable; therefore, in heating-dominated climates, it does not affect the placement of the interior vapour barrier.

The vapour permeance of a 3½-inch-thick softwood CLT panel is <0.5 US perms at normal indoor RH levels, based on the typical vapour permeance of solid softwood. Therefore, the CLT panel itself will control the flow of vapour through the assembly in most situations. No additional vapour-retarding layers such as polyethylene or self-adhered membranes are required in this assembly because the intention is to allow as much drying through this assembly as possible, while still allowing flow to occur slowly through the CLT panels. This is particularly important in cooling-dominated climates where inward vapour drive would be restricted by these layers.

4.3.7 Effective R-Values

The effective R-values for exterior insulated CLT panel walls with 3 to 8 inches of R-4/inch and R-5/inch exterior insulation are summarized in Table 4.3.1. These effective R-values are determined using three-dimensional thermal modelling which accounts for the wood within the 3½-inch CLT panel (R-1.2/inch) and the screws (assumed for modelling purposes to be a maximum of #12 screws at 12-inch vertical spacing and 16-inch horizontal spacing) through the exterior insulation. The use of #8 or #10 screws and greater spacing will result in less thermal bridging and slightly higher R-values; however, the corresponding tables are not provided here. For comparison, Table 4.3.2 provides the effective R-values for an alternative cladding strategy that uses thermal girt spacers in depths of 3½ to 6 inches with semi-rigid mineral fibre, and Table 4.3.3 provides effective R-values of adhered insulation (i.e., EIFS or other adhered approach). To determine the effective R-value for 5½-inch CLT panels, R-2.4 can be added to each of the R-values in these two tables.

Table 4.3.1 Effective R-values for assembly of mass timber CLT panels with R-4/inch or R-5/inch exterior insulation and screw fasteners (#12 at 12x16 inches o.c.) though the insulation, by thickness of insulation.

Wood framing	Exterior insulation [R-value/inch (RSI/cm)]	**Exterior insulation thickness**					
		3 inches R-value (RSI)]	4 inches [R-value (RSI)]	5 inches [R-value (RSI)]	6 inches [R-value (RSI)]	7 inches [R-value (RSI)]	8 inches [R-value (RSI)]
3½-inch-thick CLT panels	**R-4/inch (0.28/cm)**	17.2 (3.0)	20.9 (3.7)	24.4 (4.3)	27.9 (4.9)	31.6 (5.6)	35.0 (6.2)
	R-5/inch (0.34/cm)	19.8 (3.5)	24.4 (4.3)	28.7 (5.1)	32.9 (5.8)	37.3 (6.6)	41.5 (7.3)

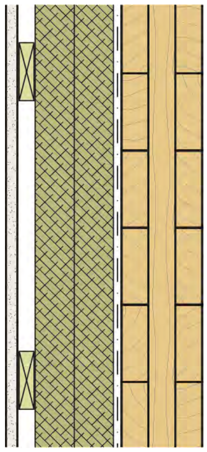
Table 4.3.2 Effective R-values for assembly of mass timber CLT panels with R-4.2/inch exterior insulation (semi-rigid mineral fibre, R-4.2/inch) and thermal girt spacers spaced at 24 inches o.c. x 16 inches, by spacer depth. (Source: cascadiawindows.com)

Wood framing	**Spacer depth and exterior insulation value**			
	3.5-inch spacer, R-14.7 [R-value (RSI)]	**4-inch spacer, R-16.8** [R-value (RSI)]	**5-inch spacer, R-21.0** [R-value (RSI)]	**6-inch spacer, R-25.2** [R-value (RSI)]
3.5-inch-thick CLT panels	16.4 (2.9)	18.0 (3.2)	21.1 (3.7)	24.2 (4.3)

Table 4.3.3 Effective R-values for assembly of mass timber CLT panels with R-4/inch or R-5/inch exterior insulation adhered to the wall and no fasteners, by thickness of insulation.

Wood framing	**Exterior insulation layer, [R-value/inch (RSI/cm)]**	**Exterior insulation thickness**					
		3-inches [R-value (RSI)]	**4 inches** [R-value (RSI)]	**5 inches** [R-value (RSI)]	**6 inches** [R-value (RSI)]	**7 inches** [R-value (RSI)]	**8 inches** [R-value (RSI)]
3½-inch-thick CLT panels	**R-4/inch (0.28/cm)**	17.8 (3.1)	21.9 (3.9)	25.8 (4.5)	29.7 (5.2)	33.8 (6.0)	37.8 (6.7)
	R-5/inch (0.34/cm)	20.7 (3.6)	25.8 (4.5)	30.7 (5.4)	35.6 (6.3)	40.7 (7.2)	45.6 (8.0)

EXTERIOR-INSULATED MASS TIMBER PANEL: SUMMARY



PLAN VIEW

EXTERIOR

- Cladding
- Airspace
- 1x3 wood strapping, screwed through insulation
- Rigid mineral-fibre insulation or other suitable insulation (thickness to suit R-value requirement)
- Vapour-permeable sheathing membrane
- CLT panel
- Furring and gypsum board (if required for aesthetics or fire code; no interior vapour control in any climate)

INTERIOR

CONTROLLING EXTERIOR MOISTURE

This rainscreen wall assembly anticipates control of the majority of exterior moisture at the exterior cladding while recognizing that a small amount of incidental moisture will likely migrate behind the exterior cladding (to varying degrees depending on type). Any moisture that does penetrate the cladding is allowed to drain through the rainscreen cavity behind the exterior cladding, and out of the assembly at cross-cavity flashing locations. Further drying of the cavity is facilitated by evaporation and by ventilation of the cavity.

Cladding (Water-Shedding Surface, First Plane of Protection)

Any type of cladding can be used with this wall assembly. The strategy for attaching the cladding will depend on the weight and support requirements for the cladding. With rigid insulation (rigid mineral fibre, 8 pcf and greater; XPS), the cladding can be attached to strapping that is screwed directly through the exterior insulation using long screws into the CLT panel. Semi-rigid mineral or glass fibre insulation may also be used, however the density of this insulation is insufficient to attach with screws through the insulation. This approach requires the use of additional framing or discrete clip cladding supports.

Water-Resistive Barrier (Second Plane of Protection)

The water-resistive barrier is the vapour-permeable sheathing membrane. There are a variety of sheet products that could be used, as well as some liquid-applied products. The sheathing membrane needs to be vapour permeable to allow for some outward migration of vapour in any climate.

CONTROLLING AIR FLOW: AIR BARRIER

The CLT panels themselves are usually not sufficiently airtight to be an air barrier due to the potential gaps between the individual wood pieces that make up the panels. In addition, the continuity between panel joints needs to be addressed. Because a water-resistive barrier is required on the exterior of the panels, the simplest approach is to use this membrane as the air barrier, with all joints tapped and sealed where necessary. The sheathing membrane is sandwiched between the CLT and the exterior insulation in this assembly, which addresses structural support. The application of a self-adhered or liquid-applied vapour-permeable membrane to the sheathing would have comparable performance. Continuity of this air-barrier membrane through details and interfaces is critical in terms of whole-building airtightness.

CONTROLLING HEAT FLOW

Exterior insulation serves to keep the CLT panels warm and dry. The use of rigid or semi-rigid mineral-fibre /glass fibre insulation is recommended on the exterior. Mineral or glass fibre is vapour open and also hydrophobic and will not readily absorb or retain moisture. Any moisture that incidentally enters the exterior insulation will drain out or dry by vapour diffusion. The amount of exterior insulation required will depend on the R-value target for the assembly.

If insulation must be placed on the interior side of the CLT panels, it should only be done in conjunction with exterior insulation. In order to not affect the assembly durability, no more than one-third of the total the nominal insulation R-value should be placed to the interior of the CLT panel (i.e., two-thirds of R-value outside to one-third of R-value inside). The interior insulation should be vapour-permeable mineral or glass fibre to allow drying.

The use of vapour-tight foam insulation (EPS, XPS, or Polyiso) may be considered to control inward vapour flow. The use of non-combustible insulation such as rigid mineral fibre may be required in fire codes in some jurisdictions.

CONTROLLING VAPOUR FLOW: VAPOUR RETARDER

The CLT panel itself will control the flow of vapour through the assembly in most situations. No additional vapour-retarding layers such as polyethylene or self-adhered membranes are required in this assembly because the intention is to allow as much drying through this assembly as possible. This is particularly important in cooling-dominated climates where inward vapour drive would be restricted by these layers, and in cases where the CLT panels get wet during construction.

DETAILING

Detailing of wall assemblies comprised of exterior-insulated CLT mass timber panel requires some simple modifications to standard wood-frame construction practices. Some details for CLT walls are provided in Chapter 5.

APPLICATION

This assembly as shown will perform well in all climate zones and for all MURB exposure levels.

In exposed locations in wet climates, pressure moderation may be considered for taller wood-frame buildings in order to control rainwater penetration and reduce moisture loading within the rainscreen cavity.

FACTORS LIMITING PERFORMANCE

Detailing of the cladding and flashing is important in order to restrict the amount of water that penetrates the water-shedding surface, and to allow open airflow at the top and bottom of the wall cavities in order for ventilation to occur.

The use of insulation types that are alternative to those mentioned above may negatively affect hygrothermal performance and must be carefully considered in the design of a split-insulation assembly.

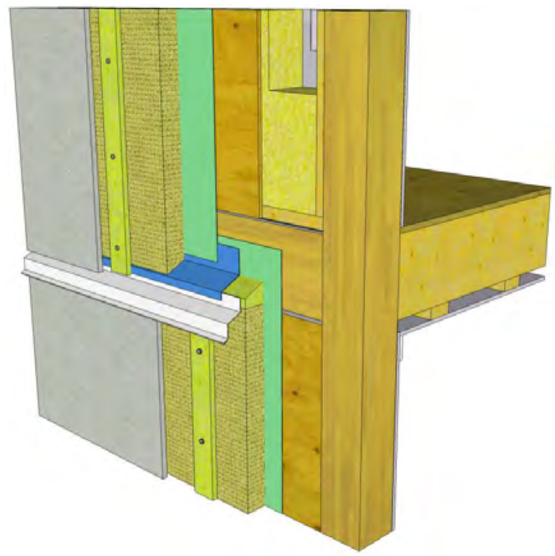
Cladding attachment must be carefully considered. The support of lightweight claddings on vertical strapping attached through the insulation is acceptable. The support of heavier claddings may consider the use of intermittent clips or wood shear blocks.

There may be a desire to place additional insulation on the interior side of this CLT panel. This will reduce the temperature of the CLT panel and may result in decreased durability in some climate zones.

4.4 Wood-Frame Infill Wall for Wood Post-and-Beam Construction

Wood post-and-beam construction is not common in residential MURB construction; however, it is frequently used in recreational, custom residential, and other buildings that often require heavy timber framing for structural loads, or in buildings where the timber members are designed to be features of the interior or exterior finish.

The assembly of a non-bearing, wood-frame, exterior infill wall between post-and-beam construction would be split insulated or exterior insulated to insulate over the heavy timber members on the exterior. Without such exterior insulation the timber posts and beams would become thermal bridges in the building enclosure, although timbers offer a considerable level of insulation themselves.



Post-and-beam wood-frame construction uses large wood members for structure and non-bearing wood-frame infill walls. Split or exterior-insulated assemblies address thermal bridging at large framing members.

The building-enclosure design of such wood-frame walls should follow the guidance covered in Sections 4.1 and 4.3. The interior finish of the columns and beams may be left exposed, similar to CLT walls of some buildings, where fire codes allow.

Key design considerations for this infill wall are that it is not a gravity load-bearing wall, and that it must be installed with provisions to allow for deflection of the load-bearing beams. A deflection allowance (gap) is provided at the top of each infill wall. The gap will also make it more convenient to install the infill wall panels; however, it is critically important to seal the gaps properly, such as by using foam and rubber gaskets, to achieve the required airtightness and to improve durability performance. Selected details are provided in Chapter 5.

The effective-R values provided for split-insulation walls (Section 4.1) provided estimated R values for the application of wood-frame infill wall panels. Thermal calculation is required for detailed assemblies, depending on the assembly design and the size of the structural members.

4.5 Wood-Frame Infill Wall for Concrete-Frame Buildings

Potentially, wood-frame infill walls can be used as non-bearing exterior walls in mid- and high-rise buildings framed with non-combustible concrete or steel. This has been a practice in northern Europe for a few decades. The opportunity to use wood-based infill walls in these applications could provide significant thermal improvement over traditional steel stud or concrete block infill walls.

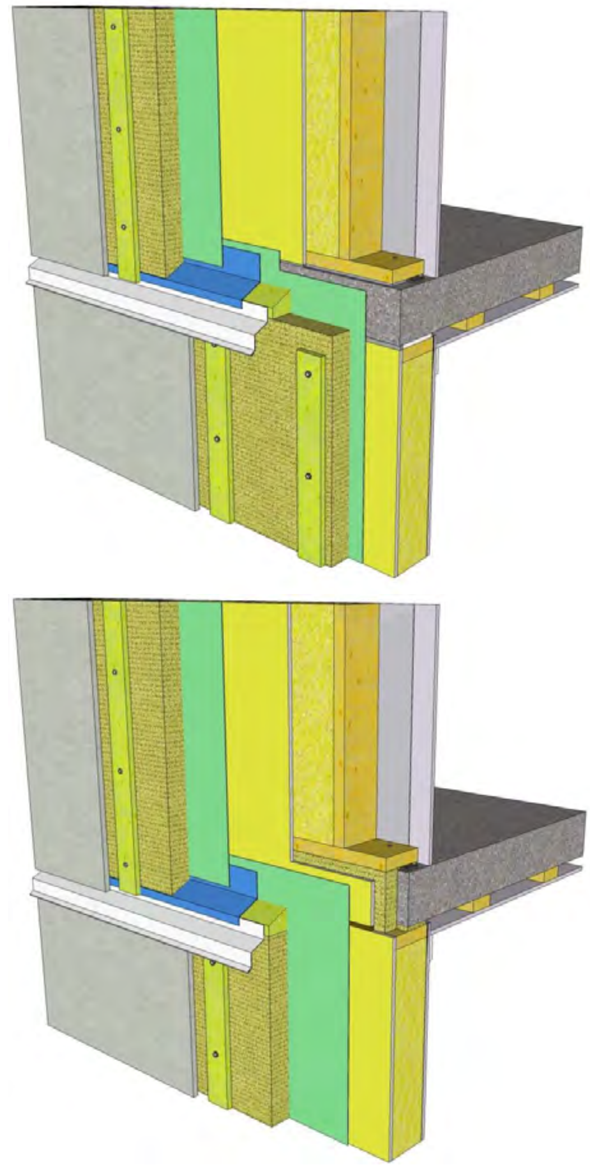
Current Canadian and American building codes have restrictions about the use of combustible materials in non-combustible buildings (taller than 3 storeys). Designers must provide assemblies and other solutions to satisfy the fire and safety requirements. This may involve using additional fire-protection methods such as non-combustible cladding, fire-retardant-treated wood, gypsum sheathing, or sprinkler arrangements.

The infill wall assembly could be insulated in the stud cavity, split insulated, or exterior insulated. Higher performance walls would likely be split insulated, following the guidance covered in Section 4.1. The wood framing and sheathing may be installed flush with the concrete slab (flush) or overhanging the slab edge (overhanging). The overhanging arrangement allows for insulation to be installed on the exterior of the concrete slab edge to reduce thermal bridging.

Key design considerations for a non-bearing wood-frame exterior infill wall are that it is not gravity load bearing, and that it must be installed with provisions for allowing deflection of the main building structure (i.e., slab-edge deflection tolerances). Similar to that for infill steel studs, a deflection allowance of ½ to ¾ inches is typically provided at the top of each infill wall panel. With wood framing this top attachment can be made using 90-degree metal clips attached to the underside of the slab and attached with slotted connections to the top plate of the wood-frame wall.

A conceptual sketch is shown for an overhanging infill wall and a flush installed wall with exterior insulation over the wall panel. Additional details are provided in Chapter 5.

The effective-R values provided for split-insulation walls (Section 4.1) provided estimated R values for the application of wood-frame infill wall panels. Further thermal calculation is necessary to account for the concrete slab edge and detailing of this condition.



Exterior insulated, wood-frame infill wall for concrete structures: flush and overhanging.

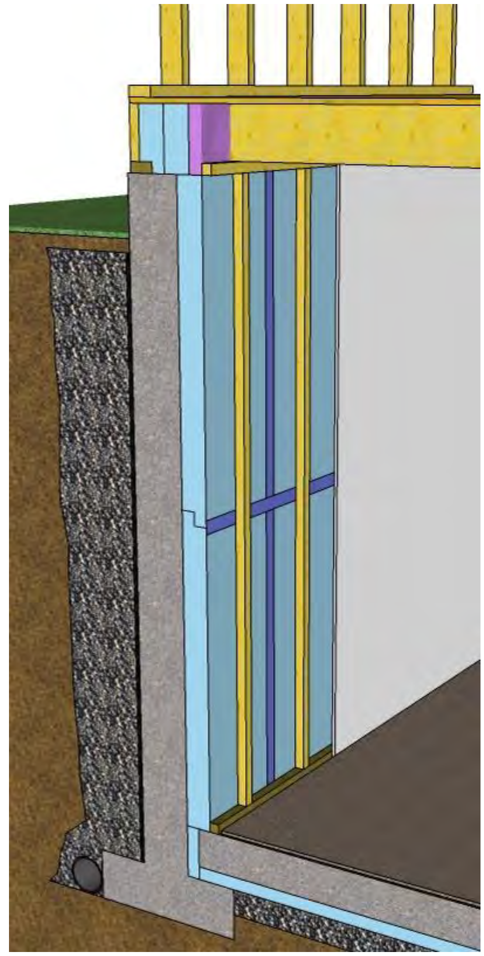
4.6 Comparison of Highly Insulated Exterior Wall Assemblies

Table 4.6.1 provides a summary of many of the benefits and limitations of each of the highly insulated exterior wall assemblies presented in the previous sections. Some of the benefits or limitations may be climate dependant.

Table 4.6.1 Highly insulated exterior wall assemblies: benefits and limitations.

Wall-insulation strategy	Benefits	Limitations
Split insulation: vapour-open exterior (mineral fibre, glass fibre)	• Thermally efficient; minimizes thermal bridging through exterior insulation combined with optimized cladding supports. • Increases durability; performs better hygrothermally than a traditional stud-insulated wall in heating climates. • Attachment of cladding to exterior strapping results in a rainscreen wall assembly. • Protected air barrier (limited penetrations).	• New construction method to many trades. • Sequencing is important. • Cladding attachment through the exterior insulation must be considered. • Inward vapour drive from absorptive claddings must be addressed in wet/humid climate zones by use of ventilated claddings. • Drained/ventilated rainscreen assembly details are new to many jurisdictions in North America.
Split insulation: vapour-closed exterior (foam)	• Thermally efficient; minimizes thermal bridging through exterior insulation with optimized cladding supports. • Potential for inward vapour drive can be addressed in hot–humid climates by applying foam insulation on exterior. • Attachment of cladding to exterior strapping results in a rainscreen wall assembly. • Provides a protected air barrier (limited penetrations).	• New construction method to many trades. • Sequencing is important. • Cladding attachment through the exterior insulation must be considered. • Hygrothermally does not perform as well as vapour-open exterior insulation in heating climates. • In heating climates care must be taken to avoid dual vapour barrier scenario (poly or other impermeable interior finish). • In heating climates, need to use more exterior foam to reduce moisture risk from condensation or accidental wetting. • Drained/ventilated rainscreen assembly details are new to many jurisdictions in North America.
Double-stud insulation	• Trade is familiar with stud-wall details and traditional placement of air/vapour/water-resistant barrier control layers—minor change from standard practice. • Trade is familiar with cladding attachment—no difference from standard practice.	• Generally results in thicker walls resulting in less interior floor space. • Has a higher risk of moisture damage from rainwater penetration and air leakage than a traditional 2x6 wall. • Has a higher risk of moisture damage than a split-insulation wall. Less forgiving when exposed to leaks. • Inward vapour drive from absorptive claddings must be addressed in wet/humid climate zones by use of ventilated claddings or exterior foam insulation and exterior vapour control.
Exterior-insulated mass timber	• Exterior-insulated wall performs better hygrothermally than a traditional stud-insulated wall, in all climates. • CLT panel may form the interior finish (fire code permitting). • Attachment of cladding to exterior strapping results in a rainscreen wall assembly. • Provided a protected air barrier (limited penetrations).	• New construction method to many trades. • Relying only on exterior insulation for the majority of thermal resistance results in thicker walls and less interior floor space. • Cladding attachment through the exterior insulation must be considered. • Inward vapour drive from absorptive claddings must be addressed in wet/humid climate zones. by use of ventilated claddings. • CLT panels have ability to store a large volume of water, necessitating additional protection to panels during construction. • Drained/ventilated rainscreen assembly details are new to many jurisdictions in North America.

4.7 Interior-Insulated Foundation Wall



Below-grade walls are in a very different environment than above-grade walls and therefore require a different building-enclosure design. The key differences are the potential for hydrostatic pressure to exist and the lesser temperature variations within the soil. Below-grade assemblies are mostly concrete assemblies and are not a focus of this guide, although in small MURBs permanent wood foundations may be used (see relevant standards in *Permanent Wood Foundations* by the Canadian Wood Council for details). Two assemblies are included here to represent the best practice for the below-grade concrete walls of wood-based buildings.

This section describes a thermally efficient below-grade wall assembly consisting of rigid XPS or closed-cell spray-foam insulation placed on the interior side of the concrete foundation wall. Traditionally in cold climates many below-grade walls may have been insulated on the interior with fibreglass insulation between wood framing and a polyethylene vapour barrier installed on the interior. This assembly does not perform well from a moisture-management standpoint, and where higher effective R-values are required it also fails to perform adequately. Therefore the use of moisture-tolerant, high R-value XPS or closed-cell spray-foam insulation is recommended for such walls. Stud framing or strapping is placed entirely to the interior of the insulation and does not result in thermal bridging of the insulation. Gypsum drywall is installed as an interior finish and thermal barrier between the foam plastic insulation and interior.

4.7.1 Key Considerations

Assuring performance of below-grade poured-in-place concrete walls must include normal good concrete-construction practices such as proper mix design, construction and control joint waterproofing, and crack control. For many walls at dry sites, these techniques combined with damp proofing will be sufficient. However, more robust assemblies and details including waterproofing along with vertical drainage provisions need to be used when hydrostatic pressure exists.

Insulation placed on the interior of the concrete results in colder concrete and the potential for condensation of indoor air on the concrete. It is therefore important that gaps between the insulation boards be sealed so that warm air does not have a path to move against the cold concrete wall and then condense on the cold surface. An uneven concrete surface could make the tight fit difficult, necessitating the use of closed-cell spray polyurethane foam in some scenarios.

Consideration for and detailing of the continuity of the below-grade wall insulation with the above-grade walls and slab-on-grade insulation are important to the overall thermal performance of the building.

4.7.2 Controlling Exterior Moisture

Water-Shedding Surface

This assembly anticipates the control of the majority of the exterior ground moisture at the drainage composite. In many situations, good drainage at this layer should eliminate the potential for hydrostatic pressure on the wall. In situations where hydrostatic pressure will be experienced, additional precautions must be taken, including the installation of a fully bonded waterproof membrane, as well as vertical drainage leading to a perimeter drainage system.

Water-Resistive Barrier

In wall assemblies where no hydrostatic pressure is experienced, minor amounts of water may penetrate to the damp proofing on the face of the concrete wall. This layer should be adequate to control minor amounts of moisture if used in conjunction with appropriate joint and crack control details for the concrete wall. If a hydrostatic head is present, then this waterproofing will be relied on to manage moisture from the exterior.

4.7.3 Air Barrier

The concrete wall is the most airtight element in this assembly and is the easiest to make continuous with adjacent building-enclosure assemblies such as the concrete floor slab and the above-grade walls. However, with interior insulation approaches it is very important that gaps between the insulation boards be sealed so that air does not have a path to move against the cold concrete wall and potentially condense. The use of closed-cell spray-in-place polyurethane foam instead of board insulation can address this concern.

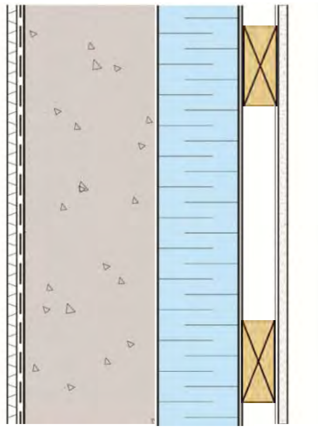
4.7.4 Vapour Barrier

The exterior damp proofing or waterproofing, the XPS or closed-cell spray-foam insulation, and the concrete are all relatively impermeable to vapour flow. These layers will limit the inward and outward migration of water vapour. The nature of the exterior environment (generally wet soil) means that there will be no drying to the exterior through this assembly. Drying to the interior is the only alternative for removal of minor amounts of moisture from any source.

4.7.5 Effective R-Values

The effective R-values for rigid insulated below-grade walls are similar to the nominal insulation R-values. Thermal bridging through the wall assembly is minimal and not generally a consideration because the insulation is installed in a continuous manner over the foundation wall, and wood framing is installed to the interior of the insulation. Insulation at the interior is temporarily adhered to the concrete wall using adhesive and is held in place by wood framing or is sprayed on (in the case of spray foam). Typically, detailed calculations of effective R-values are not generally necessary, and R-2 (RSI 0.4) can simply be added to the nominal insulation R-value to account for the concrete, interior finishes (drywall), any air spaces between un-insulated framing, and the interior air film. Effective R-values of R-22 (RSI 3.9) and greater can therefore be achieved with this assembly by the placement of 4 inches of XPS(R-5/inch), or 4 inches of closed-cell spray polyurethane foam insulation (R-5/inch aged), on the interior of the concrete foundation wall.

INTERIOR INSULATED FOUNDATION WALL SUMMARY



PLAN VIEW

EXTERIOR

- Plastic drainage composite
- Damp proofing (or waterproofing)
- Concrete foundation wall
- Extruded polystyrene (XPS) or closed-cell spray foam
- Wood framing (studs or strapping)
- Gypsum board

INTERIOR

CONTROLLING EXTERIOR MOISTURE

Water-Shedding Surface

This assembly anticipates the control of the majority of the exterior ground moisture at the drainage composite. In many situations, good drainage at this layer should eliminate the potential for hydrostatic pressure on the wall. In situations where hydrostatic pressure will be experienced, additional precautions must be taken including the installation of a fully bonded waterproof membrane, as well as vertical drainage leading to a perimeter drainage system. Proper site drainage is needed.

Water-Resistive Barrier

In wall assemblies where no hydrostatic pressure is experienced, minor amounts of water may penetrate to the damp proofing on the face of the concrete wall. This layer should be adequate to control minor amounts of moisture if used in conjunction with appropriate joint and crack control details for the concrete wall. If a hydrostatic head is present, then this waterproofing will be relied on to manage moisture from the exterior.

CONTROLLING AIR FLOW: AIR BARRIER

The concrete wall is the most airtight element in this assembly and is the easiest to make continuous with adjacent building enclosure assemblies such as the concrete floor slab and the above-grade walls. However, with interior insulation approaches it is very important that gaps between the insulation boards be sealed so that air does not have a path to move against the cold concrete wall and then potentially condense. The use of closed-cell spray-in-place polyurethane foam instead of board insulation can better address this concern.

CONTROLLING HEAT FLOW

Either XPS or closed-cell spray-foam insulation is typically used in this application because both products are relatively resistant to moisture within the concrete and are air and vapour impermeable.

CONTROLLING VAPOUR FLOW: VAPOUR RETARDER

The exterior damp proofing or waterproofing, the extruded polystyrene (XPS) or closed-cell spray-foam insulation, and the concrete are all relatively impermeable to vapour flow. These layers will limit the inward and outward migration of water vapour. The nature of the exterior environment (generally wet soil) means that there will be no drying to the exterior through this assembly. Drying to the interior is the only alternative for drying of minor amounts of moisture from any source.

DETAILING

Details for this concrete wall assembly are provided in conjunction with the details for the above-grade wood-frame wall assembly in Chapter 5.

APPLICATION AND FACTORS LIMITING PERFORMANCE

The primary considerations regarding modifications to this assembly are related to the presence of a hydrostatic head and the need for greater attention to waterproofing.

The concrete wall is durable and protects layers located to the interior. Foundation walls can be very difficult and expensive to access once the building is complete. As a result, it is prudent to design conservatively with respect to water-penetration control and to use durable materials.

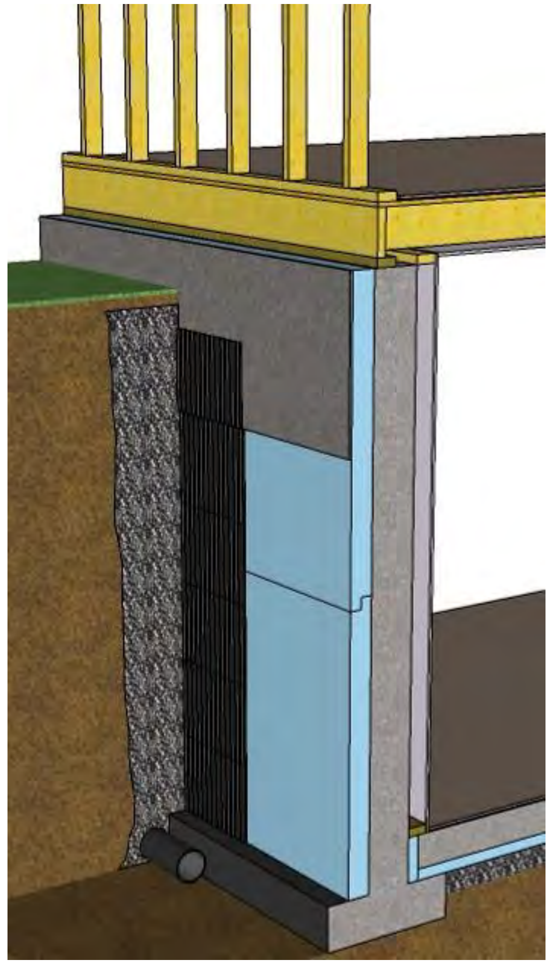
Assuring performance of below-grade poured-in-place concrete walls must include good concrete construction practices such as proper mix design, construction and control joint waterproofing, and crack control. For many walls at dry sites, these techniques combined with damp proofing will be sufficient; however, more robust assemblies and details, including waterproofing along with vertical drainage provisions, need to be used when hydrostatic pressure exists. Good site drainage is also important.

Insulation placed on the interior of the concrete results in colder concrete and potential for condensation of indoor air on the concrete. It is therefore important that gaps between the insulation boards be sealed so that air does not have a path to move against the cold concrete wall and potentially condense. An uneven concrete surface could make the tight fit difficult. The use of closed-cell spray-in-place polyurethane foam is advantageous in this respect.

Consideration for and detailing of the continuity of the below-grade wall insulation with the above-grade walls and slab-on-grade insulation are important to the overall thermal performance of the building.

4.8 Exterior-Insulated Foundation Wall

This alternative, thermally efficient, below-grade wall assembly consists of rigid moisture-tolerant insulation placed on the exterior side of the concrete foundation wall. XPS insulation is typically used for this application; however, rigid mineral fibre /glass fibre or expanded polystyrene can also be used, provided the selected manufacturer's products are moisture tolerant and suitable for use below grade, and provided that drainage is addressed at the face of the insulation to eliminate hydrostatic pressure. In termite zones, mineral insulation or preservative-treated foam insulation should be used. The insulation exposed above grade should be properly protected.



4.8.1 Key Considerations

Assuring performance of below-grade poured-in-place concrete walls must include normal good concrete construction practices such as proper mix design, construction and control joint waterproofing, and crack control. For many walls at dry sites these techniques combined with damp proofing will be sufficient. However more robust assemblies and details, including waterproofing along with vertical drainage provisions, need to be used when hydrostatic pressure exists.

Insulation placed on the exterior of the concrete foundation wall keeps the concrete warmer and drier than will interior insulation. Generally, exterior-insulated basements remain drier than interior insulated spaces.

Protecting the below-grade insulation from UV light and damage at the exposed above-grade portions is necessary. Some insulation products come with protection boards attached, or they can be protected with an appropriate cladding.

Detailing for the continuity of the below-grade wall insulation with the above-grade walls and slab-on-grade insulation is important to the overall thermal performance of the building.

4.8.2 Controlling Exterior Moisture

Water-Shedding Surface

This assembly anticipates the control of the majority of the exterior ground moisture at the drainage composite. In many situations, good drainage at this layer should eliminate the potential for hydrostatic pressure on the wall. In situations where hydrostatic pressure will be experienced, additional precautions must be taken, including the installation of a fully bonded waterproof membrane, as well as vertical drainage leading to a perimeter drainage system.

Water-Resistive Barrier

In wall assemblies where no hydrostatic pressure is experienced, minor amounts of water may penetrate to the damp proofing on the face of the concrete wall. This layer should be adequate to control minor amounts of moisture if used in conjunction with appropriate joint and crack control details for the concrete wall. If a hydrostatic head is present, then this waterproofing will be relied on to manage moisture from the exterior.

4.8.3 Air Barrier

The concrete wall is the most airtight element in this assembly and is the easiest to make continuous with the adjacent building-enclosure assemblies such as the concrete floor slab and the above-grade walls.

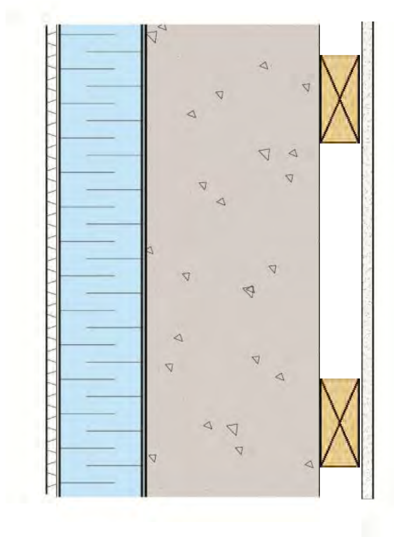
4.8.4 Vapour Barrier

The exterior damp proofing or waterproofing, the XPS insulation, and the concrete are all relatively impermeable to vapour flow. These layers will limit the inward and outward migration of water vapour. The nature of the exterior environment (generally wet soil) means that there will be no drying to the exterior through this assembly. Drying to the interior is the only alternative for removing minor amounts of moisture from any source. The limited outward drying potential makes this assembly relatively sensitive to moisture due to water ingress. By placing the insulation on the exterior, the concrete will be kept warm and drier than in an interior insulated scenario.

4.8.5 Effective R-Values

As discussed in the previous section, the effective R-values for rigid, insulated, below-grade walls are similar to the nominal insulation R-values because the insulation is continuous. Typically, detailed calculations of effective R-value are not generally necessary, and R-2 (RSI 0.4) can simply be added to the nominal insulation R-value to account for the concrete, interior finishes (drywall), any air spaces between un-insulated framing, and the interior air film. Effective R-values of R-22 (RSI 3.9) and greater can therefore be achieved with this assembly by the placement of 4 inches of XPS(R-5/inch), or 5 inches of rigid mineral fibre /glass fibre or expanded polystyrene (R-4/inch), on the exterior of the concrete foundation wall.

EXTERIOR-INSULATED FOUNDATION WALL SUMMARY



PLAN VIEW

EXTERIOR

- Plastic drainage composite
- Extruded polystyrene (XPS) or other suitable insulation
- Damp proofing (or waterproofing)
- Concrete foundation wall
- Air space
- Wood framing
- Gypsum board

INTERIOR

CONTROLLING EXTERIOR MOISTURE

Water-Shedding Surface

This assembly anticipates the control of the majority of the exterior ground moisture at the drainage composite. In many situations, good drainage at this layer should eliminate the potential for hydrostatic pressure on the wall. In situations where hydrostatic pressure will be experienced, additional precautions must be taken, including installing a fully bonded waterproof membrane as well as vertical drainage leading to a perimeter drainage system. Proper site drainage is also needed.

Water-Resistive Barrier

In wall assemblies where no hydrostatic pressure is experienced, minor amounts of water may penetrate to the damp proofing on the face of the concrete wall. This layer should be adequate to control minor amounts of moisture if used in conjunction with appropriate joint and crack control for the concrete wall. If a hydrostatic head is present, then this waterproofing will be relied on to manage moisture from the exterior.

CONTROLLING AIR FLOW: AIR BARRIER

The concrete wall is the most airtight element in this assembly and is the easiest to make continuous with adjacent building-enclosure assemblies, such as the concrete floor slab and the above-grade walls.

CONTROLLING HEAT FLOW

Extruded polystyrene insulation (XPS) is typically used in this application, and in damp or wet environments below grade, because it is relatively unaffected by moisture. Other acceptable insulation products may include rigid mineral-fibre insulation (free-draining) and high-density expanded polystyrene insulation (EPS, moisture tolerant).

CONTROLLING VAPOUR FLOW: VAPOUR RETARDER

The exterior damp proofing or waterproofing, the extruded polystyrene (XPS) insulation, and the concrete are all relatively impermeable to vapour flow. These layers will limit the inward and outward migration of water vapour. The nature of the exterior environment (generally wet soil) means that there will be no drying to the exterior through this assembly. Drying to the interior is the only alternative for drying of minor amounts of moisture from any source. The limited outward drying potential makes this assembly relatively sensitive to moisture due to water ingress. By placing the insulation on the exterior, the concrete will be kept warm and drier than in an interior insulated scenario.

DETAILING

Details for this concrete wall assembly are provided in conjunction with the details for the above-grade wood-frame wall assembly in Chapter 5.

APPLICATION AND FACTORS LIMITING PERFORMANCE

The primary consideration regarding modifications to this assembly is related to the presence of a hydrostatic head and the need for waterproofing rather than damp proofing.

The concrete wall is durable and it protects layers located to the interior. Exterior layers are subject to damage during construction but once construction is complete the potential for damage is minimal. Foundation walls can be very difficult and expensive to access from the exterior once the building is complete. As a result, it is prudent to design conservatively with respect to water-penetration control and to use durable materials.

Assuring performance of below-grade poured-in-place concrete walls must include good concrete construction practices such as proper mix design, construction and control joint waterproofing, and crack control. For many walls at dry sites these techniques combined with damp proofing will be sufficient. However, more robust assemblies and details, including waterproofing along with vertical drainage provisions, need to be used when hydrostatic pressure exists.

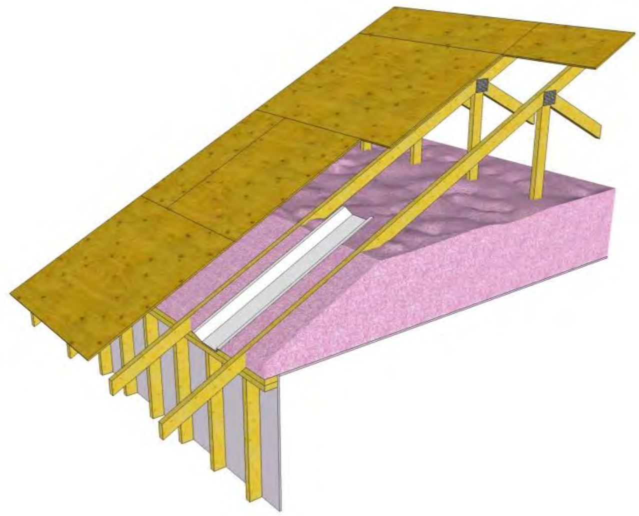
Insulation placed on the exterior of the concrete foundation wall will keep the concrete warmer and drier than if interior insulation is used. Generally, exterior-insulated basements are drier than interior-insulated ones.

Protecting the below-grade insulation from UV light and other potential damages at the exposed above-grade portions is necessary. Some insulation products come with protection boards attached, or they can be protected with an appropriate cladding.

Detailing for the continuity of the below-grade wall insulation with the above-grade walls and slab-on-grade insulation is important to the overall thermal performance of the building.

4.9 Pitched-Roof, Vented Attic Assembly

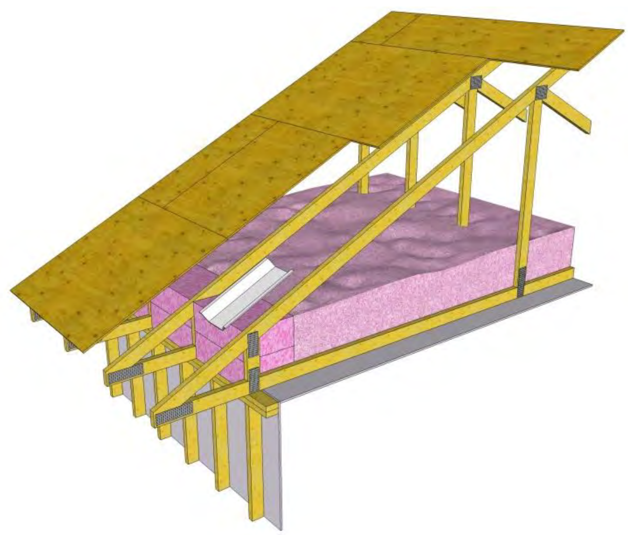
This sloped roof assembly is typical of wood-frame construction across North America. High effective R-values can be achieved with this roof assembly by adding greater depths of loose-fill insulation, such as blown cellulose or fibreglass. Flash-and-fill application of open- or closed-cell spray foam on the ceiling with a topping of low-density loose-fill insulation is a solution that also addresses airtightness of the ceiling plane.



Pitched roof assembly shown with blown-in fibreglass insulation and baffle vents at the eaves, to allow ventilation of the attic space.

Insulation effectiveness is diminished at the eaves, but can be improved by raised-heel trusses, or the use of deeper top chords (i.e., 2x6 or 2x8, instead of 2x4), or greater depth of insulation within the centre of the attic.

Adding greater depths of insulation to a vented attic assembly in an energy-efficient building will increase the potential for slightly higher moisture levels for the sheathing and the potential for condensation of outdoor ventilation air on the underside of the sheathing from night sky cooling. Therefore airtightness of the ceiling is critical, and in humid and marine climate zones the use of preservative-treated plywood or OSB, the installation of roof decking may be necessary to increase durability.



Pitched roof assembly with raised heel trusses to allow for greater insulation thickness at the eaves. Batt insulation (shown here), wood sheathing, or insulation guards are necessary at the perimeter of the roof to prevent the loose-fill insulation in the attic from spilling into the soffit area and out of the enclosure.

This assembly provides acceptable performance in all climate zones provided that the ceiling's air barrier is constructed in a continuous manner and that ducts do not leak into the attic space. In situations where mechanical equipment and duct-work is placed within the attic or where the ceiling has numerous penetrations and ducts, and hence is difficult to air seal, moisture-related performance issues typically arise. In a MURB, there should be no need to place HVAC equipment within the attic space because it would be placed within a more accessible mechanical room on the upper floor or on the rooftop or within the basement.

Soffit and ridge vent openings (minimum 1:300 net free area is typical, as per North American building codes) are provided in typical attic roofs to ventilate the underside of the wood decking in order to remove moisture in the wintertime and to reduce temperatures and overheating during the summer and in hot climate zones.

4.9.1 Controlling Exterior Moisture: Water-Penetration Control

This assembly sheds all exterior moisture by gravity drainage over shingled materials. The underlayment provides a secondary line of protection. The water-shedding surface and the water-resistive barrier may be coincident. However, the sloped nature of the surface means that shedding and drainage capabilities are good and the shingled materials do not need to be resistant to a hydrostatic head of water (similar to what would be required for a membrane on a low-slope roof).

4.9.2 Air Barrier

Both the sealed-polyethylene and airtight-drywall approaches can be used as air-barrier strategies in this assembly. Detailing at intersecting wall assemblies and penetrations are important factors in air-barrier effectiveness.

4.9.3 Vapour Barrier

In heating climates, polyethylene provides the vapour retarder for control of outward vapour flow. Vapour-retarder paint could also be used instead of polyethylene, as long as the ceiling drywall formed part of the air-barrier strategy. If closed-cell spray foam is used in a flash-and-fill insulation and air-sealing strategy, then it would also perform the vapour-retarder function.

4.9.4 Effective R-Values

The effective R-value of this roof assembly is affected primarily by the reduction of the insulation at the eaves compared to the centre of the attic where insulation is at full depth. The wood trusses (often 2x4s buried in 12 to 18 inches of insulation) have only a minor reduction on the effective R-value. Similar to wood-frame walls, thermal-bridging through trusses and joists must be accounted for in effective insulation values of wood-frame roofing assemblies as provided in codes and standards such as ASHRAE 90.1's Table A2.4, reproduced in 0. Note that in this table, standard framing assumes that the insulation is tapered around the perimeter, with a resultant decrease in thermal resistance. Advanced framing assumes a full and even depth of insulation extending to the outside edge of exterior walls, which is achievable if raised heel trusses are used. Wood-framing is 2x4 spaced at 24 inches o.c. with standard fibreglass fill insulation (as denoted by total nominal R-value). Further information about these assumptions can be found within ASHRAE 90.1, Table A2.4.

The effective R-value of a sloped roof assembly is affected primarily by the reduction of the insulation at the eaves compared to the centre of the attic where insulation is at full depth. As is evident from the ASHRAE values provided above, the wood trusses buried in more than 12 to 18 inches of insulation create only a minor reduction on the effective R-value. The following tables can be used to determine the effective R-value of the eave and the width of the eave based on the roof slope. This information can then be used to calculate an overall effective R-value for the roof. To convert from R-value to RSI, divide by 5.678.

Table 4.9.1 Effective R-values for assembly of attic roofs with wood trusses and joists (ASHRAE 90.1, Table A2.4).

Nominal Insulation R-value (RSI)	Assembly Effective R-value (RSI)
Wood-Truss Attic, Standard Framing	
None	1.6 (0.29)
11 (1.94)	11.0 (1.94)
13 (2.29)	12.3 (2.17)
19 (3.35)	18.9 (3.32)
30 (5.28)	29.4 (5.18)
38 (6.69)	37.0 (6.52)
49 (8.63)	47.6 (8.39)
60 (10.57)	58.8 (10.36)
Wood-Truss Attic, Advanced Framing	
None	1.6 (0.29)
11 (1.94)	11.4 (2.00)
13 (2.29)	12.8 (2.26)
19 (3.35)	19.6 (3.45)
30 (5.28)	31.3 (5.50)
38 (6.69)	38.5 (6.77)
49 (8.63)	50.0 (8.81)
60 (10.57)	62.5 (11.01)
Wood Joists, Single Rafter Roof in Flat Roof or Cathedral Ceiling	
None	2.4 (0.42)
11 (1.94)	11.4 (2.00)
13 (2.29)	12.8 (2.26)
15 (2.64)	14.1 (2.48)
19 (3.35)	18.2 (3.2)
21 (3.70)	19.2 (3.39)
25 (4.40)	23.3 (4.10)
30 (5.28)	27.8 (4.89)
38 (6.69)	35.7 (6.29)

Table 4.9.2 Determination of width of eaves based on insulation depth in the centre of attic minus depth of insulation at eaves

Width of Eave [inches]												
Roof Slope		**Insulation Depth in Centre of Attic Minus Depth at Roof Edge [in]**										
Ratio	**Angle [°]**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**30**	**36**	**42**	**48**
1:12	4.8	72	108	144	180	216	252	288	360	432	504	576
2:12	9.5	36	54	72	90	108	126	144	180	216	252	288
3:12	14.0	24	36	48	60	72	84	96	120	144	168	192
4:12	18.4	18	27	36	45	54	63	72	90	108	126	144
5:12	22.6	14	22	29	36	43	50	58	72	86	101	115
6:12	26.6	12	18	24	30	36	42	48	60	72	84	96
7:12	30.3	10	15	21	26	31	36	41	51	62	72	82
8:12	33.7	9	14	18	23	27	32	36	45	54	63	72
9:12	36.9	8	12	16	20	24	28	32	40	48	56	64
10:12	39.8	7	11	14	18	22	25	29	36	43	50	58
11:12	42.5	7	10	13	16	20	23	26	33	39	46	52
12:12	45.0	6	9	12	15	18	21	24	30	36	42	48

Table 4.9.3 Effective R-values of the eaves.

Effective R-Value of Eave									
R-Value at Edge of Attic	**R-value in Centre of Attic**								
	24	**36**	**48**	**60**	**72**	**84**	**96**	**120**	**144**
12	17	22	26	30	33	37	40	47	53
24	24	30	35	39	44	48	52	60	67
36	-	36	42	47	52	57	61	70	78
48	-	-	48	54	59	64	69	79	87
60	-	-	-	60	66	71	77	87	96
72	-	-	-	-	72	78	83	94	104

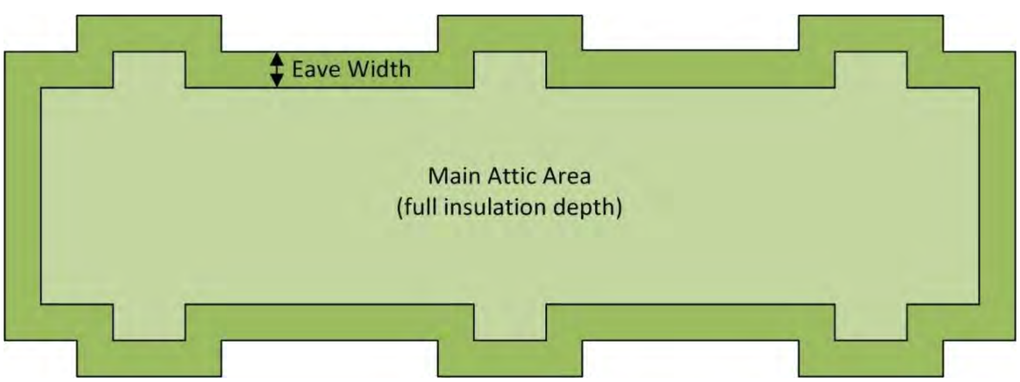


Fig. 4.9.1 Example of a MURB plan view showing width of the eaves and main area of the roof.

An example calculation of the effective R-value of a roof is provide below for the case of a 20 foot by 50 foot 4:12 sloped roof with 15 inches of R-4/inch in the centre of the attic, which tapers to 3 inches at the edge of the roof.

For the purposes of this example, the limited effect of thermal bridging of the roof framing has been ignored. It should be noted that this method provides an approximation of the roof's R-value; however, corners are not accounted for accurately, so actual R-values may vary slightly. For most purposes, however, this method is sufficient.

1. Calculate the total roof area, the perimeter of the roof, and the differential insulation depth.

$$Total\ Roof\ Area = 20\ ft \times 50\ ft = 1000\ ft^2$$

$$Roof\ Perimeter = (20\ ft \times 2) + (50\ ft \times 2) = 140\ ft$$

$$Differential\ Insulation\ Depth = Depth\ in\ Centre\ of\ Attic - Depth\ at\ Eaave$$

$$= 15\text{"} - 3\text{"} = 12\text{"}$$

2. Look-up the width of the eave in Table 4.9.2 0using differential insulation depth of 12".

$$Width\ of\ Eave\ from\ Table = 36\ in = 3\ ft$$

3. Calculate the area of the eave and the main attic area.

$$Area\ of\ Eave = A_{Eave} = 3\ ft \times 140\ ft = 420\ ft^2$$

$$Main\ Attic\ Area = A_{Main} = 1000\ ft^2 - 420\ ft^2 = 580\ ft^2$$

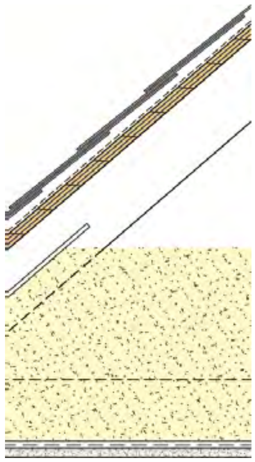
4. Look-up the effective R-value of the eave area using Table 4.9.3, based on R-value in the centre being R-60 (15" x R-4/inch) and at the edge being R-12 (3" x R-4/inch).

$$R_{Eave} = 30\ h \cdot ft^2 \cdot °\text{F}/Btu$$

5. Calculate the effective R-value.

$$Effective\ R - value\ of\ Attic = \frac{A_{Total}}{\frac{A_{Eave}}{R_{Eave}} + \frac{A_{Main}}{R_{Main}}} = \frac{1000}{\frac{420}{30} + \frac{580}{60}} = 42\ h \cdot ft^2 \cdot °\text{F}/Btu$$

PITCHED ROOF: VENTED ATTIC ASSEMBLY SUMMARY



SECTION VIEW

EXTERIOR

- Shingles (asphalt, concrete, clay tile, cedar, etc.)
- Underlayment
- Roof sheathing (plywood or OSB)
- Roof framing
- Vented airspace (attic)
- Batt insulation
- Polyethylene (where necessary for vapour control)
- Interior gypsum board

INTERIOR

CONTROLLING EXTERIOR MOISTURE: WATER-PENETRATION CONTROL

This assembly sheds all exterior moisture by gravity drainage over sloped shingled materials. The underlayment (where used) provides a secondary line of protection. The water-shedding surface is the shingles and the water-resistive barrier is the underlay. The sloped nature of the surface means that shedding and drainage capabilities are good and the shingled materials do not need to be resistant to a hydrostatic head of water.

CONTROLLING AIR FLOW: AIR BARRIER

In cold climates, both the sealed polyethylene and airtight drywall approaches can be used as air-barrier strategies in this assembly. Detailing at intersecting wall assemblies and penetrations is important in air-barrier effectiveness.

CONTROLLING HEAT FLOW

Low-density fibrous insulation, such as blown cellulose or fibreglass, is commonly used in this assembly. The use of a flash-and-fill application of open- or closed-cell spray foam with a topping of low-density loose fill is also an insulation strategy solution that also addresses airtightness of the ceiling plane.

CONTROLLING VAPOUR FLOW: VAPOUR RETARDER

In heating climates, polyethylene provides the vapour retarder for control of outward vapour flow. Vapour-retarder paint could also be used instead of polyethylene as long as the ceiling drywall forms part of the air-barrier strategy. Alternatively, foil-back drywall may be used to replace polyethylene and drywall for vapour control. If closed-cell spray foam is used in a flash-and-fill insulation and air-sealing strategy, then it would also perform the vapour-retarder function.

DETAILS

Details for this wood-frame roof assembly are provided in conjunction with the details for the above-grade wood-frame wall assembly in Chapter 5.

APPLICATION

This assembly is common and has a history of good performance. Good performance can be expected under most circumstances for low-rise construction. The exception to this may be a low-slope application on a more exposed site where uplift forces may limit the use of some shingle products. Note that concrete and cedar shingle products are not usually applied directly over sheathing and rely on alternative strapping support arrangements.

FACTORS LIMITING PERFORMANCE

Detailing of flashing, gutters, and downspouts is important for the successful performance of this assembly. The performance of the assembly also depends on a combination of adequate attic venting and airtightness of the ceiling.

The good venting capability of this assembly will help to dry the assembly in the event of a minor leak. Details are important in ensuring that this venting capability exists; however, the assembly does not accommodate the presence of any significant amount of moisture within the vented roof space. Exterior moisture that penetrates at the location of a roof leak can sit on top of polyethylene and saturate the roof framing prior to being detected.

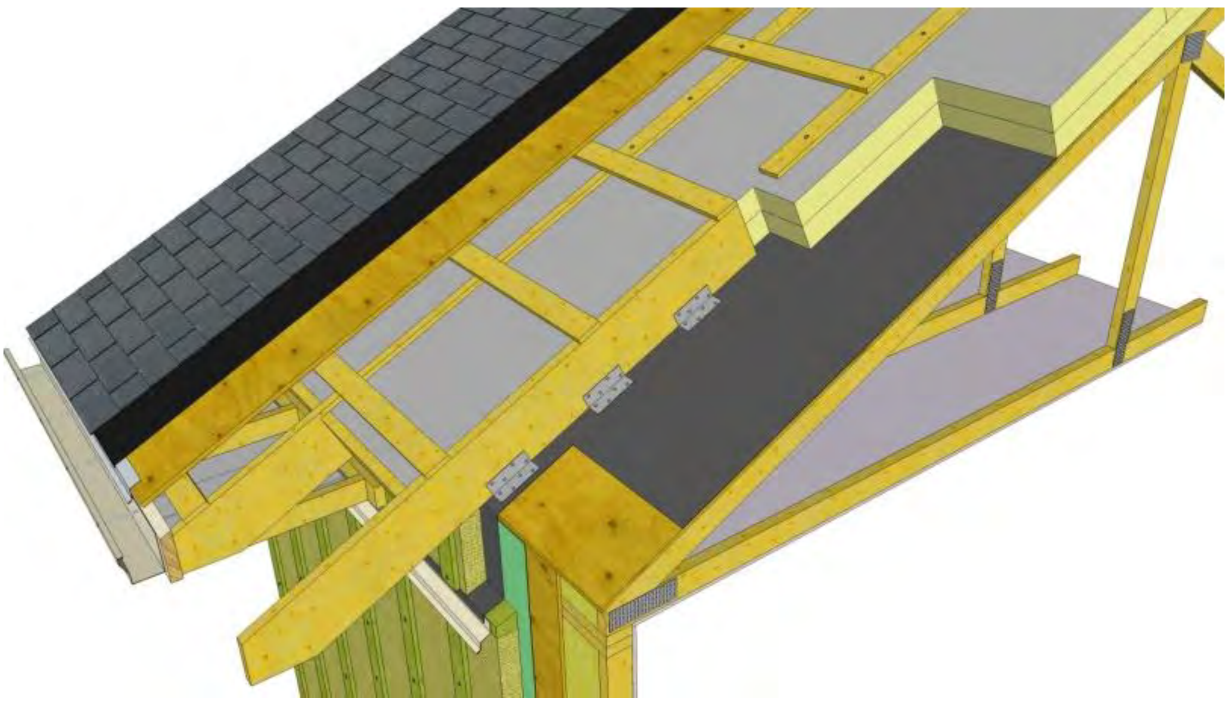
This assembly provides acceptable performance in all climate zones provided that the ceiling air barrier is constructed in a continuous manner and that ducts do not leak into the attic space. In situations where mechanical equipment and duct work is placed within the attic or where the ceiling has numerous penetrations and ducts, and hence is difficult to air-seal, moisture-related performance issues typically arise. In a MURB there should be no need to place HVAC equipment within the attic space, because it would be placed within a more accessible mechanical room on the upper floor, on the rooftop, or within the basement.

Soffit and ridge vent openings (minimum 1:300 net free area is typical) are provided in typical attic roofs to ventilate the underside of the wood decking in order to remove moisture in the wintertime and to reduce temperatures and overheating during the summer and in hot climate zones.

In humid and marine climate zones the use of preservative-treated plywood or OSB roof decking can further increase the durability performance of this assembly.

4.10 Pitched-Roof, Exterior Insulated Assembly

This sloped roof assembly is designed with the insulation entirely above the roof structure. The insulation value is provided by exterior rigid insulation placed on top of the roof sheathing and creating a conditioned attic or living space. The trusses can be installed without rafter tails, and sheathing runs from the roof to the wall in one continuous line. This is to create a continuous interface for the exterior self adhered membrane to tie in to the exterior air barrier on the wall. This roof/wall interface is a more robust and simpler approach than the sometimes difficult roof/wall interface found on the conventional pitched roof with a vented attic. High R-values can be achieved through the use of thick rigid insulation above the structural roof sheathing, and additional insulation (sprayfoam) may be used at the interior to reduce exterior insulation depth. The exterior insulation can be installed with strapping and long screws to attach it to the roof sheathing. At the eaves, the overhang joists extend up the roof as far as is structurally needed and provide an overhang. Horizontal purlins are installed to provide cross ventilation, and exterior wood decking, underlayment, and shingles can be installed in the same matter as a conventional sloped roof. Metal roof and concrete tiles will not necessarily require wood decking, supported directly on the horizontal purlins, though an water resistant underlay would be suggested on top of the exterior insulation.



Pitched roof assembly shown with exterior rigid insulation and cross strapping to allow ventilation below the upper roof deck. Note the use of 2x10 or 2x12 lumber only at the eaves for overhang structure support.

This approach to a sloped roofing assembly provides some important benefits. By moving the air barrier/vapour retarder to the exterior of the sheathing, there is no need to detail the interior gypsum ceiling around the penetrations, and at the roof/wall interface. This is because by creating a conditioned attic space the roof sheathing is kept warm and there is less concern for moisture in the attic. On the outside, the roof is more durable and has more redundancy against moisture penetration, as any moisture that makes penetrates the roofing and exterior wood decking can be drained on top of either the rigid insulation, or at the self adhered membrane.

Soffit and ridge vent openings (1:150 net free area is recommended) are provided to ventilate the underside of the outermost wood sheathing in order to remove moisture in the winter time, keep roofing cold to minimize ice-damming, and to reduce temperatures and overheating during the summer.

4.10.1 Controlling Exterior Moisture: Water-Penetration Control

This assembly sheds all exterior moisture by gravity drainage over shingled materials. The underlayment provides a secondary line of protection. The water-shedding surface and the water-resistive barrier in some assemblies may be coincident. However, the sloped nature of the surface means that shedding and drainage capabilities are good and the shingled materials do not need to be resistant to a hydrostatic head of water (similar to what would be required for a membrane on a low-slope roof). Any incidental moisture can be drained by either the rigid insulation beneath the wood decking, or at the self adhered membrane on the inner most roof sheathing.

4.10.2 Air Barrier

The self adhered membrane is used as the air barrier on top of the roof sheathing. At the eaves the membrane ties in to the wall air barrier membrane and single line of air tightness at the interface.

4.10.3 Vapour Barrier

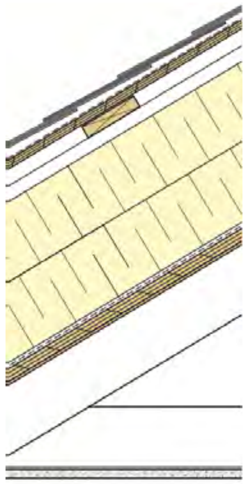
The self adhered membrane provides the vapour retarder for control of outward vapour flow.

4.10.4 Effective R-Values

The effective R-values for an exterior insulated sloped roof assembly are similar to the nominal insulation R-values. Thermal bridging through the assembly is not generally a consideration, except at roof penetrations and at the eaves where there are overhang joists, because the insulation is installed in a continuous manner over the roof deck at the exterior. Detailed calculations of effective R-values may not be necessary, and the nominal insulation R-value can be taken and added to approximately R-2 to account for the supporting structure and finishes, the air spaces between the framing, and the exterior and interior air films.

If the insulation is bridged by fasteners other than nails or screw fasteners (i.e., joists at the eaves), the effect of the thermal bridging through the insulation should be accounted for. Some guidance is provided in ASHRAE 90.1 for these applications; however, thermal modelling may need to be performed for some situations.

PITCHED ROOF: VENTED ATTIC ASSEMBLY SUMMARY



SECTION VIEW

EXTERIOR

- Shingles (asphalt, concrete, clay tile, cedar, etc.)
- Underlayment
- Roof sheathing (plywood or OSB) if required for roofing support
- Horizontal and vertical wood strapping (vented airspace)
- Overhang joists at eaves
- Rigid insulation (polyiso, XPS, mineral wool)
- Self adhered membrane
- Roof sheathing
- Roof framing
- Attic (interior conditioned space)
- Interior gypsum board

INTERIOR

CONTROLLING EXTERIOR MOISTURE: WATER-PENETRATION CONTROL

This assembly sheds all exterior moisture by gravity drainage over sloped shingled materials. The underlayment provides a secondary line of protection. The water-shedding surface is the shingles and the water-resistive barrier is the underlay. The sloped nature of the surface means that shedding and drainage capabilities are good and the shingled materials do not need to be resistant to a hydrostatic head of water.

CONTROLLING AIR FLOW: AIR BARRIER

The self adhered membrane is used as the air barrier on top of the roof sheathing. At the eaves the membrane ties in to the wall air barrier membrane and creates a single line of air tightness at the interface.

CONTROLLING HEAT FLOW

Rigid board insulation, such as polyisocyanurate, extruded polystyrene (XPS), or rigid mineral wool can be used on top of the roof sheathing in this assembly. Sprayfoam insulation may be added at the interior to reduce the depth of exterior rigid insulation.

CONTROLLING VAPOUR FLOW: VAPOUR RETARDER

In heating climates, a self adhered membrane provides the vapour retarder for control of outward vapour flow.

DETAILS

Details for this wood-frame roof assembly are provided in conjunction with the details for the above-grade wood-frame wall assembly in Chapter 5.

APPLICATION

This assembly is relatively new but has the ability to perform well. Good performance can be expected under most circumstances for low-rise construction. The exception to this may be a low-slope application on a more exposed site where uplift forces may limit the use of some shingle products. Note that concrete and cedar shingle products are not usually applied directly over sheathing and can use the wood strapping for support.

FACTORS LIMITING PERFORMANCE

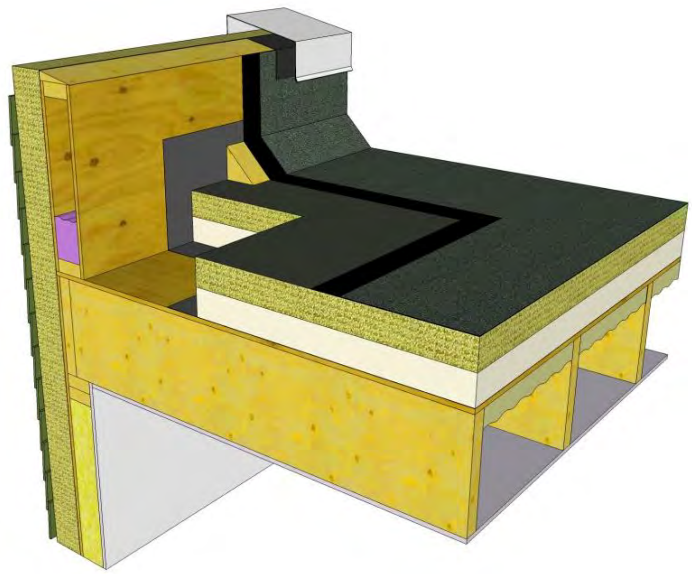
Detailing of flashing, gutters, and downspouts is important for the successful performance of this assembly. The performance of the assembly also depends on a combination of adequate wood decking ventilation and air tightness of the self adhered membrane at the roof sheathing. The venting capability of this assembly will help to dry the assembly in the event of a minor leak. Details are important in ensuring that this venting capability exists. The assembly can accommodate the presence of more significant amounts of moisture within the vented roof space. Exterior moisture that penetrates at the location of a roof leak can be drained to the eaves on top of the rigid insulation or the self adhered membrane. Moisture beyond the innermost roof sheathing can be detected quickly as it reaches the interior drywall.

This assembly provides acceptable performance in all climate zones provided the air barrier is constructed in a continuous manner. This assembly accommodates the use of mechanical equipment and penetrations of the ceiling drywall, as the attic is a conditioned space.

Soffit and ridge vent openings (minimum 1:150 net free area is recommended) are provided in typical sloped roofs to ventilate the underside of the wood decking in order to remove moisture in the wintertime and to reduce temperatures and overheating during the summer and in hot climate zones.

In humid and marine climate zones the use of preservative-treated plywood or OSB roof decking can further increase the durability performance of this assembly.

4.11 Low-Slope Conventional Roof Assembly



This low-slope conventional roof assembly is common in wood-frame construction across North America. High effective R-values within this assembly are easy to achieve using greater depths of rigid insulation above the sheathing. Polyisocyanurate (R-5/inch) alone is typically used in this application, or in combination with a more dimensionally stable top layer (e.g., rigid mineral fibre, R-3.7 to R-4/inch).

The use of spray foam could be considered (as shown in the adjacent image), i.e., sprayed to the underside of the roof sheathing to increase the effective R-value of the assembly and/or decrease the amount of exterior insulation required above the sheathing. Open-cell spray foam is recommended for vapour permeability and to give the roof the ability to dry in case it is wetted initially or while in service. (The foam should not be sprayed on when the wood is wet.) A safe maximum R-value for the spray foam would be one-third of the total nominal R-value (i.e., two-thirds R-value above deck and one-third R-value below), although further analysis is recommended for the particular climate zone, because in warmer climates a greater amount of spray-foam insulation could be placed below the roof deck.

This assembly provides acceptable performance in all climate zones provided that a durable roofing membrane is selected and properly detailed, and that airflow is controlled.

4.11.1 Controlling Exterior Moisture: Water-Penetration Control

This assembly anticipates the control of all of the moisture at the waterproof membrane. The water-shedding surface and the water-resistive barrier are coincident. Water must drain over the low slope of the membrane to drains or to perimeter scuppers. The assembly is sensitive to exterior moisture that penetrates at the location of a roof leak; water can migrate within the insulation and quickly saturate the roof if undetected.

4.11.2 Air Barrier

The waterproof membrane can be considered the primary element of the air barrier in this assembly. Alternatively, the self-adhered membrane applied to the roof sheathing could form part of the air-barrier system and is typically detailed as such to prevent the exfiltration of indoor air into the roof insulation and contact with the roof membrane.

4.11.3 Vapour Barrier

The roof sheathing and self-adhered membrane provide sufficient vapour resistance to control outward vapour flow. The plywood roof decking and foam insulation also provide sufficient vapour resistance at the interior, such that a vapour-permeable underlay could be used, and thereby allow the roof insulation some drying capability inwards should it be installed wet, or become wet during construction.

4.11.4 Effective R-Values

The effective R-values for a conventionally insulated roof assembly are similar to the nominal insulation R-values. Thermal bridging through the assembly is not generally a consideration, except at roof penetrations and parapets, because the insulation is installed in a continuous manner over the roof deck at the exterior. Detailed calculations of effective R-values are not generally necessary, and the nominal insulation R-value can be taken and added to approximately R-4 to account for the supporting structure and finishes, the air spaces between the framing, and the exterior and interior air films.

If the insulation is bridged by fasteners other than nails or screw fasteners (i.e., by metal clips or continuous purlins for sloped metal roofs), the effect of the thermal bridging through the insulation should be accounted for (building codes may require this). Some guidance is provided in ASHRAE 90.1 for these applications; however, thermal modelling may need to be performed for some situations.

Effective R-values of R-40 (RSI 7.0) and greater can therefore be achieved with this assembly by the placement of 8 inches of polyisocyanurate (R-5/inch). R-50 (RSI 8.8) can be achieved with 10 inches of polyisocyanurate.

One area where effective insulation values are commonly misunderstood is associated with the use of tapered insulation for low-slope roofs. There is a non-linear relationship between the insulation's taper depth and the U-value, making it impossible to estimate the overall effective R-value by simple linear interpolation. Essentially, the effective R-value cannot be calculated by taking the value half way between R_{max} and R_{min}. See Table 4.11.1 and Table 4.11.2.

For rectangular (shape in plan view) tapered insulation, the linear method consistently overstates the effective R-value. For the triangular (shape in plan view) insulation that is sloped towards a point (centre drained configuration), the linear method understates the effective R-value; however, for triangular insulation that slopes towards a side (perimeter drained configuration), the linear method overstates the effective R-value. The overstating and understating is most pronounced in instances where there is a large difference between minimum and maximum insulation R-values.

Guidance for calculating the effective R-value for tapered insulation packages based on the slope configuration is provided in Table 4.11.3 for a single slope, Table 4.11.4 for sloped triangles to centre drains, and Table 4.11.5 for sloped triangle to perimeter drains. Effective R-values have been calculated based on integrated area-weighted U-values for triangular shapes.

It is also possible to insulate this type of roof between the roof joists using spray polyurethane foam insulation alone. This insulation is bridged by the roof joists and is therefore less effective than insulation installed above the roof deck; however, the relatively low conductivity of wood (compared with steel framing, for example) still makes insulating between the joists a reasonable option (Table 4.11.6).

Table 4.11.1 Comparison of R-value calculations, for rectangular tapered insulation.

R_{min} [R-value (RSI)]	R_{max} [R-value (RSI)]	**R-average: linear (incorrect)** [R-value (RSI)]	**R-effective: correct** [R-value (RSI)]
5 (0.88)	20 (3.52)	12.5 (2.20)	**10.8 (1.90)**
20 (3.52)	25 (4.40)	22.5 (3.96)	**22.4 (3.95)**
10 (1.76)	60 (10.57)	35.0 (6.16)	**27.9 (4.91)**

Table 4.11.2 Comparison of R-value calculations, for a centre-drained configuration of triangular tapered insulation.

R_{min} [R-value (RSI)]	R_{max} [R-value (RSI)]	**R-average: linear (Incorrect)** [R-value (RSI)]	**R-effective: correct** [R-value (RSI)]
5 (0.88)	20 (3.52)	12.5 (2.20)	**13.9 (2.45)**
20 (3.52)	25 (4.40)	22.5 (3.96)	**23.3 (4.10)**
10 (1.76)	60 (10.57)	35.0 (6.16)	**39.0 (6.87)**

Table 4.11.3 Effective R-values for tapered insulation, single slope (rectangular to one side).

Rmax →

Rmin ↓	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	35	40	45	50	55	60
1	1.0	1.4	1.8	2.2	2.5	2.8	3.1	3.4	3.6	3.9	4.4	4.9	5.4	5.9	6.3	7.5	8.5	9.6	10.6	11.6	12.5	13.5	14.4
2	-	2.0	2.5	2.9	3.3	3.6	4.0	4.3	4.7	5.0	5.6	6.2	6.7	7.3	7.8	9.1	10.3	11.5	12.7	13.8	14.9	16.0	17.1
3	-	-	3.0	3.5	3.9	4.3	4.7	5.1	5.5	5.8	6.5	7.1	7.8	8.4	9.0	10.4	11.7	13.0	14.3	15.5	16.7	17.9	19.0
4	-	-	-	4.0	4.5	4.9	5.4	5.8	6.2	6.5	7.3	8.0	8.7	9.3	9.9	11.5	12.9	14.3	15.6	16.9	18.2	19.5	20.7
5	-	-	-	-	5.0	5.5	5.9	6.4	6.8	7.2	8.0	8.7	9.5	10.1	10.8	12.4	14.0	15.4	16.8	18.2	19.5	20.9	22.1
6	-	-	-	-	-	6.0	6.5	7.0	7.4	7.8	8.7	9.4	10.2	10.9	11.6	13.3	14.9	16.4	17.9	19.4	20.8	22.1	23.5
7	-	-	-	-	-	-	7.0	7.5	8.0	8.4	9.3	10.1	10.9	11.6	12.4	14.1	15.8	17.4	18.9	20.4	21.9	23.3	24.7
8	-	-	-	-	-	-	-	8.0	8.5	9.0	9.9	10.7	11.5	12.3	13.1	14.9	16.6	18.3	19.9	21.4	22.9	24.4	25.8
9	-	-	-	-	-	-	-	-	9.0	9.5	10.4	11.3	12.2	13.0	13.8	15.7	17.4	19.1	20.8	22.4	23.9	25.4	26.9
10	-	-	-	-	-	-	-	-	-	10.0	11.0	11.9	12.8	13.6	14.4	16.4	18.2	20.0	21.6	23.3	24.9	26.4	27.9
12	-	-	-	-	-	-	-	-	-	-	12.0	13.0	13.9	14.8	15.7	17.7	19.6	21.5	23.3	25.0	26.6	28.2	29.8
14	-	-	-	-	-	-	-	-	-	-	-	14.0	15.0	15.9	16.8	19.0	21.0	22.9	24.8	26.6	28.3	30.0	31.6
16	-	-	-	-	-	-	-	-	-	-	-	-	16.0	17.0	17.9	20.2	22.3	24.3	26.2	28.0	29.8	31.6	33.3
18	-						-	-	-	-	-	-	-	18.0	19.0	21.3	23.5	25.6	27.6	29.5	31.3	33.1	34.9
20	-						-	-	-	-	-	-	-	-	20.0	22.4	24.7	26.8	28.9	30.8	32.7	34.6	36.4
25	-						-	-	-	-	-	-	-	-	-	25.0	27.4	29.7	31.9	34.0	36.1	38.0	40.0
30	-						-	-	-	-	-	-	-	-	-	-	30.0	32.4	34.8	37.0	39.2	41.2	43.3
35	-						-	-	-	-	-	-	-	-	-	-	-	35.0	37.4	39.8	42.1	44.2	46.4
40	-						-	-	-	-	-	-	-	-	-	-	-	-	40.0	42.5	44.8	47.1	49.3
45	-						-	-	-	-	-	-	-	-	-	-	-	-	-	45.0	47.5	49.8	52.1
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50.0	52.5	54.8
55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	55.0	57.5
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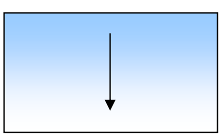


Table 4.11.4 Effective R-values for tapered insulation, sloped triangle (roof with centre drain)

Rmax →

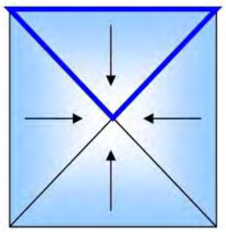
Rmin ↓	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	35	40	45	50	55	60
1	1.0	1.6	2.2	2.8	3.3	3.9	4.4	5.0	5.5	6.0	7.1	8.2	9.2	10.2	11.3	13.9	16.4	19.0	21.5	24.1	26.6	29.2	31.7
2	-	2.0	2.6	3.3	3.9	4.4	5.0	5.6	6.1	6.7	7.8	8.9	10.0	11.0	12.1	14.7	17.4	20.0	22.6	25.1	27.7	30.3	32.9
3	-	-	3.0	3.7	4.3	4.9	5.5	6.1	6.7	7.2	8.4	9.5	10.6	11.7	12.8	15.5	18.1	20.8	23.4	26.0	28.6	31.2	33.8
4	-	-	-	4.0	4.7	5.3	5.9	6.5	7.1	7.7	8.9	10.0	11.2	12.3	13.4	16.1	18.8	21.5	24.2	26.8	29.5	32.1	34.7
5	-	-	-	-	5.0	5.7	6.3	6.9	7.5	8.1	9.3	10.5	11.7	12.8	13.9	16.7	19.5	22.2	24.9	27.6	30.2	32.9	35.5
6	-	-	-	-	-	6.0	6.7	7.3	7.9	8.6	9.8	11.0	12.2	13.3	14.5	17.3	20.1	22.8	25.6	28.3	30.9	33.6	36.3
7	-	-	-	-	-	-	7.0	7.7	8.3	8.9	10.2	11.4	12.6	13.8	15.0	17.8	20.6	23.4	26.2	28.9	31.6	34.3	37.0
8	-	-	-	-	-	-	-	8.0	8.7	9.3	10.6	11.8	13.0	14.2	15.4	18.3	21.2	24.0	26.8	29.5	32.3	35.0	37.7
9	-	-	-	-	-	-	-	-	9.0	9.7	11.0	12.2	13.4	14.7	15.9	18.8	21.7	24.5	27.3	30.1	32.9	35.6	38.3
10	-	-	-	-	-	-	-	-	-	10.0	11.3	12.6	13.8	15.1	16.3	19.3	22.2	25.1	27.9	30.7	33.5	36.2	39.0
12	-						-	-	-	-	12.0	13.3	14.6	15.9	17.1	20.2	23.1	26.0	28.9	31.8	34.6	37.4	40.2
14	-						-	-	-	-	-	14.0	15.3	16.6	17.9	21.0	24.0	27.0	29.9	32.8	35.6	38.5	41.3
16	-						-	-	-	-	-	-	16.0	17.3	18.6	21.8	24.9	27.9	30.8	33.8	36.7	39.5	42.4
18	-						-	-	-	-	-	-	-	18.0	19.3	22.5	25.7	28.7	31.7	34.7	37.6	40.5	43.4
20	-						-	-	-	-	-	-	-	-	20.0	23.3	26.4	29.5	32.6	35.6	38.5	41.5	44.4
25	-						-	-	-	-	-	-	-	-	-	25.0	28.3	31.5	34.6	37.7	40.7	43.7	46.7
30	-						-	-	-	-	-	-	-	-	-	-	30.0	33.3	36.5	39.7	42.8	45.8	48.9
35	-						-	-	-	-	-	-	-	-	-	-	-	35.0	38.3	41.5	44.7	47.8	50.9
40	-						-	-	-	-	-	-	-	-	-	-	-	-	40.0	43.3	46.5	49.7	52.9
45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	45.0	48.3	51.6	54.8
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50.0	53.3	56.6
55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	55.0	58.3
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60.0

Table 4.11.5 Effective R-values for tapered insulation, sloped triangle (perimeter drains).

Rmax →

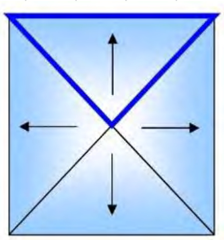
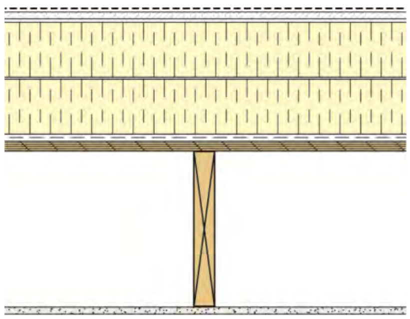
Rmin ↓	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	35	40	45	50	55	60
1	1.0	1.3	1.5	1.8	2.0	2.2	2.4	2.5	2.7	2.9	3.2	3.5	3.8	4.1	4.4	5.1	5.8	6.4	7.0	7.6	8.2	8.8	9.3
2	-	2.0	2.3	2.6	2.8	3.1	3.3	3.5	3.7	4.0	4.3	4.7	5.1	5.4	5.8	6.6	7.4	8.1	8.8	9.5	10.2	10.9	11.5
3	-	-	3.0	3.3	3.6	3.9	4.1	4.4	4.6	4.9	5.3	5.7	6.1	6.5	6.9	7.8	8.7	9.5	10.3	11.0	11.8	12.5	13.2
4	-	-	-	4.0	4.3	4.6	4.9	5.2	5.4	5.7	6.2	6.6	7.1	7.5	7.9	8.9	9.8	10.7	11.6	12.4	13.2	14.0	14.7
5	-	-	-	-	5.0	5.3	5.6	5.9	6.2	6.5	7.0	7.5	7.9	8.4	8.8	9.9	10.9	11.8	12.7	13.6	14.4	15.3	16.1
6	-	-	-	-	-	6.0	6.3	6.6	6.9	7.2	7.8	8.3	8.8	9.3	9.7	10.8	11.9	12.8	13.8	14.7	15.6	16.5	17.3
7	-	-	-	-	-	-	7.0	7.3	7.6	7.9	8.5	9.1	9.6	10.1	10.6	11.7	12.8	13.8	14.8	15.8	16.7	17.6	18.5
8	-	-	-	-	-	-	-	8.0	8.3	8.6	9.2	9.8	10.4	10.9	11.4	12.6	13.7	14.8	15.8	16.8	17.8	18.7	19.6
9	-	-	-	-	-	-	-	-	9.0	9.3	10.0	10.5	11.1	11.6	12.2	13.4	14.6	15.7	16.8	17.8	18.8	19.8	20.7
10	-	-	-	-	-	-	-	-	-	10.0	10.6	11.3	11.8	12.4	12.9	14.2	15.4	16.6	17.7	18.7	19.8	20.8	21.7
12	-						-	-	-	-	12.0	12.6	13.3	13.9	14.4	15.8	17.1	18.3	19.4	20.6	21.6	22.7	23.7
14	-						-	-	-	-	-	14.0	14.7	15.3	15.9	17.3	18.6	19.9	21.1	22.3	23.4	24.5	25.6
16	-						-	-	-	-	-	-	16.0	16.7	17.3	18.8	20.2	21.5	22.8	24.0	25.2	26.3	27.4
18	-						-	-	-	-	-	-	-	18.0	18.7	20.2	21.7	23.0	24.3	25.6	26.8	28.0	29.2
20	-						-	-	-	-	-	-	-	-	20.0	21.6	23.1	24.5	25.9	27.2	28.5	29.7	30.9
25	-						-	-	-	-	-	-	-	-	-	25.0	26.6	28.1	29.6	31.0	32.4	33.7	34.9
30	-						-	-	-	-	-	-	-	-	-	-	30.0	31.6	33.2	34.7	36.1	37.5	38.8
35	-						-	-	-	-	-	-	-	-	-	-	-	35.0	36.6	38.2	39.7	41.2	42.6
40	-						-	-	-	-	-	-	-	-	-	-	-	-	40.0	41.6	43.2	44.7	46.2
45	-						-	-	-	-	-	-	-	-	-	-	-	-	-	45.0	46.6	48.2	49.8
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50.0	51.6	53.2
55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	55.0	56.6
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60.0

Table 4.11.6 Effective R-value added to assembly by installation of spray foam between joists, by joist spacing and thickness of insulation.

Joist spacing	**Spray foam [R-value/inch (RSI/25.4 mm)]**	**Thickness of spray foam between joists**		
		2 inches [R-value (RSI)]	**4 inches** [R-value (RSI)]	**6 inches** [R-value (RSI)]
16 inches	**3.7/inch: ½ pcf open cell (0.7/25.4 mm)**	6.0 (1.1)	11.7 (2.1)	17.2 (3.0)
	5/inch - 2 pcf closed cell (0.9/25.4 mm)	7.9 (1.4)	15.2 (2.7)	22.3 (3.9)
24 inches	**3.7/inch - ½ pcf open cell (0.7/25.4 mm)**	6.2 (1.1)	12.3 (2.2)	18.2 (3.2)
	5/inch - 2 pcf closed cell (0.9/25.4 mm)	8.4 (1.5)	16.3 (2.9)	24.0 (4.2)

LOW SLOPE CONVENTIONAL ROOF ASSEMBLY SUMMARY

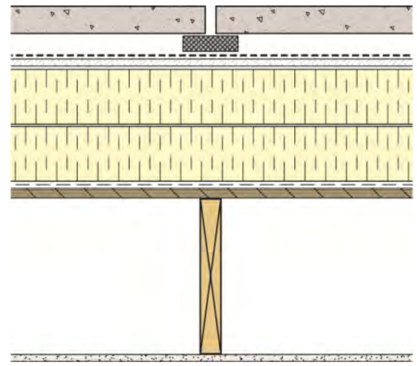


ROOF

EXTERIOR

- Pavers and pedestal system (roof deck)
- Waterproof roof membrane system
- Protection board
- Rigid insulation layers
- SAM air/vapour barrier
- Roof sheathing
- Roof joists
- Interior gypsum board

INTERIOR



ROOF DECK

CONTROLLING EXTERIOR MOISTURE: WATER-PENETRATION CONTROL

This assembly anticipates the control of all of the moisture at the waterproof membrane. The water-shedding surface and the water-resistive barrier are coincident. Water must drain over the low slope of the membrane to drains or to perimeter scuppers. The assembly is sensitive to exterior moisture that penetrates at the location of a roof leak; water can migrate within the insulation and quickly saturate the roof if undetected.

CONTROLLING AIR FLOW: AIR BARRIER

The waterproof membrane can be considered the primary element of the air barrier in this assembly. Typically, however, the self-adhered membrane applied to the roof sheathing would form part of the air-barrier system and is typically detailed as such to prevent the exfiltration of indoor air into the roof insulation and underneath the roof membrane.

CONTROLLING HEAT FLOW

Polyisocyanurate (R-5/inch) alone is typically used in this application, or in combination with a more dimensionally stable top layer (e.g., a 2 to 4-inch layer of rigid mineral fibre, R-4/inch). The use of expanded or extruded polystyrene (ESP or XPS) is not recommended within this assembly due to the poor dimensional stability. EPS is often used below other types of insulation where it is protected from temperature extremes (polyisocyanurate or mineral fiber) as part of a sloped taper package.

Spray foam on the underside of the roof sheathing could be used to increase the effective R-value of the assembly and/or to decrease the amount of exterior insulation required above the sheathing. Foam should not be sprayed when the wood is wet; open-cell spray foam is recommended for vapour permeability. As a general rule of thumb, the maximum spray foam R-value would be one-third of the total nominal R-value (i.e., two-thirds R-value above deck and one-third R-value below).

CONTROLLING VAPOUR FLOW: VAPOUR RETARDER

The roof sheathing and self-adhered membrane provide sufficient vapour resistance to control outward vapour flow. The plywood roof decking and foam insulation also provide sufficient vapour resistance at the interior, such that a vapour-permeable underlay could be used, thus allowing the roof insulation some drying capability inwards should the insulation be installed wet, or become wet during construction or while in service.

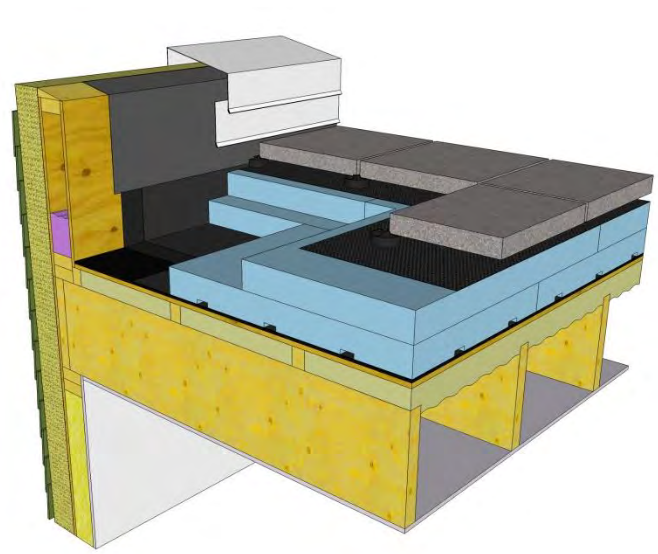
DETAILS AND APPLICATION

Details for this wood-frame roof assembly are provided in conjunction with details for the above-grade wood-frame wall assembly in Chapter 5. Many of these assemblies are in service and have provided good performance.

FACTORS LIMITING PERFORMANCE

Detailing of the interfaces and penetrations is a significant factor in the overall performance of the assembly. Draining the roof is fundamental to its durable performance; therefore the location and sizing of drains, and providing a positive slope to the drains, are critical design features.

4.12 Inverted (Protected Membrane) Roof Assembly



This low-slope inverted (protected membrane) roof and roof deck assembly are common in wood-frame construction across North America. This assembly lends itself well to residential roof decks over living space that is suitable pedestrian traffic and green roof assemblies because the membrane is protected below the insulation and ballast, i.e., away from traffic, UV radiation, and temperature fluctuations.

High effective R-values within this assembly are easy to achieve using greater depths of rigid insulation above the waterproofing membrane, though there may be practical limits on the depth of insulation due to the height of exterior door threshold and other detailing considerations.

Extruded polystyrene insulation (XPS) is used for this application because it is moisture tolerant. The use of spray foam could be considered (as shown in the adjacent image), i.e., sprayed to the underside of the roof sheathing to increase the effective R-value of the assembly and/or to decrease the amount of exterior insulation required above the sheathing. Open-cell spray foam is recommended for vapour permeability and to give the roof the ability to dry in case it is wetted initially or while in service (the foam should not be sprayed on when the wood is wet). A safe maximum R-value for the spray foam would be one-third of the total nominal R-value (i.e., two-thirds R-value above deck and one-third R-value below), although further analysis is recommended for the particular climate zone, because in warmer climates a greater amount of spray-foam insulation could be placed below the roof deck.

This assembly provides acceptable performance in all climate zones provided that a durable roofing membrane is selected and properly detailed.

4.12.1 Controlling Exterior Moisture: Water-Penetration Control

This assembly anticipates the control of all of the exterior moisture that might occur at the roof's waterproof membrane system, with some amounts of water shed to the drainage system at the top of the ballast and insulation layers. The large amount of water that penetrates through to the waterproof membrane means that the water-shedding surface and the water-resistive barrier can be considered to be coincident at the membrane.

4.12.2 Air Barrier

The waterproof membrane can be considered the primary element of the air barrier in this assembly.

4.12.3 Vapour Barrier

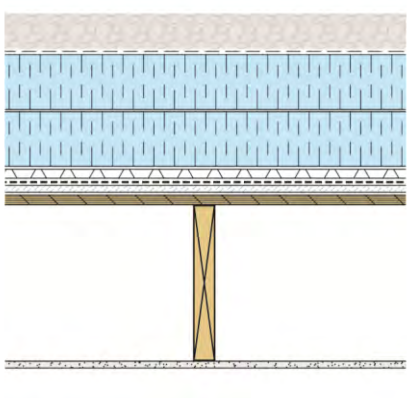
The roof's waterproof membrane system provides sufficient vapour resistance for controlling outward vapour flow at an ideal location because moisture present on either side of this membrane has an opportunity to drain or dry.

4.12.4 Effective R-Values

The effective R-values for an inverted roof assembly are similar to the nominal insulation R-values. Thermal bridging through the assembly is not generally a consideration, except at roof penetrations and parapets, because the insulation is installed in a continuous manner over the roof deck at the exterior. Consideration for reducing the amount of rainwater that percolates through the insulation joints should be included in the design. The use of water-resistant filter fabric to drain the majority of water to drains (instead of through insulation) will improve the thermal performance of this assembly during rainy weather. Studies in Europe have shown that significant reductions in the effective R-value of the insulation will occur if water is able to freely flow through the joints.

Detailed calculations of effective R-value are not generally necessary, and the nominal insulation R-value can be taken and added to approximately R-4 to account for the supporting structure and finishes, the air spaces between the framing, and the exterior and interior air films.

LOW-SLOPE INVERTED (PROTECTED-MEMBRANE) ROOF ASSEMBLY: SUMMARY

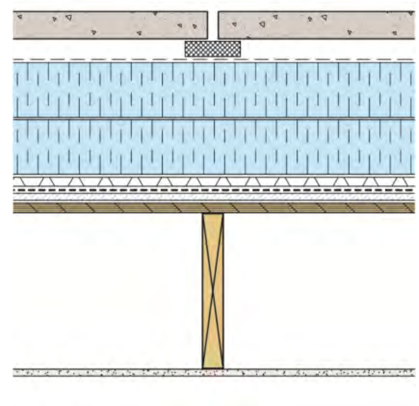


ROOF

EXTERIOR

- Pavers and pedestal system (roof deck) or gravel ballast (roof)
- Filter fabric
- Rigid insulation (XPS), joints staggered between layers
- Waterproofing membrane (SBS, hot rubber, etc.)
- Roof sheathing
- Roof framing sloped to drain
- Roof joists
- Interior gypsum board

INTERIOR



ROOF DECK

CONTROLLING EXTERIOR MOISTURE: WATER-PENETRATION CONTROL

This assembly anticipates the control of all of the exterior moisture at the roof's waterproof membrane system, with some amounts of water shed to the drainage system at the top of the ballast and insulation layers. The large amount of water that penetrates through to the waterproof membrane means that the water-shedding surface and the water-resistive barrier can be considered to be coincident at the membrane.

CONTROLLING AIR FLOW: AIR BARRIER

The roofing membrane is the primary air-barrier element in this assembly.

CONTROLLING HEAT FLOW

Extruded polystyrene insulation (XPS, R-5/inch) is used in this application because it is moisture tolerant in this wet environment. Spray foam on the underside of the roof sheathing could be used to increase the effective R-value of the assembly and/or decrease the amount of exterior insulation required above the sheathing. Foam should not be sprayed when the wood is wet, and open-cell spray foam is recommended for vapour permeability. As a general rule of thumb, the maximum R-value of spray foam would be one-third of the total nominal R-value (i.e., two-thirds R-value above deck and one-third R-value below), although it can be fine-tuned with hygrothermal analysis or based on local experience.

CONTROLLING VAPOUR FLOW: VAPOUR RETARDER

The roof's waterproof membrane system provides sufficient vapour resistance to control outward vapour flow at an ideal location because moisture present on either side of this membrane has an opportunity to drain or dry.

APPLICATION

This type of roof assembly is common and has a history of good performance.

FACTORS LIMITING PERFORMANCE

The assembly is difficult to maintain or repair because access to the membrane requires removal of the ballast and insulation. However, the waterproof membrane in this assembly is protected from loading, including thermal cycling, and is protected from UV light and pedestrian traffic—therefore it can have a longer service life than a membrane placed in more exposed environments—and it requires minimal maintenance. Detailing and positive drainage are important for successful performance of this assembly. The additional ballast load means that the roof assembly must have a greater structural capacity.

CHAPTER 5: DETAILING

The foundations, walls, roofs, doors, windows, and other elements are combined in a building project to form a complete and continuous enclosure that separates interior space from the exterior. Key functions such as air barriers, vapour retarders, water-resistive barriers, water-shedding surface, and insulation must be present, not only in each assembly of the enclosure, but also at the interfaces between assemblies, as well as at penetrations through these assemblies. This is one of the most common and challenging detailing tasks faced by designers and builders. This chapter focuses on appropriate detailing of building-enclosure interfaces and penetrations in energy-efficient assemblies.

Multi-unit residential buildings (MURBs) are typically more complex and require more details than single-family dwellings. Fig. 5.1.1 shows the typical details required to construct the building enclosure of a multi-storey wood-frame MURB. These typical details are contained within this chapter for each of the different wall and roof assemblies introduced in Chapter 4.

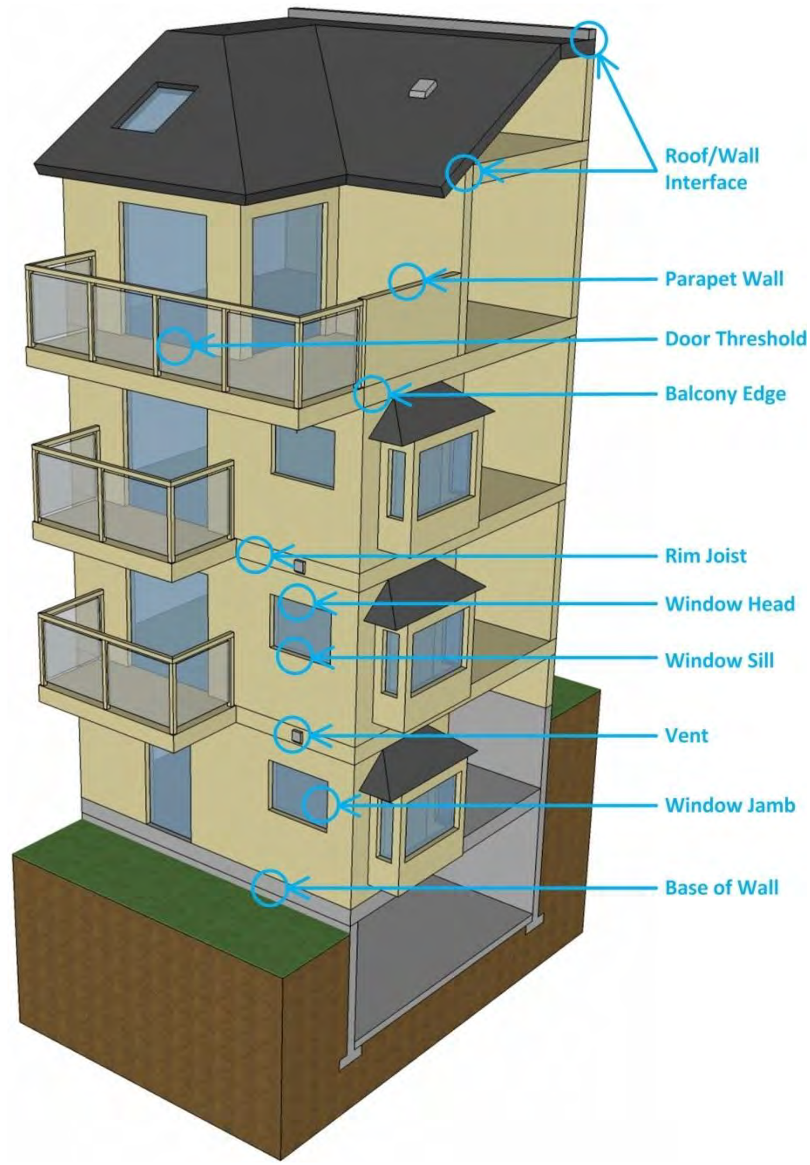


Fig. 5.1.1 Typical detailing locations for the building enclosure of a MURB.

5.1 Continuity of Critical Barriers

The term critical barrier refers to materials and components that together perform one of the primary moisture-control, air-movement, vapour-movement, and thermal-insulation functions within a building's enclosure assembly. These functions are described in greater detail in Chapter 3 and 4. The continuity of these functions must be maintained at interfaces between different assemblies and components.

Challenges arise when critical barriers are located at different planes in adjoining elements, for example, at a wall-to-window or wall-to-roof interface. It is not always clear how to effectively maintain continuity of the critical barrier through these interfaces, particularly with respect to air-barrier and thermal continuity. In addition, it is also not always clear which parties in the design and construction process are responsible for ensuring that continuity.

The details shown in the following pages are intended to illustrate acceptable solutions for interface and penetration details associated with the assemblies presented in earlier chapters. The particular design parameters are arbitrary. Desired aesthetics, cladding type, assembly type, exterior environment, interior environment, and exposure conditions, amongst other variables, make each project unique. All may affect the development of appropriate details.

A discussion of some of the key issues related to performance is provided with each set of details. In addition, for each detail, a figure (same as the detail but without the text) illustrates the location of three of the critical barriers at each detail. This includes the water-shedding surface, the water-resistive barrier, and the air barrier. The vapour-retarder layer has not been shown in an effort to allow the other critical barriers to be clearly visible. It also reflects the relative ease with which appropriate vapour retarders can be incorporated into assemblies and the fact that continuity at details is not critical in the control of vapour diffusion. Because the focus of this guide is on highly insulated assemblies and the reduction of thermal bridging, the thermal insulation is also highlighted, along with other components that may have been used to address thermal continuity (e.g., lower-conductivity wood instead of more-conductive steel). Insulation continuity may not be possible through all enclosure details and interfaces, and allowance for this in effective thermal calculations must be taken into consideration.

5.2 Two-Dimensional Detail Drawings

Two-dimensional details, as related to the building enclosures of wood-frame MURBs in marine and cold climates in North America, are described in this chapter and are presented as best practice. Extensive drawings of the details also appear in this chapter. Table 5.2.1 lists the names of the details and the figure number for the corresponding drawings.

Alternative membrane and insulation materials may be used in warmer climate zones, as per the substitute materials described. Insulation depths would also be adjusted based on a project's R-value requirements. Three-dimensional build-slides for window installation sequencing are provided later within this chapter.

The wood-framing details are shown with 2x4 framing and 3 inches of exterior insulation. In most cases the details can be adjusted for 2x6 framing or thicker exterior insulation, depending on structural and R-value requirements. Details showing CLT structure can also be adjusted for thicker CLT panels based on structural requirements. In addition, the double-stud details show a 1.5-inch gap between the rows of studs, which can also be adjusted for insulation thickness.

Table 5.2.1 List of two-dimensional details

Detail no.	Title of detail	Assembly type	Code
Foundation Details			
1	Base of Wall/Foundation	Split-insulation above-grade wall Exterior-insulated foundation wall	1- SI
		Double-stud above-grade wall Exterior-insulated foundation wall	1-DS
		Exterior-insulated mass timber panel wall Exterior-insulated foundation wall	1-MT
Frame Wall Details			
2	Rim Joist / Floor Edge	Split-insulation above-grade wall	2-SI
		Double-stud above-grade wall	2-DS
		Exterior-insulated mass timber panel wall	2-MT
		Exterior-insulated post-and-beam wall	2-PB
3	Concrete Slab Floor Edge	Split-insulation wood infill wall – overhanging	3-WI-O
		Split-insulation wood infill wall – flush	3-WI-F
Window and Door Details			
4	Window Head	Split-insulation above-grade wall	4-SI
		Double-stud above-grade wall	4-DS
		Exterior-insulated mass timber panel wall	4-MT
		Split-insulation above-grade wall Alternative head flashing detail	4-SI-2
5	Window Jamb	Split-insulation above-grade wall	5-SI
		Double-stud above-grade wall	5-DS
		Exterior-insulated mass timber panel wall	5-MT
6	Window Sill	Split-insulation above-grade wall	6-SI
		Double-stud above-grade wall	6-DS
		Exterior-insulated mass timber panel wall	6-MT
7	Door Sill/Balcony	Split-insulation above-grade wall	7-SI
		Double-stud above-grade wall	7-DS
		Exterior-insulated mass timber panel wall	7-MT
Roof Details			
8	Pitched Roof / Wall Interface	Split-insulation above-grade wall Pitched roof – vented attic	8-SI
		Double-stud above-grade wall Pitched roof – vented attic	8-DS

		Exterior-insulated mass timber panel wall Pitched roof – vented attic	8-MT
		Split-insulation above-grade wall Exterior insulated roof	8-EI
9	Low Sloped Roof / Wall Interface (Parapet)	Split-insulation above-grade wall Low slope conventional roof	9-SI
		Double-stud above-grade wall Low slope conventional roof	9-DS
		Exterior-insulated mass timber panel wall Low slope conventional roof	9-MT
Balcony Details			
10	Balcony / Wall Interface	Split-insulation above-grade wall	10-SI
Wall Penetration Details			
11	Wall Exhaust Vent	Split-insulation above-grade wall	11-SI
12	Exterior Electrical Outlet	Split-insulation above-grade wall	12-SI
13	Hose bib	Split-insulation above-grade wall	13-SI

5.2.1 Detail 1: Base of Wall/Foundation

A transition detail is needed where the above-grade wall meets the foundation wall.

At these locations there are a number of specific issues that should be addressed.

Issues

Wood in Contact with Concrete

A sill gasket is installed to retard moisture that might go through the concrete into the sill plate; however, the sill plate should be pressure-treated unless, based on NBC or IECC or a different local code, a minimum clearance of 150 mm (6 inches) between grade and wood is met.

Damp Proofing or Waterproofing

Damp proofing, insulation, and plastic drainage composite are shown on the exterior side of the foundation wall in these details. This is generally acceptable for dry or well-drained (no hydrostatic head) conditions. The drainage composite will quickly drain away any water that is present at the wall, thus helping to ensure that little water will actually reach the damp-proofing layer. Where a head of water is to be expected despite the drainage composite, a waterproof membrane should be used on the foundation wall. It is important that laps and edges of plastic drainage composites are constructed so that they do not allow soil into the drainage space. Care must be taken during construction because it is easy to displace the termination and laps.

Slope Away from the Building

A key strategy for managing moisture at the building perimeter is to have the surrounding grade slope away from the building. This greatly reduces the amount of water that comes in contact with the wall, thereby decreasing the dependence on sub-grade drainage capacity and waterproofing.

Insulating at Joist

To maintain the thermal performance of the enclosure at the rim joist, the interior side of the joist is insulated with extruded polystyrene blocks and spray-in-place foam at the edges. In assemblies with a deep rim-joist cavity, as is present in a double-stud wall, cellulose insulation should be used along with rigid and spray-in-place foam insulation.

Exterior Insulation

The extruded polystyrene used on the exterior side of the concrete foundation wall is protected from impact damage with concrete parging. This protective layer can be applied in the field, or pre-fabricated coated panels can be used. On exterior-insulated walls, effective attachment strategies must be used to secure the insulation and allow for cladding attachment.

Base of Cladding through Wall Flashing

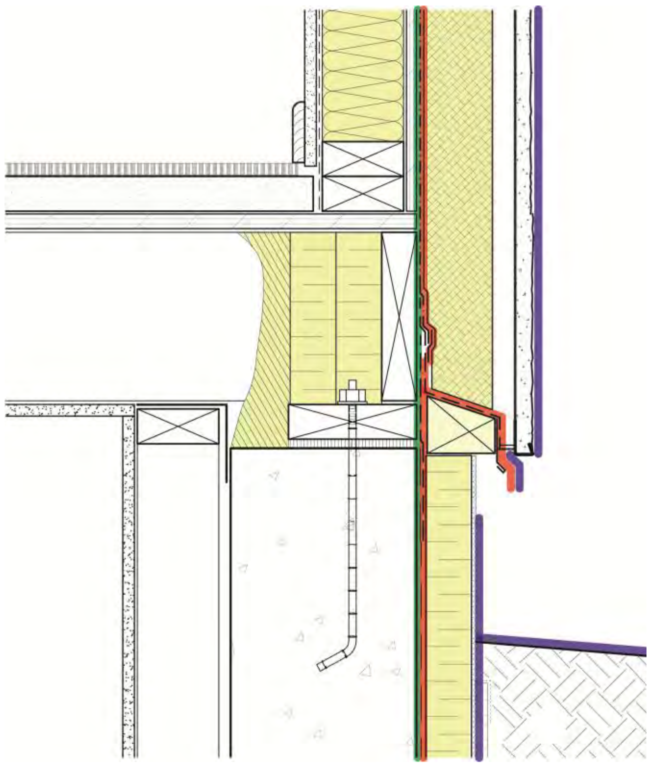
Wood blocking with a self-adhered membrane will better serve to reduce thermal bridging at flashing locations than metal flashing.

Air-Barrier Strategies

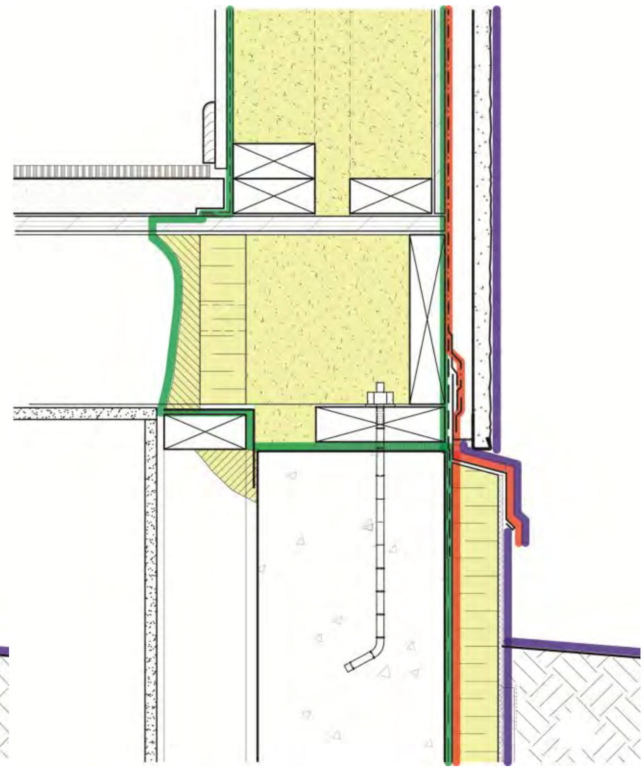
To maintain continuity of the air barrier, a transition from the sheathing membrane to the concrete waterproofing is required. This transition is provided by a strip of self-adhered membrane. For the double-stud detail a dual air barrier is shown because of the deep-stud cavity and the higher risk of condensation in the cavity. The interior polyethylene acts to prevent convective looping and humid air exfiltration, and the exterior air barrier acts to prevent wind washing.

Insect Control

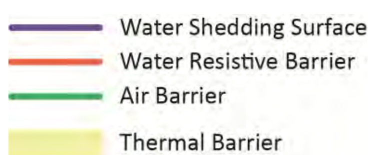
As with any wall assembly, it is important to place bug screens in locations where the rainscreen cavity is exposed. This is especially critical when insulation is in the cavity. Bug control may be required at other locations in the wall assembly as well. Termite control may facilitate alternative details and materials.

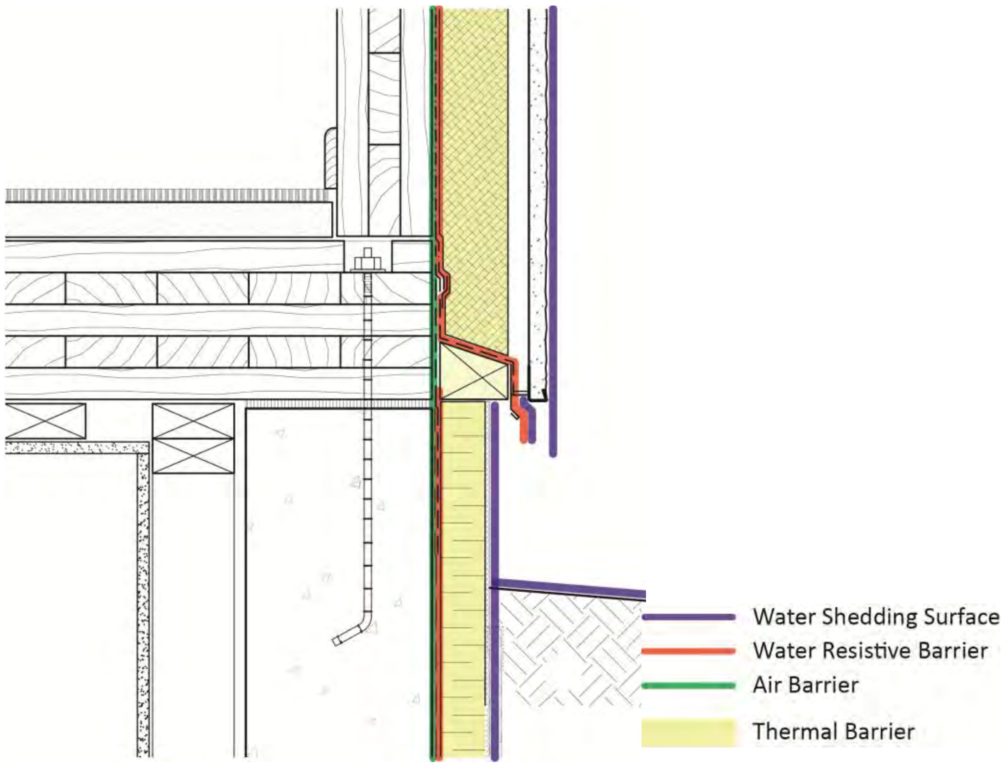


Detail 1-SI – Location of critical barriers.

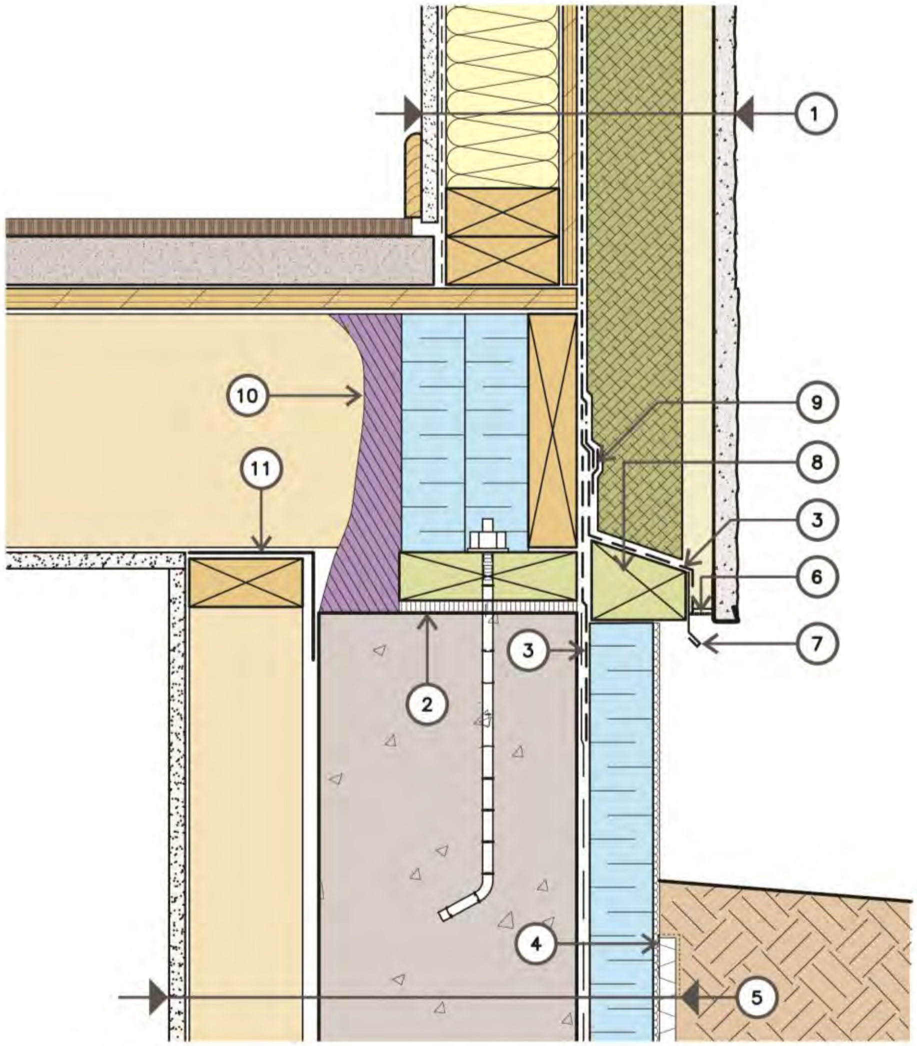


Detail 1-DS – Location of critical barriers.





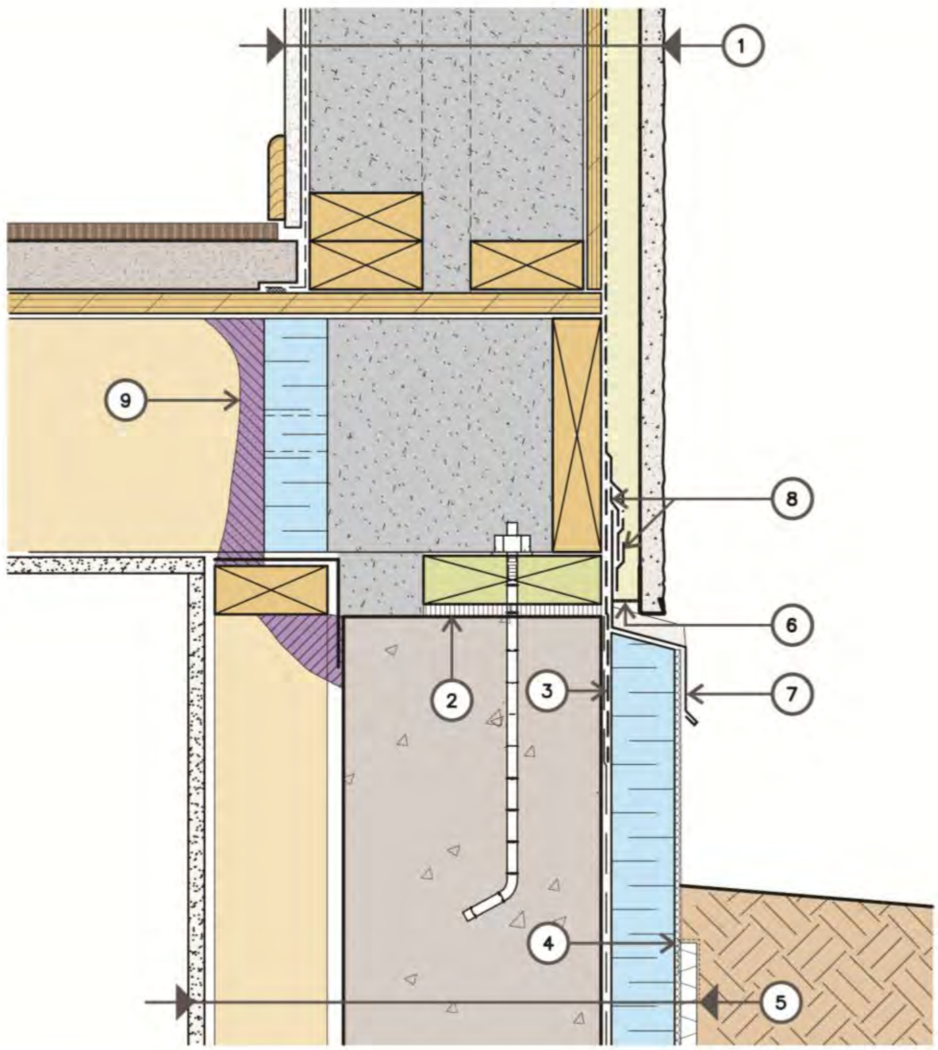
Detail 1-MT – Location of critical barriers.



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - Wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x89mm (2x4)
   - Batt insulation
   - Polyethylene
   - Gypsum board
2. Sill gasket
3. Self adhered membrane
4. Filter cloth over top of drainage mat
5. Wall Assembly
   - Plastic drainage composite
   - 50mm (2") extruded polystyrene with protective cementitious coating above grade
   - Dampproofing/waterproofing
   - Concrete foundation wall
   - 13mm (½") air space
   - Wood studs with sill plate (p.t.)
   - Gypsum board
6. Insect screen
7. Pre-finished metal flashing
8. Sloped wood blocking
9. Tape
10. Extruded polystyrene insulation with spray-in-place foam at edges
11. Sheet metal closure

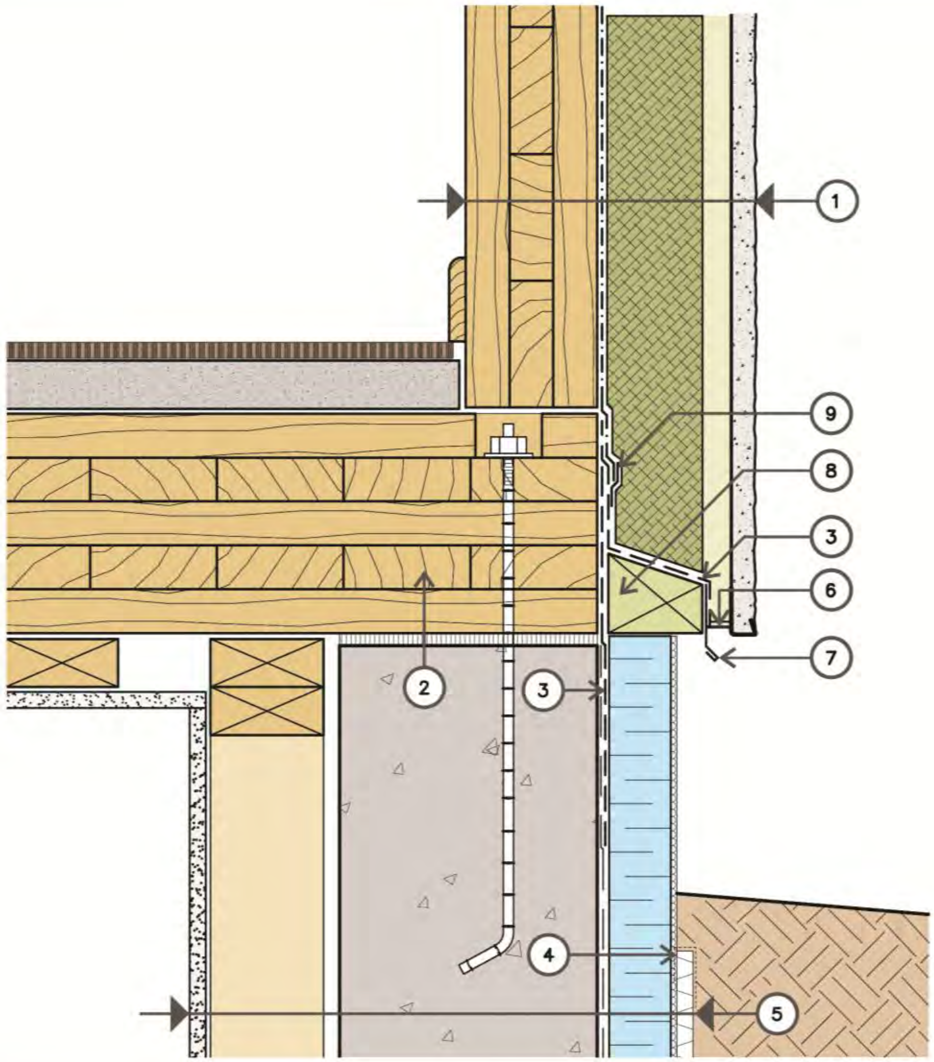
BASE OF WALL / FOUNDATION | DETAIL 1-SI



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - Wood strapping (p.t.)
   - Vapour permeable sheathing membrane
   - Sheathing
   - 2 Rows of wood framing 38x89mm (2x4) with 38mm (1½") gap (adjustable)
   - Cellulose insulation in wall cavity
   - Polyethylene
   - Gypsum board
2. Sill gasket
3. Self adhesive membrane strip
4. Filter cloth over top of drainage mat
5. Wall Assembly
   - Plastic drainage composite
   - 50mm (2") extruded polystyrene with protective cementitious coating above grade
   - Dampproofing/waterproofing
   - Concrete foundation wall
   - 13mm (½") extruded air space
   - Wood studs with sill plate (p.t.)
   - Gypsum board
6. Insect screen
7. Pre-finished metal flashing
8. Tape
9. Cellulose insulation and extruded polystyrene with spray-in-place foam at edges

BASE OF WALL / FOUNDATION | DETAIL 1-DS



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - Wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - CLT Panel
2. Sill gasket
3. Self adhered membrane strip
4. Filter cloth over top of drainage mat
5. Wall Assembly
   - Plastic drainage composite
   - 50mm (2") extruded polystyrene with protective cementitious coating above grade
   - Dampproofing/waterproofing
   - Concrete foundation wall
   - 13mm (½") air space
   - Wood studs with sill plate (p.t.)
   - Gypsum board
6. Insect screen
7. Pre-finished metal flashing
8. Sloped wood blocking
9. Tape

BASE OF WALL / FOUNDATION | DETAIL 1-MT

5.2.2 Detail 2: Rim Joist/Floor Edge

A transition detail is needed where the rim joist of the flooring system intersects the above-grade wall assemblies of different floor levels.

At these locations there are a number of specific issues that should be addressed.

Issues

Frame Shrinkage

Placement of the cross-cavity flashing at the level of the rim joist creates an effective joint to accommodate the shrinkage of the rim joist and plates.

Ventilation

The flashing will serve as the location for venting or ventilation at the top and bottom of the cavity.

Cross-Cavity Flashing

Wood blocking with a self-adhered membrane will better serve to reduce thermal bridging at flashing locations than metal flashing. Where metal flashing is used, the joints in the cross-cavity flashing should be designed and constructed to minimize the potential for water penetration. Joints should be standing seam or S-lock. Using a 3:1 slope on the cross-cavity flashing will reduce the potential for water to leak through the joints.

Insulating at Joist

To maintain the thermal performance of the enclosure at the rim joist, the interior side of the joist is insulated with extruded polystyrene blocks and spray-in-place foam at the edges. In assemblies with a deep rim-joist cavity, as is present in a double-stud wall, cellulose insulation may accompany the rigid and spray-in-place foam insulation.

Exterior Insulation

On walls with exterior insulation on the outside of the framing, effective attachment strategies must be used to secure the insulation and allow for cladding attachment. It is also important to ensure the insulation is not trapping moisture in the wall if it is vapour impermeable.

Structural Movement

In assemblies using post-and-beam construction, movement joints must be provided to accommodate deflection of load-bearing beams.

Air-Barrier Strategies

To maintain continuity of the air barrier a transition from the wall above to the wall below is required. This is provided by the placement of the vapour-permeable sheathing membrane over the rim joist and the flashing taped to it. The vapour-permeable sheathing membrane above is lapped over and taped to the flashing to provide continuity. In a double-stud wall, the polyethylene (where present depending on vapour-control requirements) on the interior may also be used as an air barrier. Where polyethylene is not present, the drywall can be made airtight (ADA approach).

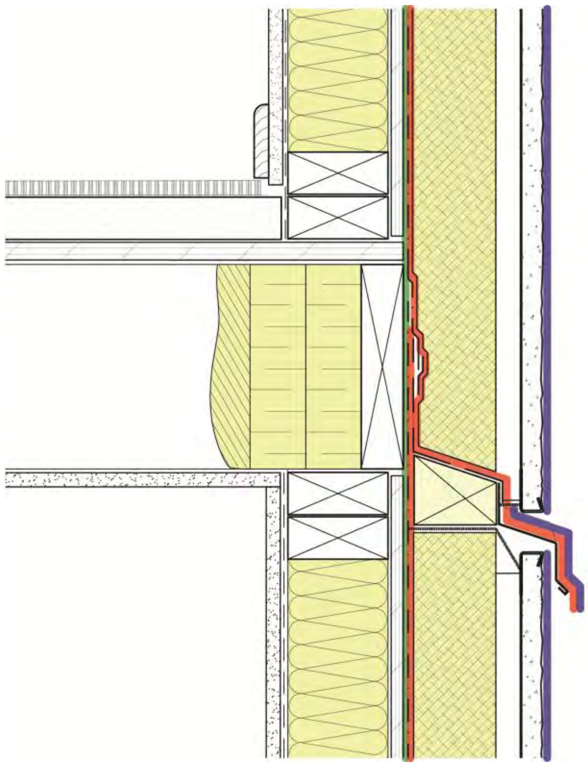


Fig. 5.2.2 Detail 2-SI – Location of Critical Barriers

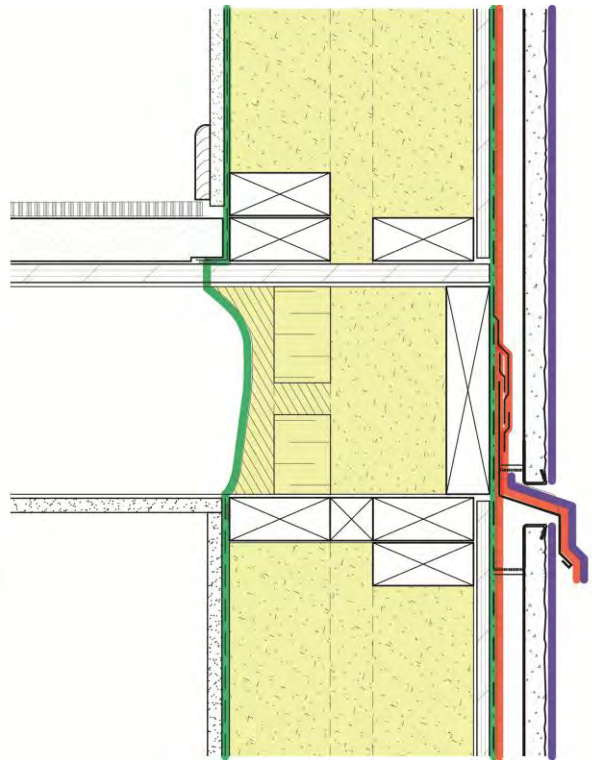


Fig. 5.2.3 Detail 2-DS – Location of Critical Barriers

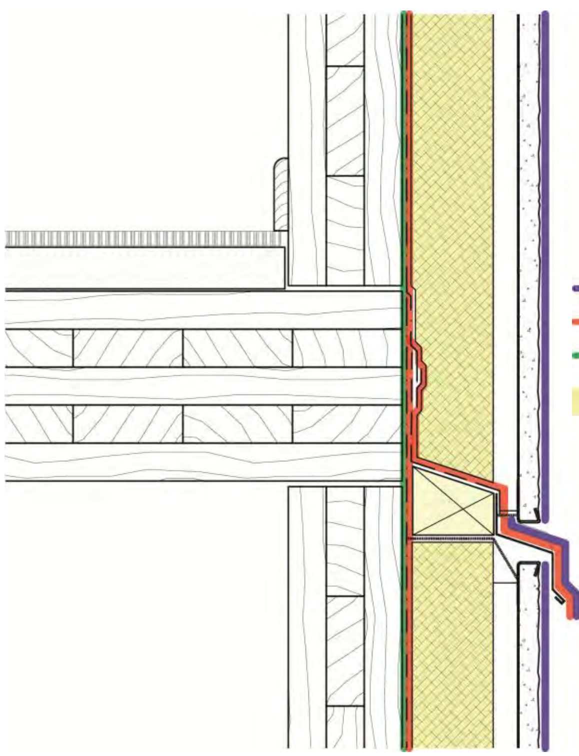


Fig. 5.2.4 Detail 2-MT – Location of Critical Barriers

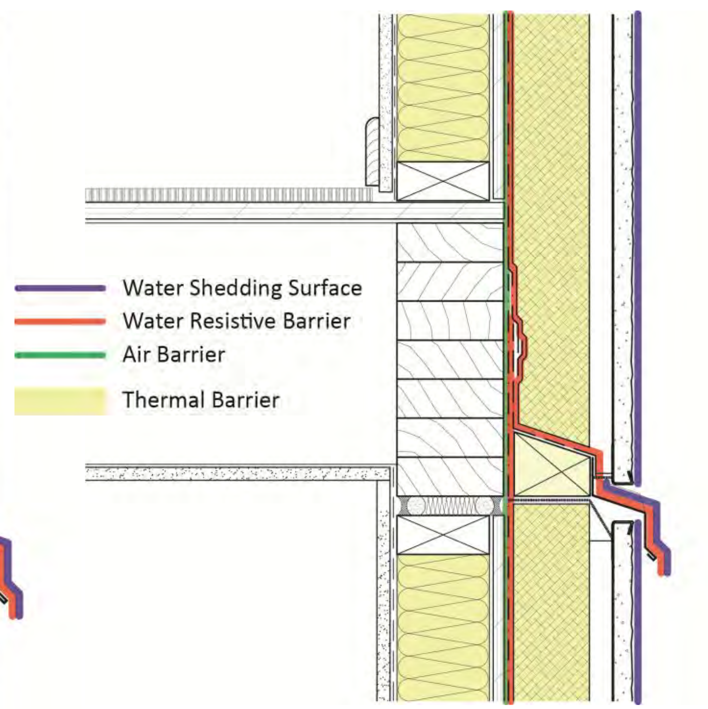
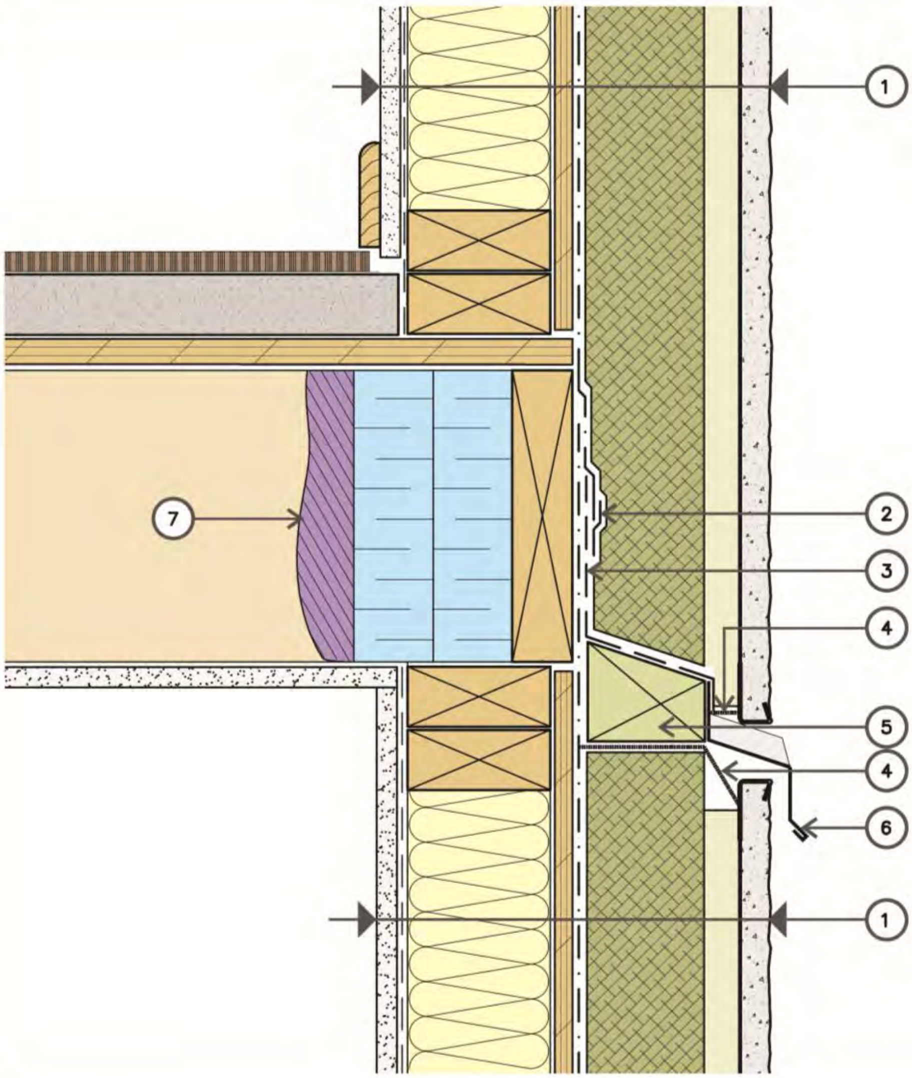


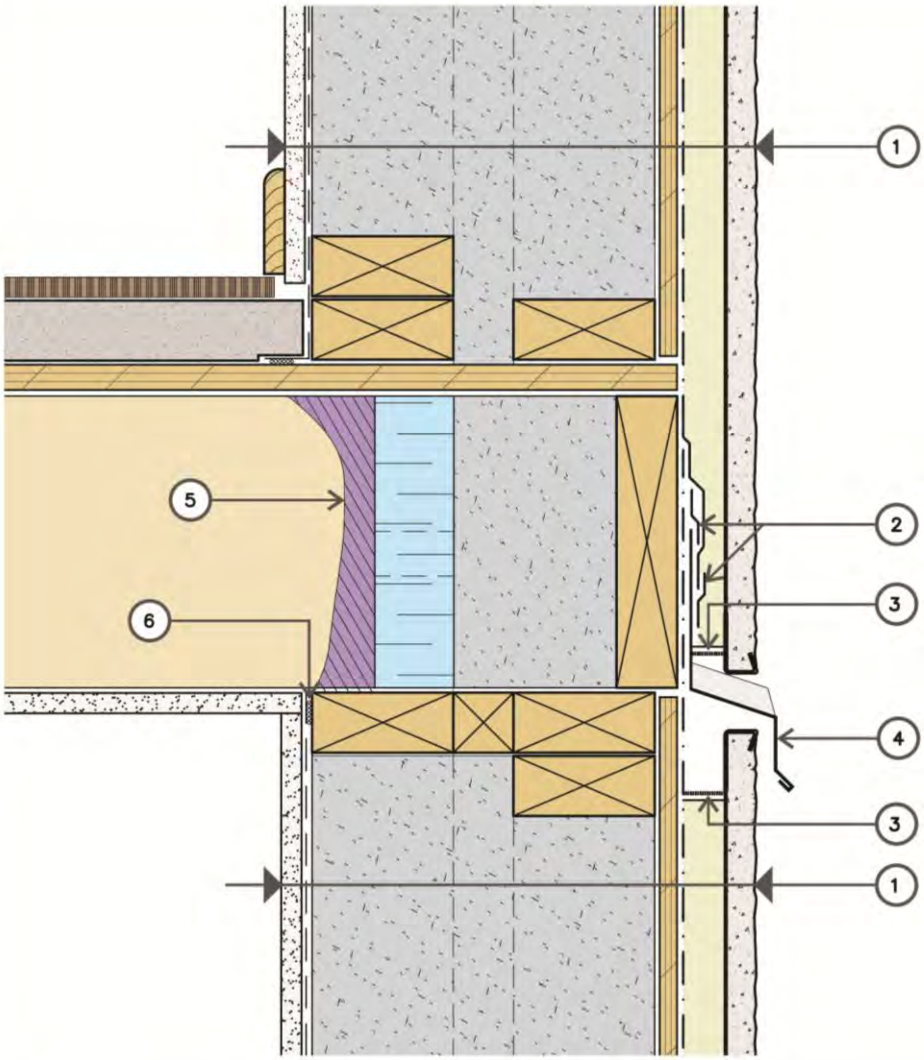
Fig. 5.2.5 Detail 2-PB – Location of Critical Barriers



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - Wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x89mm (2x4)
   - Batt insulation
   - Polyethylene
   - Gypsum board
2. Tape
3. Self adhered membrane flashing
4. Insect screen
5. Sloped wood blocking
6. Pre-finished metal flashing
7. Extruded polystyrene insulation with spray-in-place foam at edges

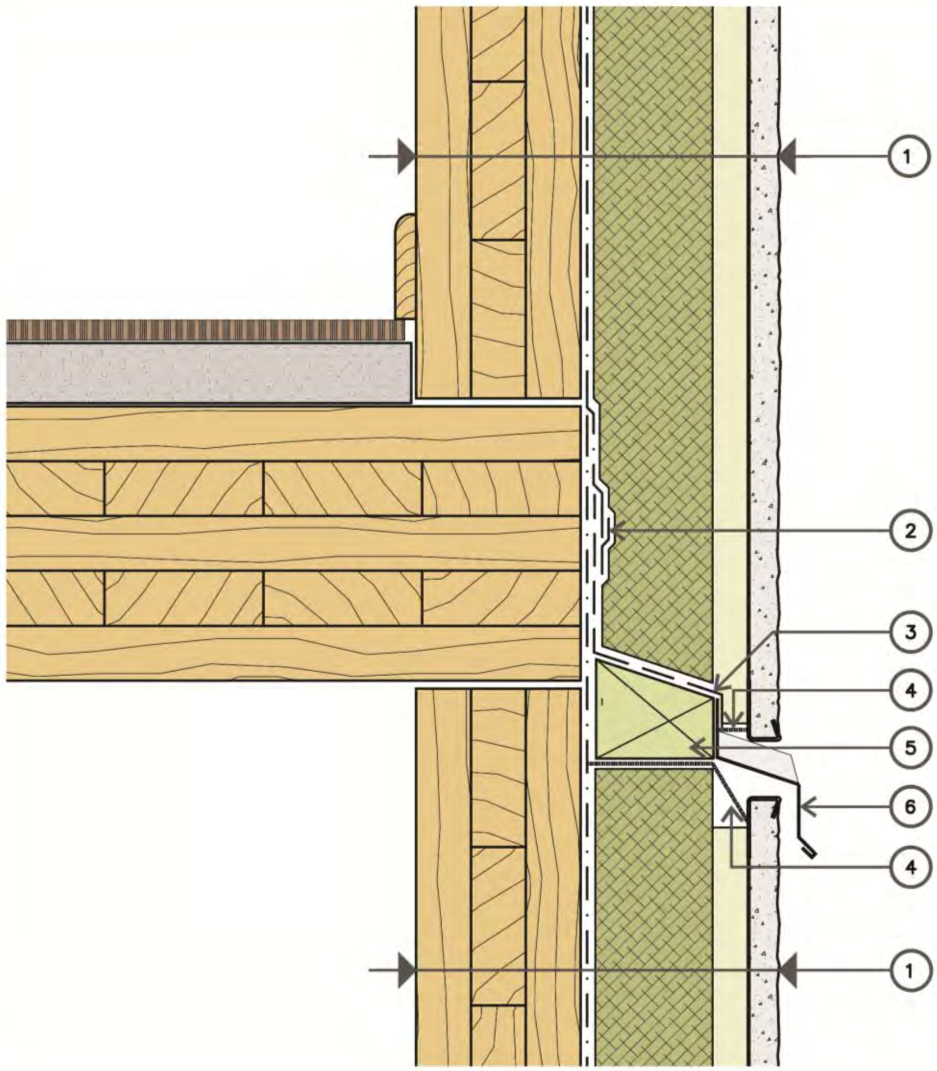
RIM JOIST | DETAIL 2-SI



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - Wood strapping (p.t.)
   - Vapour permeable sheathing membrane
   - Sheathing
   - 2 Rows of wood framing 38x89mm (2x4) with 38mm ($1\frac{1}{2}$") gap (adjustable)
   - Cellulose insulation in wall cavity
   - Polyethylene
   - Gypsum board
2. Tape
3. Insect Screen
4. Pre-finished metal flashing
5. Cellulose insulation and extruded polystyrene with spray-in-place foam at edges
6. Sealant

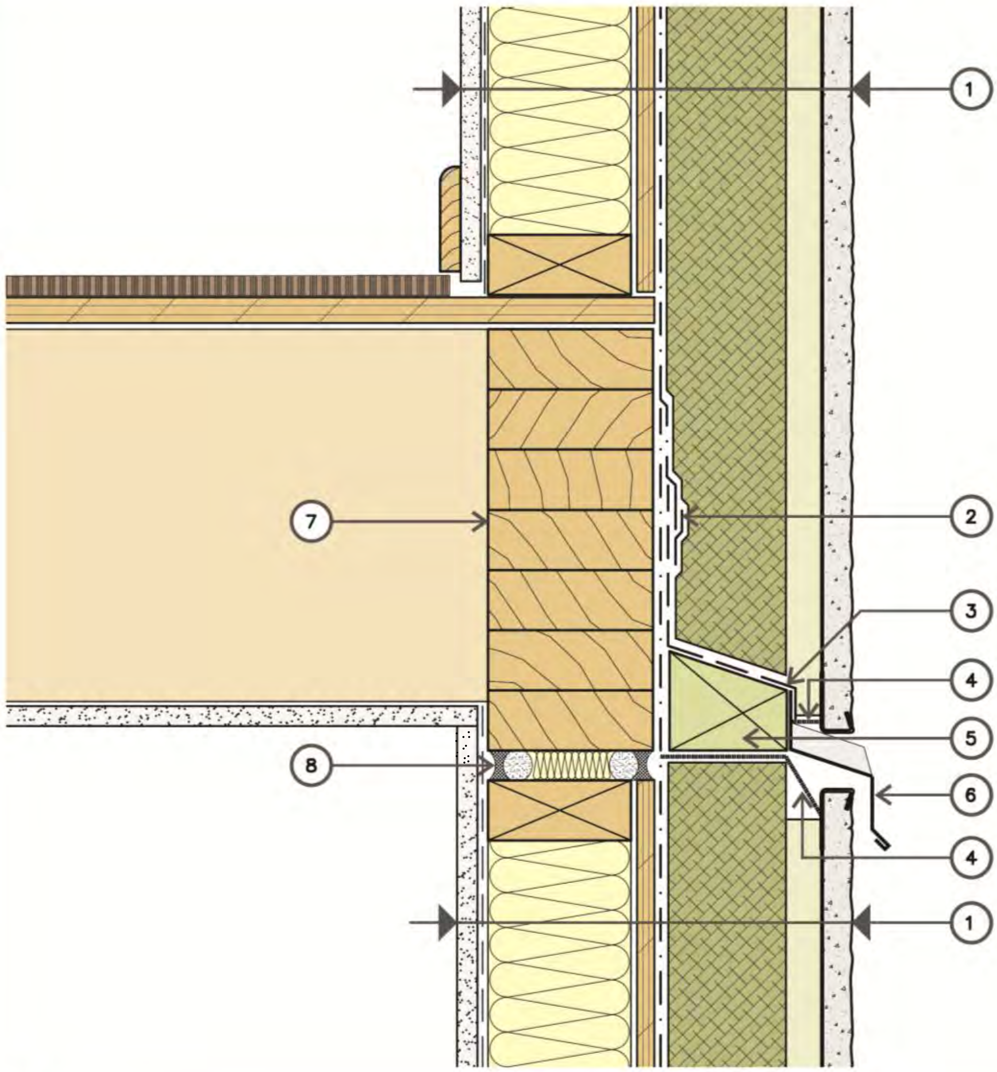
RIM JOIST | DETAIL 2-DS



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - Wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - CLT Panel
2. Tape
3. Self adhered membrane flashing
4. Insect screen
5. Sloped wood blocking
6. Pre-finished metal flashing

RIM JOIST | DETAIL 2-MT



LEGEND

1. Wall Assembly
   Cladding (stucco with backer board)
   Wood strapping (p.t.)
   76mm (3") mineral wool insulation
   Vapour permeable sheathing membrane
   Sheathing
   Wood framing 38x89mm (2x4) infill wall
   Batt insulation
   Polyethylene
   Gypsum board
2. Tape
3. Self adhered membrane flashing
4. Insect screen
5. Sloped wood blocking
6. Pre-finished metal flashing
7. Glulam beam
8. Backer rod & sealant

RIM JOIST | DETAIL 2-PB

5.2.3 Detail 3: Slab Edge

A transition detail is needed where the concrete floor assembly intersects the above-grade walls of two different floor levels.

At these locations there are a number of specific issues that should be addressed.

Issues

Structural Movement

Movement joints must be provided to accommodate slab edge deflection. This can be accomplished through the use of slotted L-brackets at the top of the infill framing.

Cross-Cavity Flashing

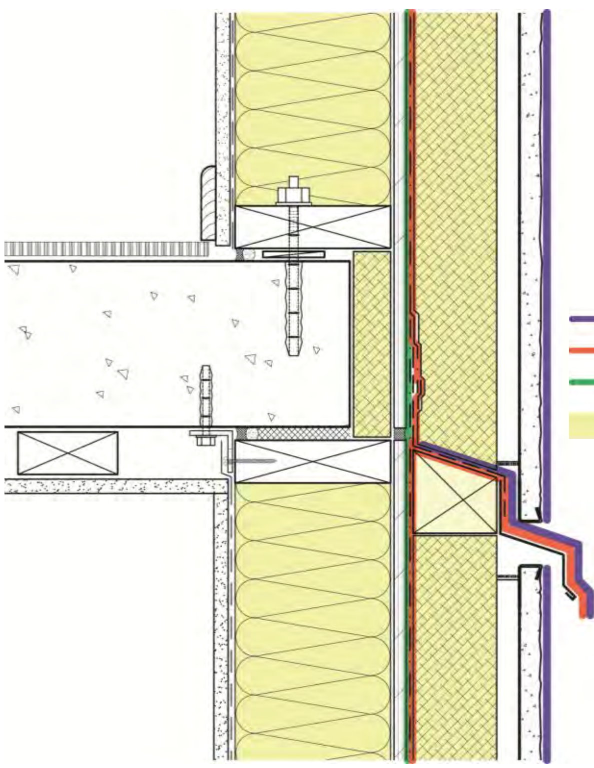
Wood blocking covered in a self-adhered membrane will better serve to reduce thermal bridging at flashing locations than metal flashing.

Insulating at the Slab Edge

Where the infill walls overhang past the slab edge, extra insulation should be used at the slab edge to achieve higher thermal efficiency of the assembly. Better fire protection is also achieved when mineral-fibre insulation is used.

Air-Barrier Strategies

To maintain continuity of the air barrier, a transition from the wall above to the wall below is required. This is provided by the placement of the vapour-permeable sheathing membrane over the slab edge or plywood and the flashing adhered to it. The vapour-permeable sheathing membrane above is lapped over and taped to the membrane flashing to provide continuity.



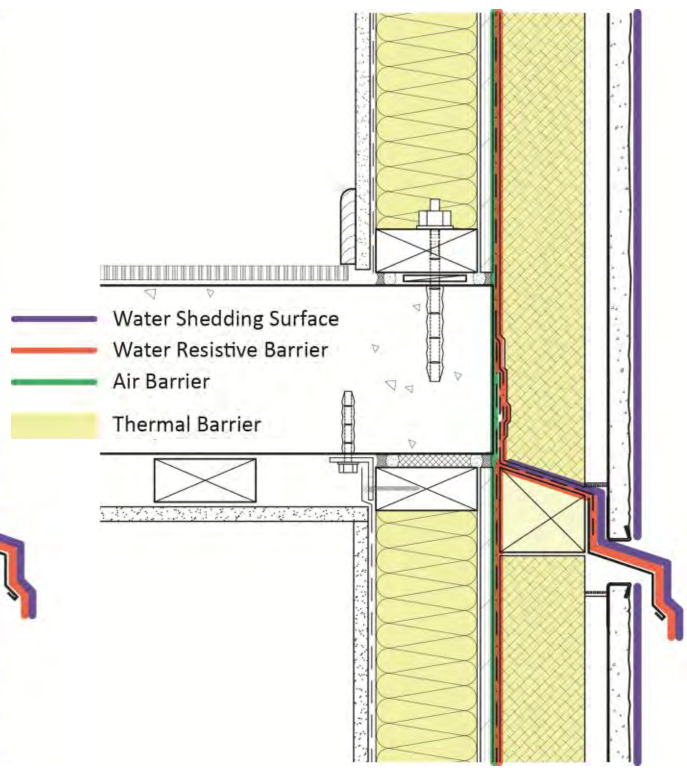
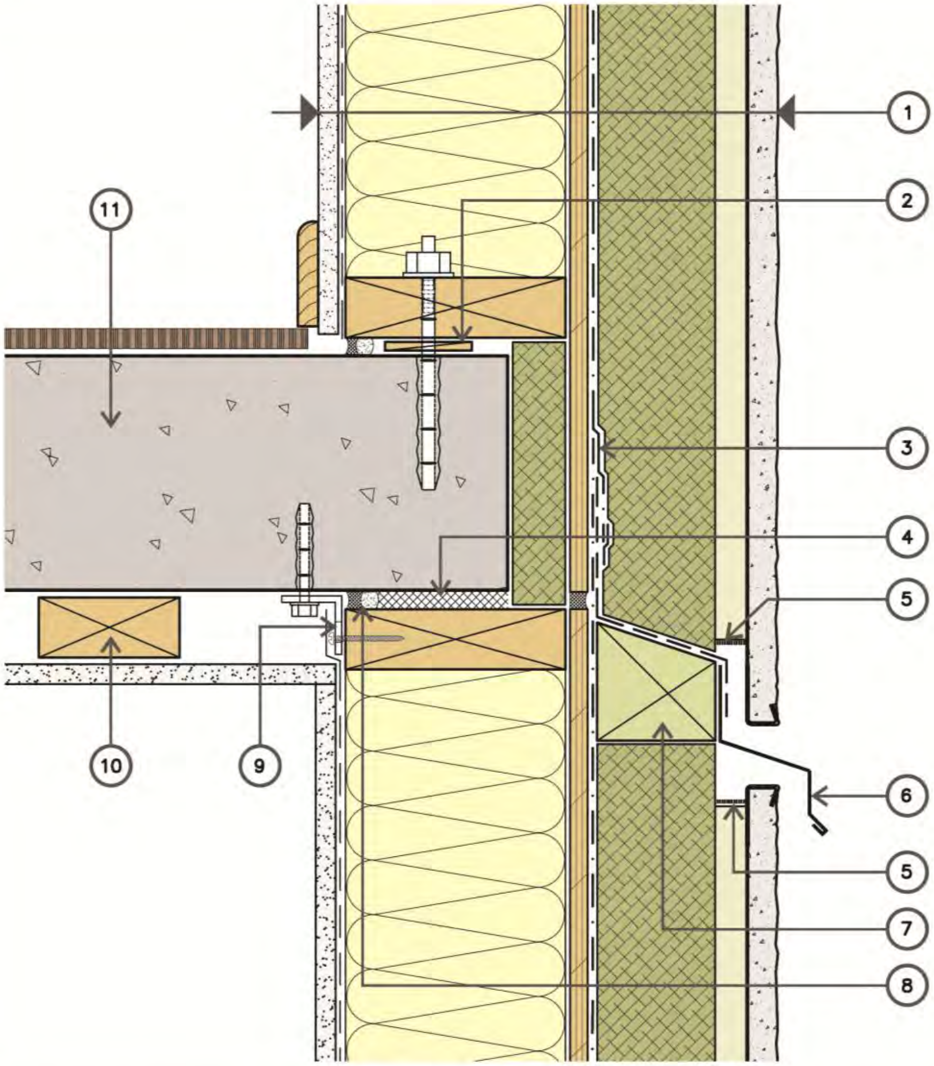


Fig. 5.2.6 Detail 2-WI-O – Location of Critical Barriers

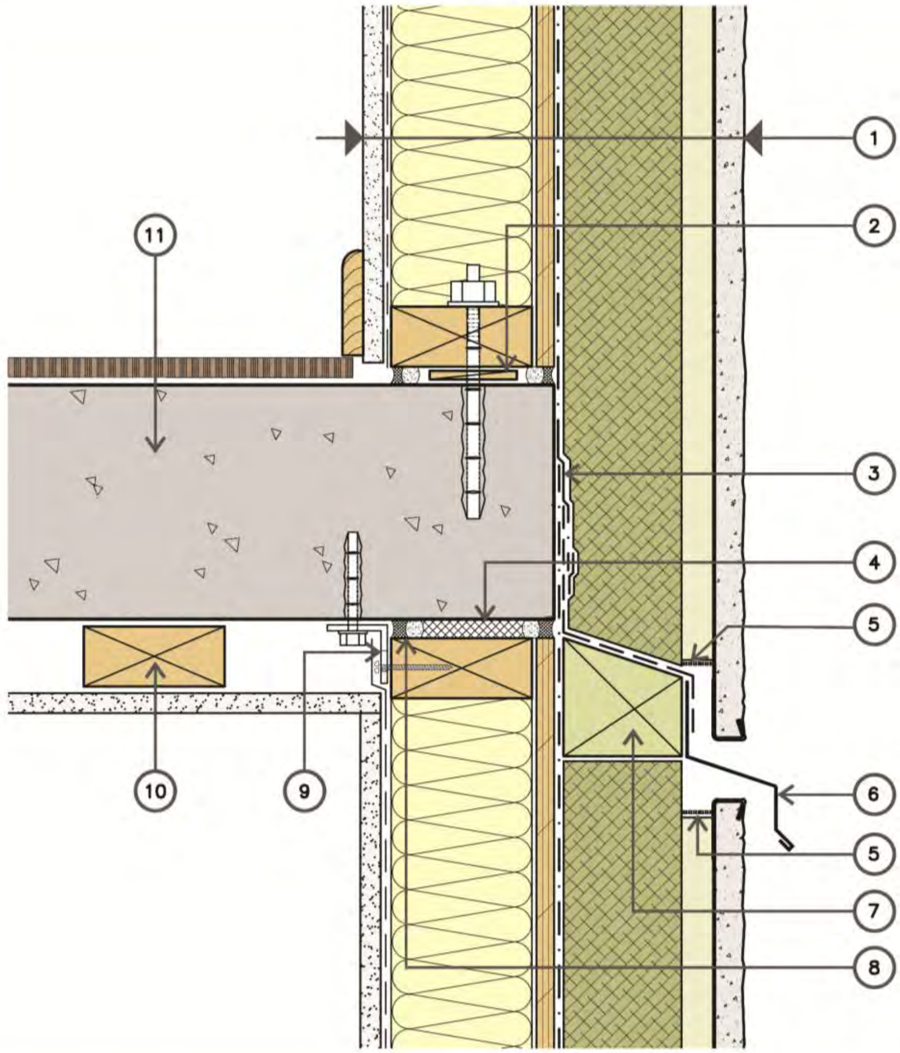
Fig. 5.2.7 Detail 3-WI-F – Location of Critical Barriers



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 76mm (3") mineral wool insulation
   - 19mm (¾") wood strapping (p.t.)
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x140mm (2x6)
   - Batt insulation
   - Polyethylene
   - Gypsum board
2. Shims
3. Vapour permeable sheathing membrane lapped over and taped to membrane flashing
4. Movement allowance joint
5. Insect Screen
6. Pre-finished metal flashing
7. Shear block
8. Backer rod & sealant
9. Slotted metal attachment clip
10. Wood furring
11. Concrete structural slab

WOOD INFILL WALL | DETAIL 3-WI-O



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 76mm (3") mineral wool insulation
   - 19mm (¾") wood strapping (p.t.)
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x89mm (2x4)
   - Batt insulation
   - Polyethylene
   - Gypsum board
2. Shims
3. Vapour permeable sheathing membrane lapped and taped to membrane flashing
4. Movement allowance joint
5. Insect screen
6. Pre-finished metal flashing
7. Shear block
8. Backer rod & sealant
9. Slotted metal attachment clip
10. Wood furring
11. Concrete structural slab

WOOD INFILL WALL | DETAIL 3-WI-F

5.2.4 Detail 4: Window Head

A transition detail is needed where the window frame meets the head of the rough window opening in the wall.

At these locations there are a number of specific issues that should be addressed.

Issues

Head Flashing

The head flashing should extend beyond the window jamb to protect the window jamb trim or cladding joint. The flashing should incorporate end dams to prevent water running off and entering the cavity.

Air-Barrier Strategies

To maintain continuity of the air barrier, a transition from the window frame to wall sheathing membrane is required. This is provided by the placement of the vapour-permeable sheathing membrane into the window head rough opening and sealing it to the window frame. The edges of the sheathing membrane may be taped with foil tape to provide a more appropriate surface for the sealant at the window frame.

Use of Adhered Membranes

The use of excessive amounts of adhered membrane should be avoided, particularly at locations that would tend to trap the downward migration of any moisture present. The presence of adhered membrane and polyethylene could create a vapour impermeable pocket from which it is very difficult for any incidental moisture to dry. Therefore, while the use of adhered membrane is advisable at the window sill and at least part way up the window jamb, its use at the window head should be avoided.

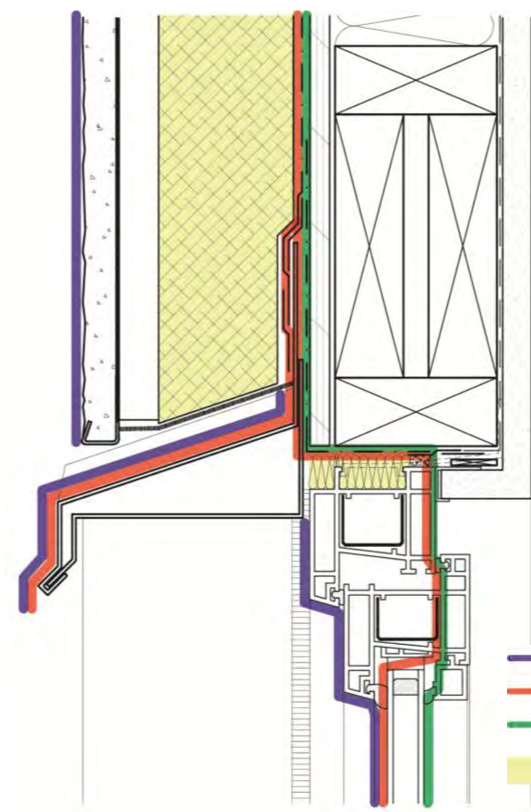


Fig. 5.2.8 Detail 4-SI – Location of Critical Barriers

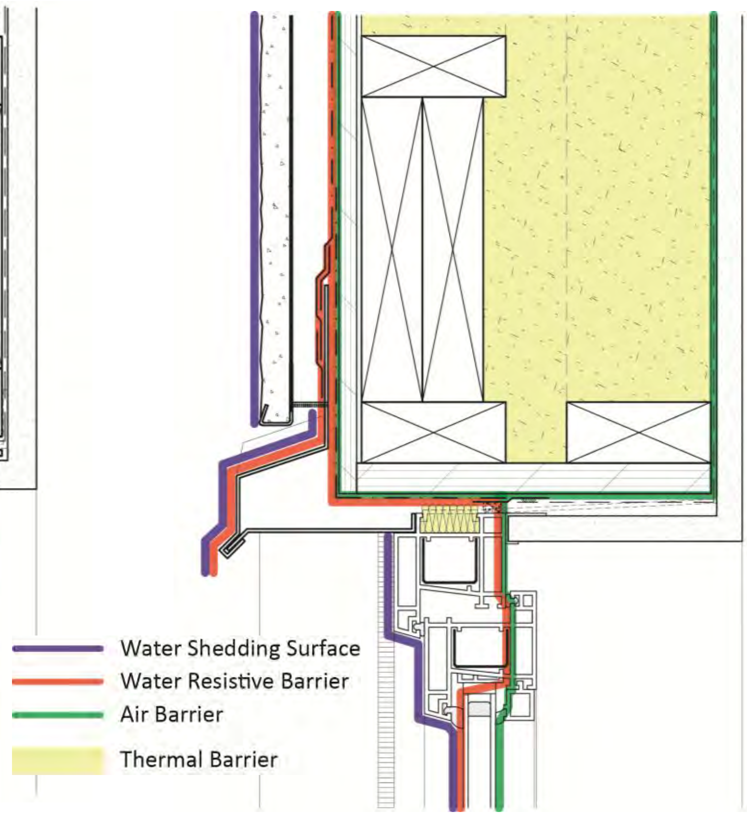


Fig. 5.2.9 Detail 4-DS – Location of Critical Barriers

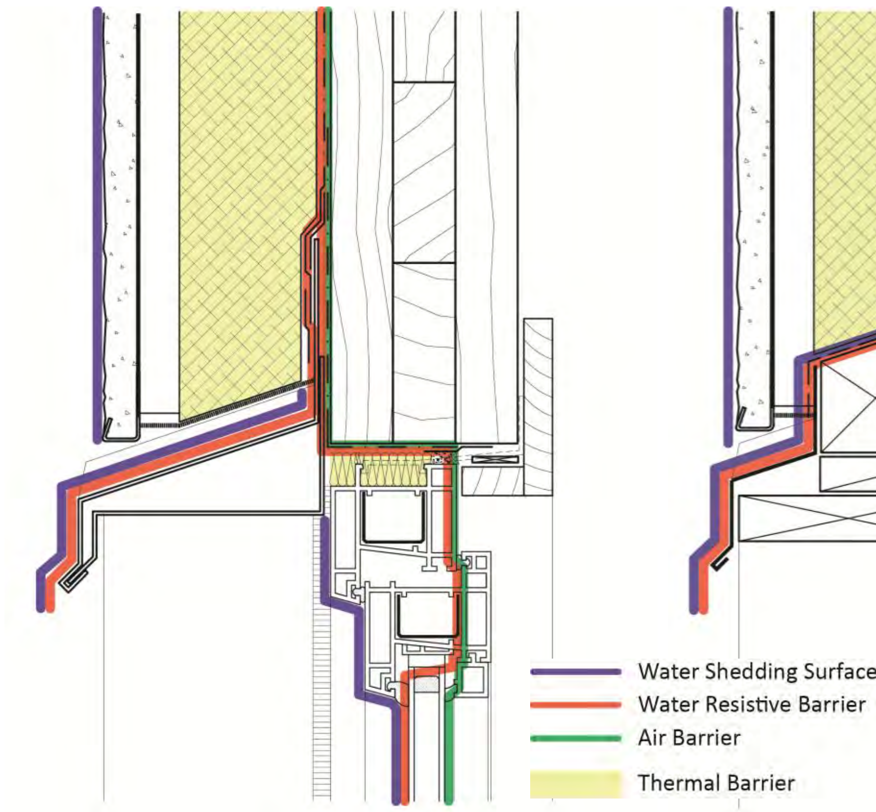


Fig. 5.2.10 Detail 4-MT – Location of Critical Barriers

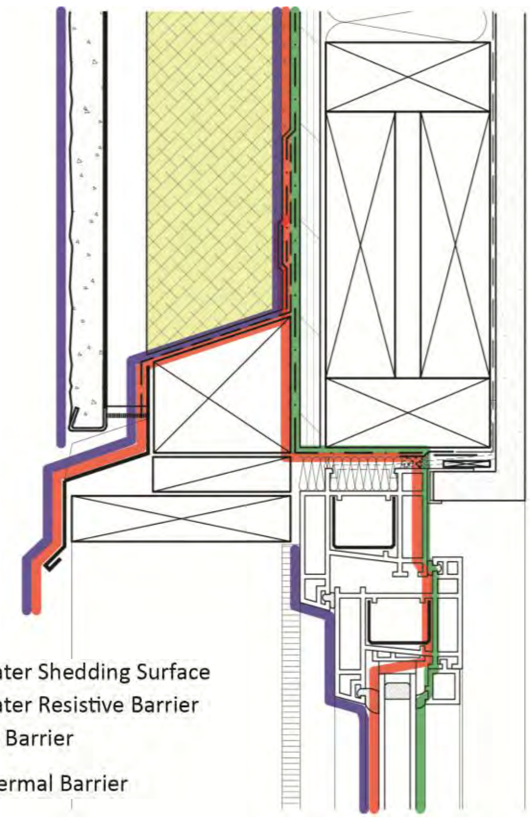
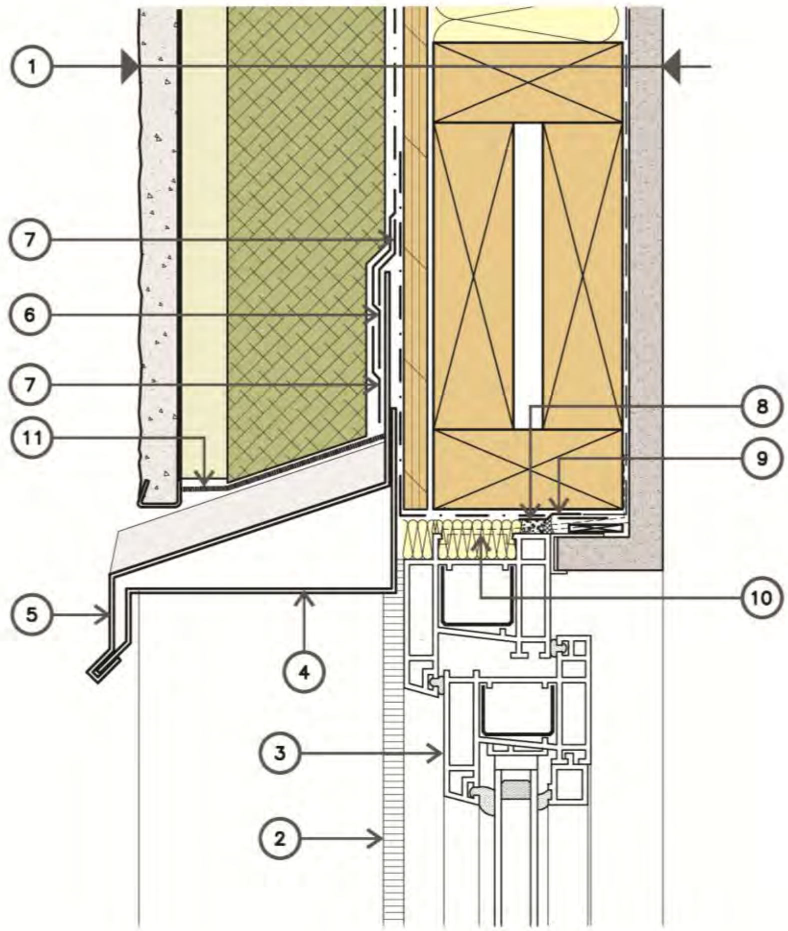


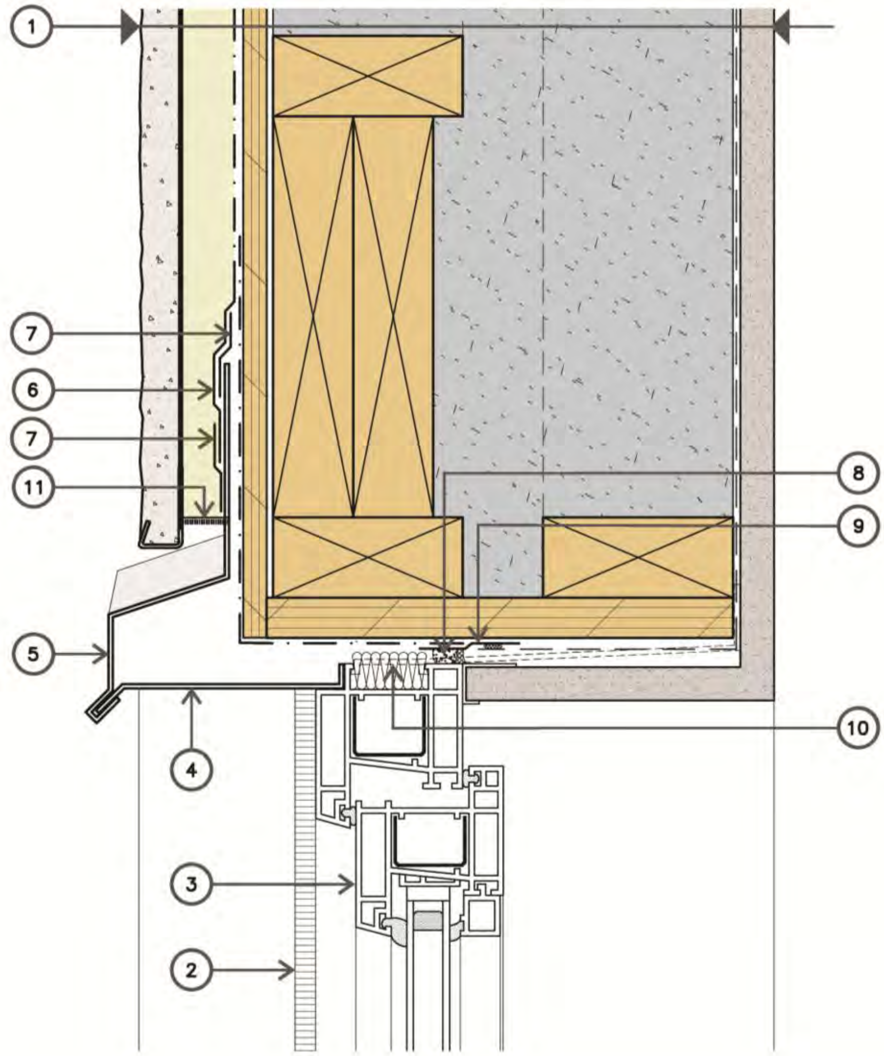
Fig. 5.2.11 Detail 4-SI-2 – Location of Critical Barriers



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (1¾") Wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x89mm (2x4)
   - Batt insulation
   - Polyethylene
   - Gypsum board
2. Sealant beyond
3. Window assembly
4. Metal closure flashing
5. Metal head flashing
6. Vapour permeable sheathing membrane lapped over and taped to flashing
7. Tape
8. Backer rod & sealant
9. Foil tape
10. Window attachment clip
11. Perforated sheet metal

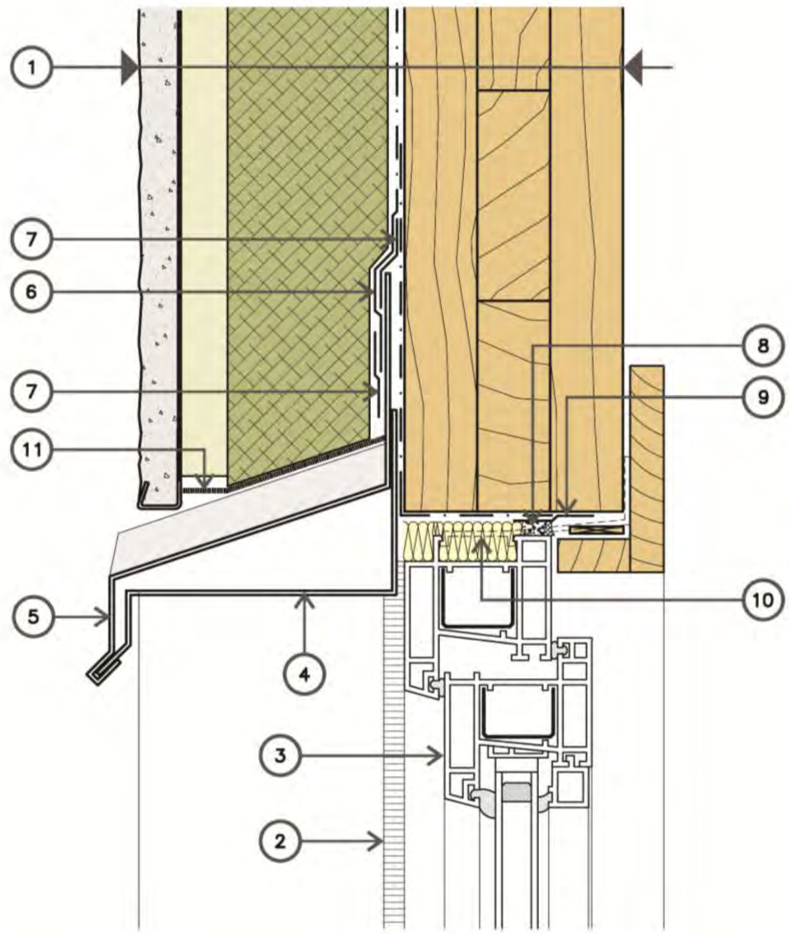
WINDOW HEAD | DETAIL 4-SI



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (1¾") Wood strapping (p.t.)
   - Vapour permeable sheathing membrane
   - Sheathing
   - 2 Rows of wood framing 38x89mm (2x4) with 38mm (1½") gap (adjustable)
   - Cellulose insulation in wall cavity
   - Polyethylene
   - Gypsum board
2. Sealant beyond
3. Window assembly
4. Metal closure flashing
5. Metal head flashing
6. Vapour permeable sheathing membrane Lapped over and taped to flashing
7. Tape
8. Backer rod & sealant
9. Foil Tape
10. Window attachment clip
11. Insect screen

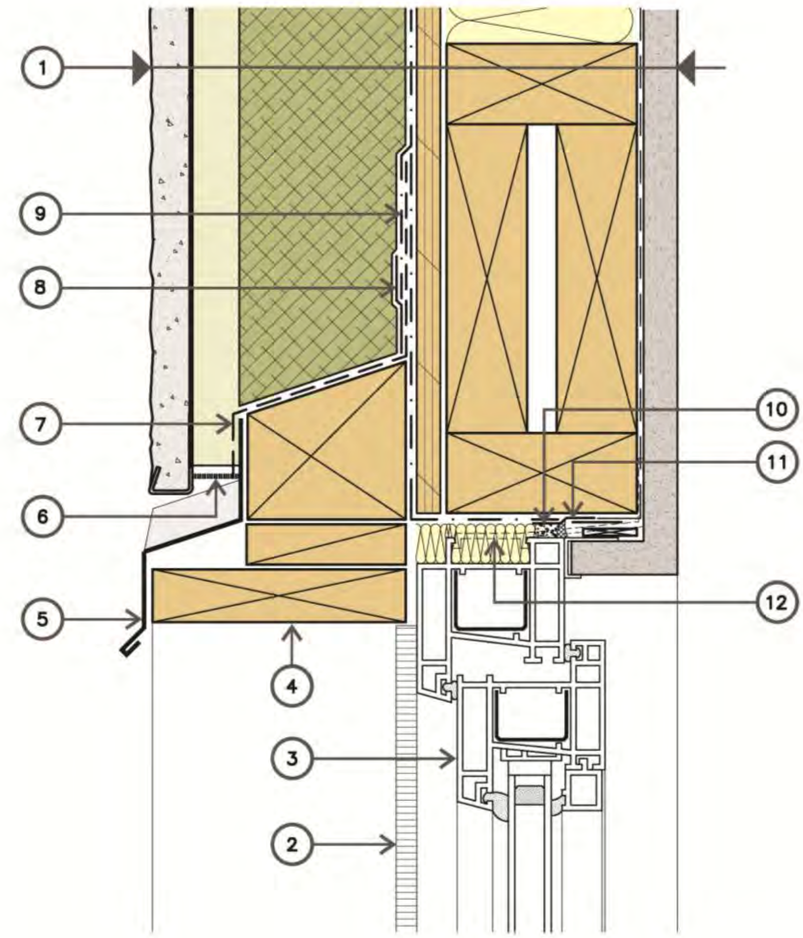
WINDOW HEAD | DETAIL 4-DS



LEGEND

1. Wall Assembly
   Cladding (stucco with backer board)
   19mm (1¾") Wood strapping (p.t.)
   76mm (3") mineral wool insulation
   Vapour permeable sheathing membrane
   CLT Panel
2. Sealant beyond
3. Window assembly
4. Metal closure flashing
5. Metal head flashing
6. Vapour permeable sheathing membrane
   Lapped over and taped to flashing
7. Tape
8. Backer rod & sealant
9. Foil Tape
10. Window attachment clip
11. Perforated sheet metal

WINDOW HEAD | DETAIL 4-MT



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (¾") Wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x89mm (2x4)
   - Batt insulation
   - Polyethylene
   - Gypsum board
2. Sealant beyond
3. Window assembly
4. Wood closure trim
5. Metal head flashing
6. Insect screen
7. Flashing membrane on sloped wood blocking
8. Tape
9. Vapour permeable sheathing membrane lapped over and taped to flashing membrane
10. Backer rod and sealant
11. Foil tape
12. Window attachment clip

WINDOW HEAD | DETAIL 4-SI-2

5.2.5 Detail 5: Window Jamb

A transition detail is needed where the window frame meets the jamb of the window opening in the wall.

At these locations there are a number of specific issues that should be addressed.

Issues

Window Placement

It may be desirable to place the window towards the interior of the assembly to allow the interior surface to be more readily washed by warm air and to lower the condensation potential. Aligning the window with the center of the wall R-value (typically center of the wall) provides the best thermal performance. This location does create the need for jamb returns on the exterior, nor larger flashing at the head and sill.

Air-Barrier Strategies

To maintain continuity of the air barrier, a transition from the window frame to the window jamb is required. This is provided by placing the vapour-permeable sheathing membrane over the window jamb and sealing it to the window frame. The edges of the sheathing membrane may be taped with foil tape to provide a more appropriate surface for the sealant at the window frame.

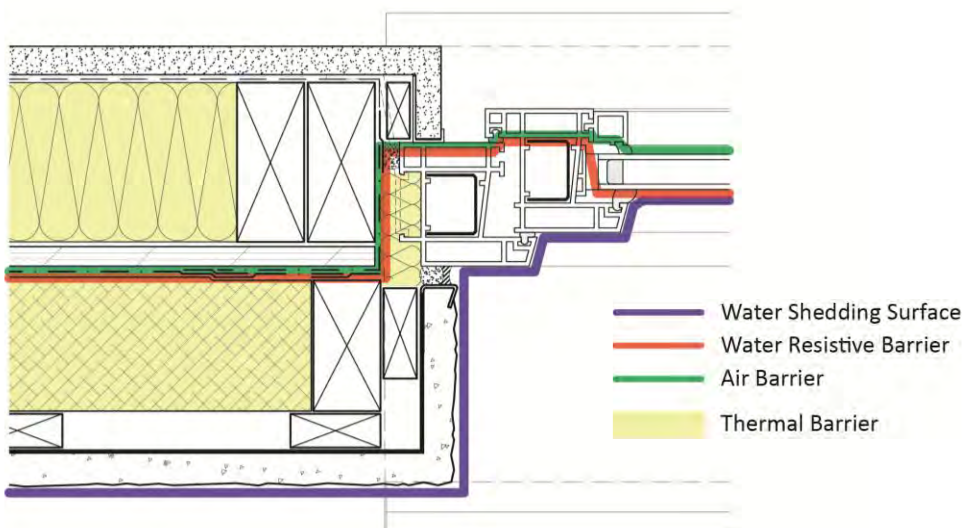


Fig. 5.2.12 Detail 5-SI – Location of Critical Barriers

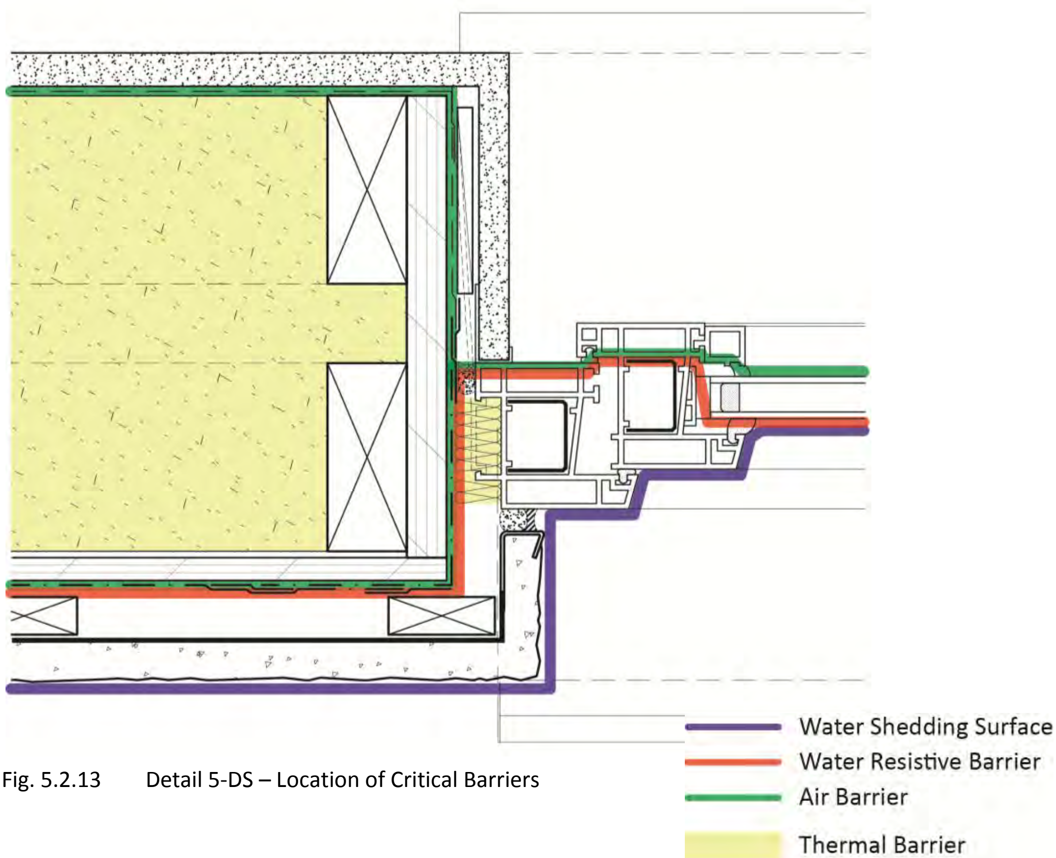


Fig. 5.2.13 Detail 5-DS – Location of Critical Barriers

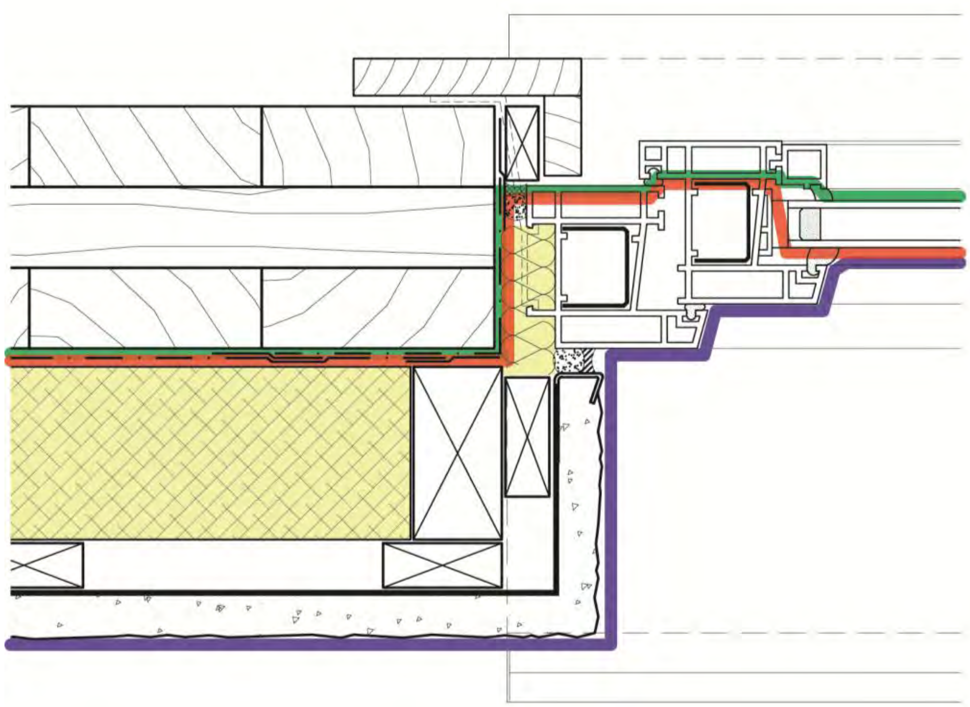
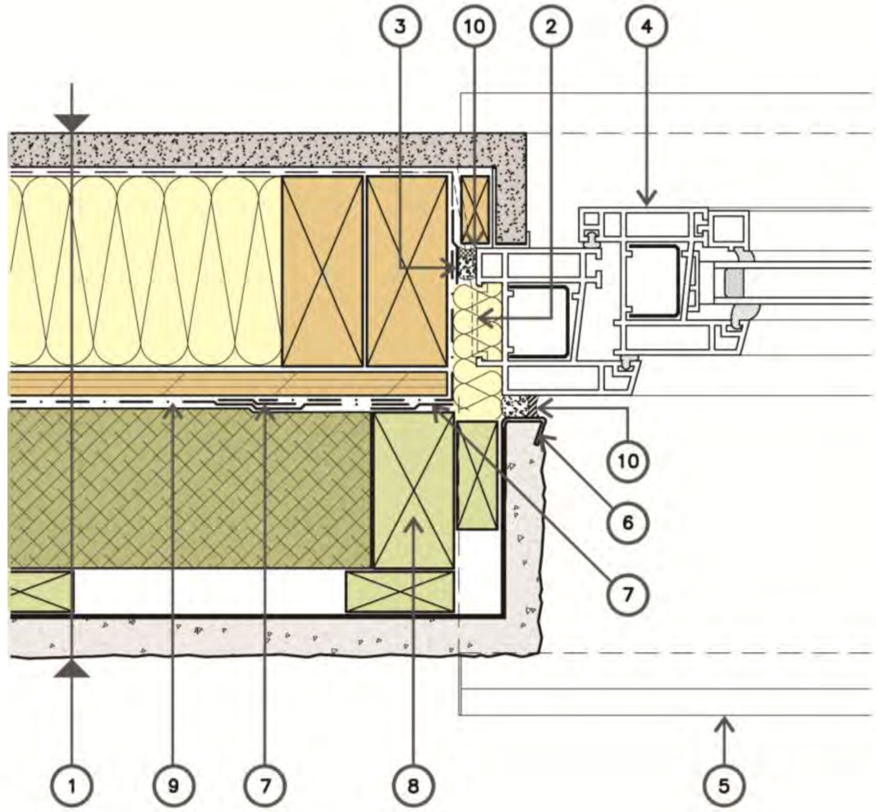


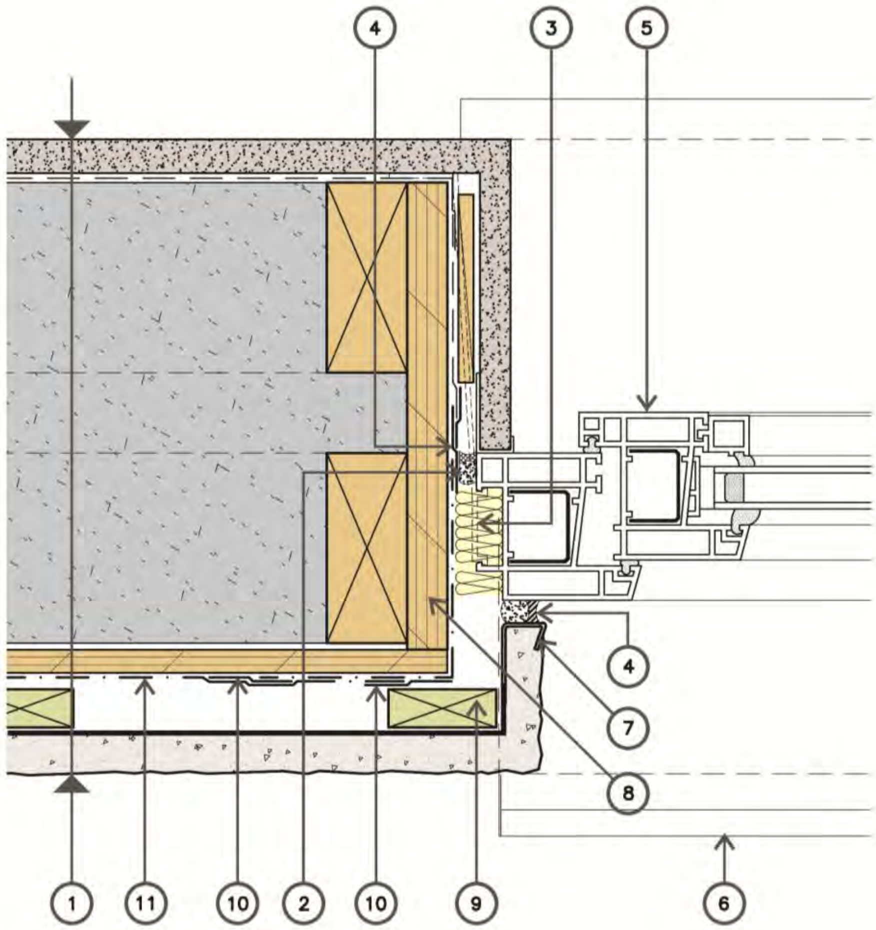
Fig. 5.2.14 Detail 5-MT – Location of Critical Barriers



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (¾") Wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x89mm (2x4) with
   - Batt insulation
   - Polyethylene
   - Gypsum board
2. Window attachment clip
3. Foil Tape
4. Window assembly
5. Sloped metal sill flashing below
6. Stucco stop
7. Tape
8. Wood blocking (p.t.)
9. Vapour permeable sheathing membrane
10. Backer rod & sealant

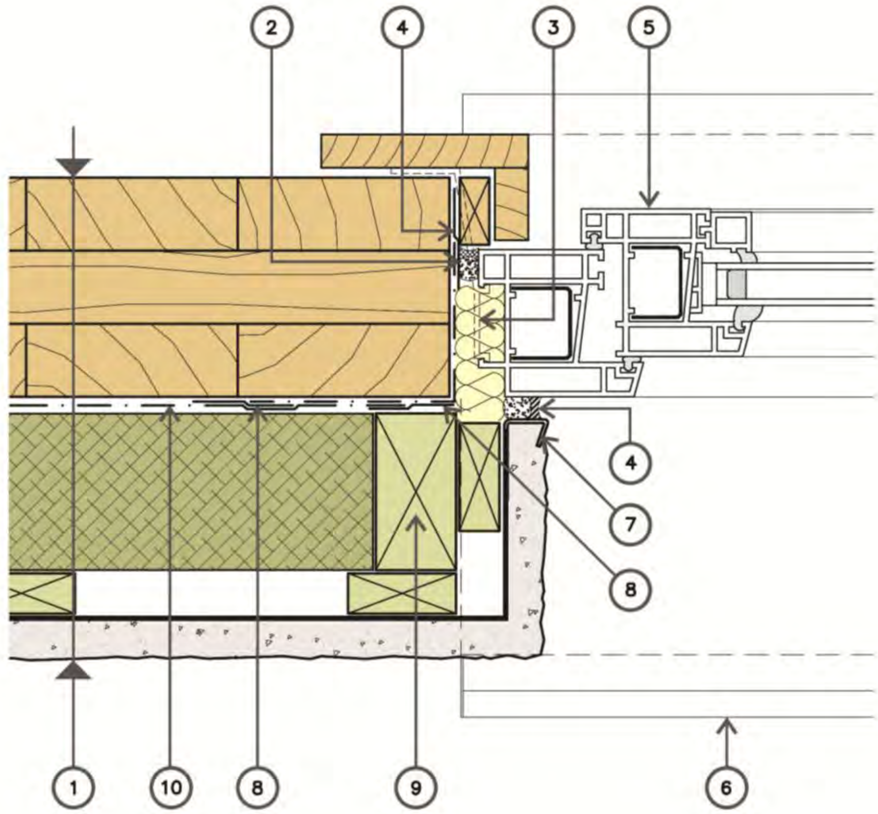
WINDOW JAMB | DETAIL 5-SI



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (¾") Wood strapping (p.t.)
   - Vapour permeable sheathing membrane
   - Sheathing
   - 2 Rows of wood framing 38x89mm (2x4) with 38mm (1½") gap (adjustable)
   - Cellulose insulation in wall cavity
   - Polyethylene
   - Gypsum board
2. Backer rod & sealant
3. Window attachment clip
4. Foil tape
5. Window assembly
6. Sloped metal sill flashing below
7. Stucco stop
8. 19mm (¾") plywood
9. 19x38mm (1x2) vertical strapping
10. Tape
11. Vapour permeable sheathing membrane

WINDOW JAMB | DETAIL 5-DS



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (¾") Wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - CLT Panel
2. Backer rod & sealant
3. Window attachment clip
4. Foil tape
5. Window assembly
6. Sloped metal sill flashing below
7. Stucco stop
8. Tape
9. Wood blocking (p.t.)
10. Vapour permeable sheathing membrane

WINDOW JAMB | DETAIL 5-MT

5.2.6 Detail 6: Window Sill

A transition detail is needed where the window frame meets the sill of the window opening in the wall.

At these locations there are a number of specific issues that should be addressed.

Issues

Drainage

The sill detail has been developed to accommodate minor water leakage that may occur through the window frame, or at the window-to-wall interface. Water that penetrates into this space between the window and the rough opening will drain onto the adhered membrane flashing and will subsequently drain off into the cavity.

For flange-mounted windows, a path must be created between the window-sill flange and the membrane (i.e., by shimming the whole window frame from the wall), or the flange must be drilled/notched to allow drainage. If adequate drainage is not provided at the window sill, water accumulation will increase the potential for leakage at any discontinuities in the membrane flashing.

Detail 6-SI shows the utilization of insulation on the exterior side of the sheathing and sheathing membrane. In this instance it is not desirable to drain sub-sill water into the insulation because it may be held against the vapour-permeable membrane and migrate inward. The detail indicates an additional flashing that drains the water to the outside of insulation. An alternative detail could drain water from the sub-sill area directly to the exterior with a metal sub-sill flashing. Care must be taken in utilizing this approach; to minimize thermal bridging, and to not introduce a moisture ingress point at the sub-sill.

Sill Drip Flashing

Sill drip flashings are necessary in order to direct water that runs down the face of the window away from the wall surface below. Sill flashings also reduce the problem of staining of the wall directly below the weep holes in the window. Some window assemblies use weep holes that drain from the bottom of the window frame. The sill details must accommodate the various locations of the weep holes.

Air-Barrier Strategies

To maintain continuity of the air barrier, a transition from the window frame to the window sill is required. This is provided by placing the self-adhered membrane over the window sill and sealing it to the window frame and the vapour-permeable sheathing membrane below.

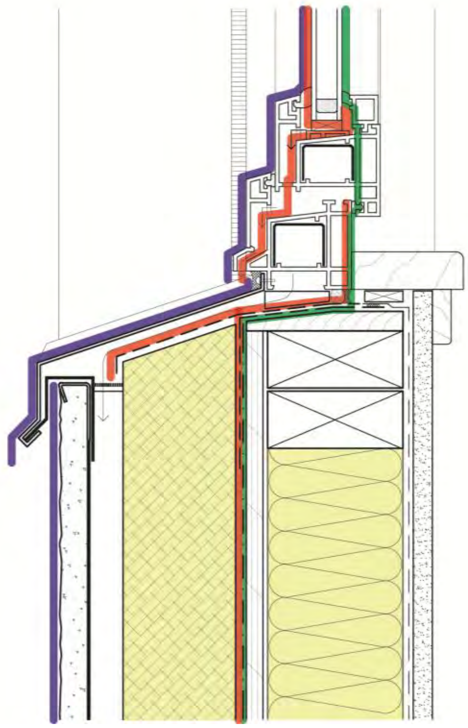


Fig. 5.2.15 Detail 6-SI – Location of Critical Barriers

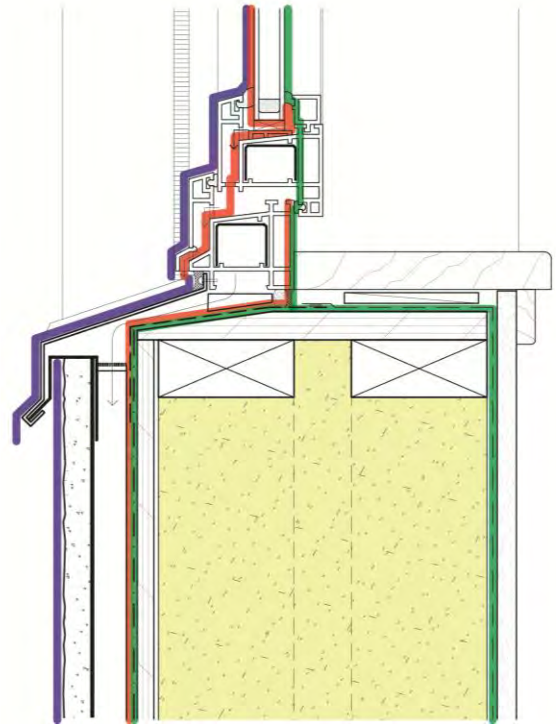


Fig. 5.2.16 Detail 6-DS – Location of Critical Barriers

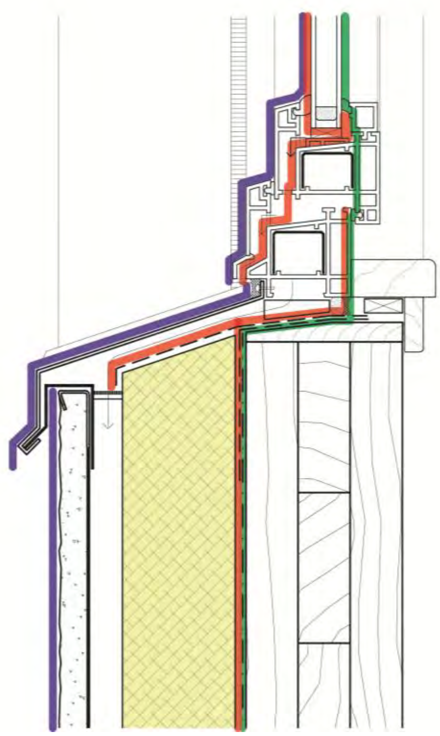
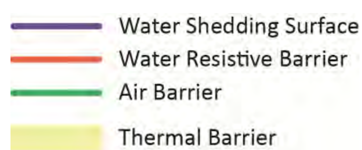
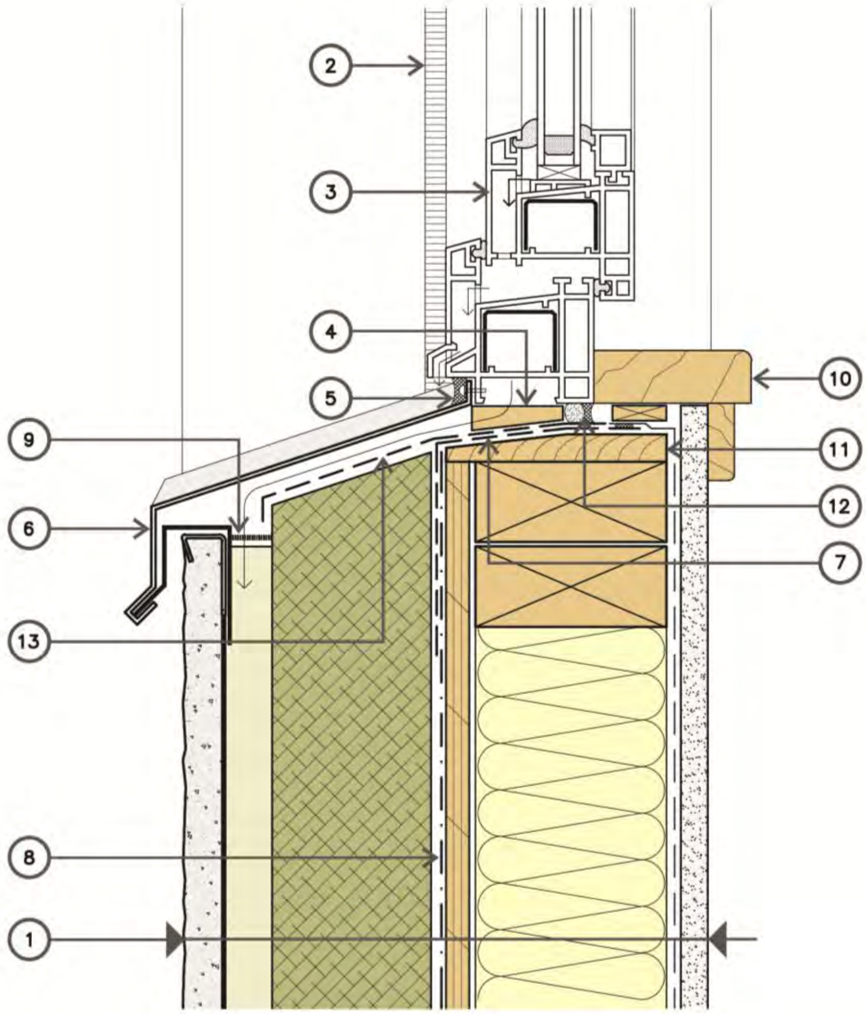


Fig. 5.2.17 Detail 6-MT – Location of Critical Barriers

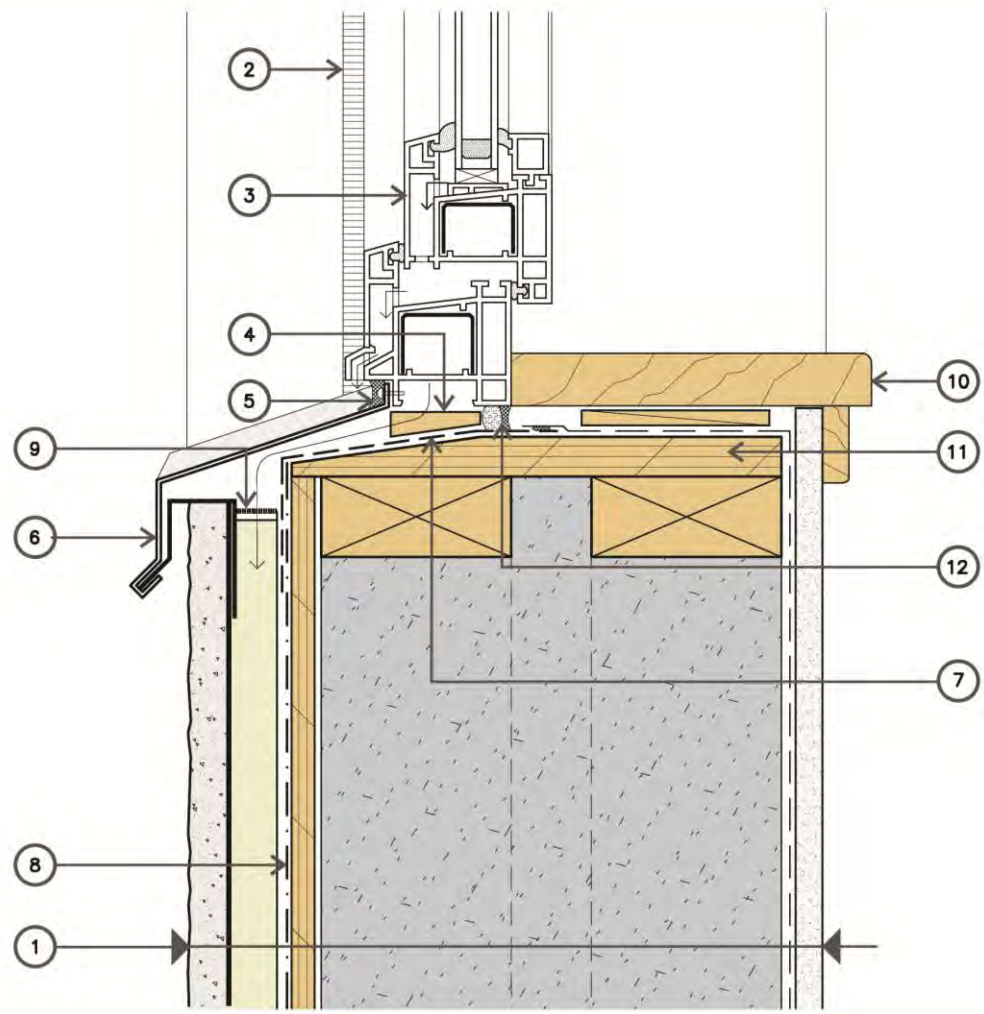




LEGEND

1. Wall Assembly
   Cladding (stucco with backer board)
   19mm (¾") Wood strapping (p.t.)
   76mm 3") mineral wool insulation
   Vapour permeable sheathing membrane
   Sheathing
   Wood framing 38x89mm (2x4) with batt insulation
   Polyethylene
   Gypsum board
2. Sealant beyond
3. Window assembly
4. Intermittent shims
5. Sealant
6. Pre-finished metal flashing with end dams
7. Sub-sill foil-faced membrane flashing
8. Vapour permeable sheathing membrane
9. Insect screen
10. Interior window trim
11. Sloped blocking
12. Backer rod & sealant
13. Foil-faced membrane skirt flashing

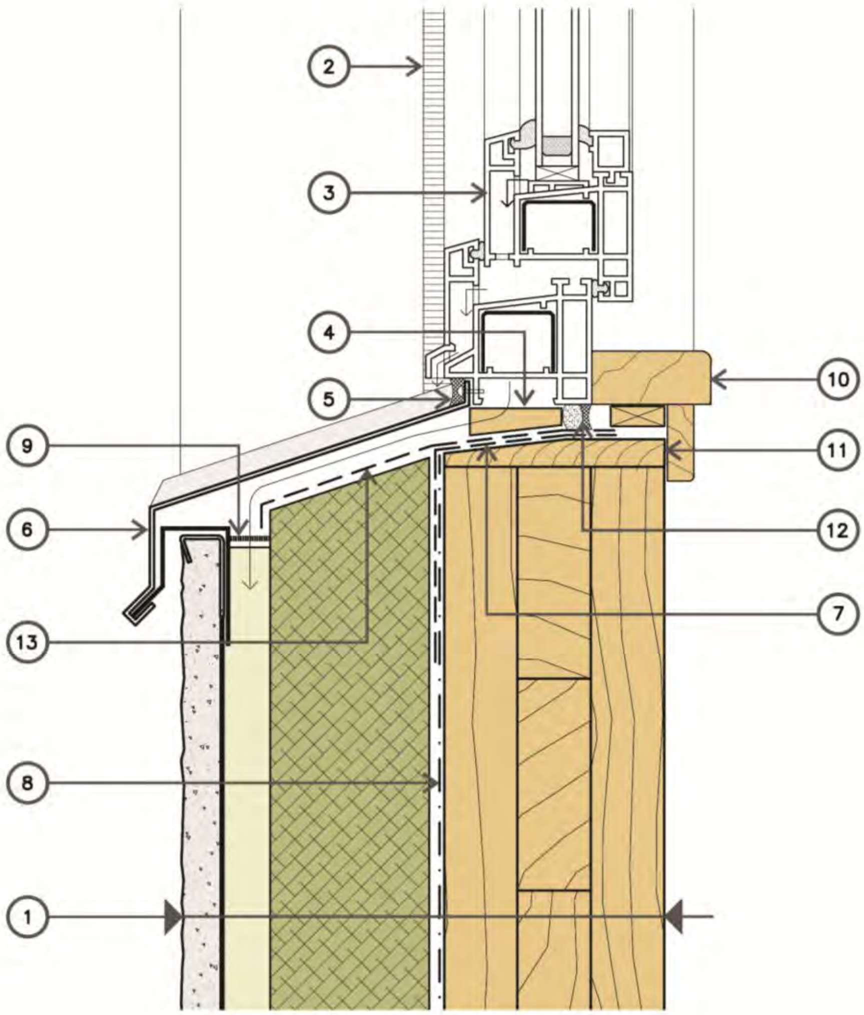
WINDOW SILL | DETAIL 6-SI



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (¾") Wood strapping (p.t.)
   - Vapour permeable sheathing membrane
   - Sheathing
   - 2 rows wood framing 38x89mm (2x4) with 38mm (1½") gap (adjustable)
   - Cellulose insulation in wall cavity
   - Polyethylene
   - Gypsum board
2. Sealant beyond
3. Window assembly
4. Intermittent shims
5. Sealant
6. Pre-finished metal flashing with end dams
7. Sub-sill foil-faced membrane flashing
8. Vapour permeable sheathing membrane
9. Insect screen
10. Interior window trim
11. 19mm (¾") sloped plywood sill
12. Backer rod & sealant

WINDOW SILL | DETAIL 6-DS



LEGEND

1. Wall Assembly
   Cladding (stucco with backer board)
   19mm (¾") Wood strapping (p.t.)
   76mm 3") mineral wool insulation
   Vapour permeable sheathing membrane
   CLT Panel
2. Sealant beyond
3. Window assembly
4. Intermittent shims
5. Sealant
6. Pre-finished metal flashing with end dams
7. Sub-sill foil-face membrane flashing
8. Vapour permeable sheathing membrane
9. Insect screen
10. Interior window trim
11. Sloped blocking
12. Backer rod & sealant
13. Foil-face membrane skirt flashing

WINDOW SILL | DETAIL 6-MT

5.2.7 Detail 7: Door Sill / Balcony

A transition detail is needed where the door frame meets the sill of the door opening in the wall.

At these locations there are a number of specific issues that should be addressed.

Issues

Sill Height

Whenever possible, door sills should be elevated above the drainage surface. The higher the door sill is elevated above the drainage surface, the less the potential for water ingress from snow melt, water backup, and splashing from the drainage surface.

Metal Flashing

The pre-finished metal flashing should be kept a minimum of 12 mm (½ inch) above the membrane surface to reduce the potential for corrosion of the flashing.

Membrane Flashing

The membrane flashing under the door threshold should lap over the balcony membrane and be of the same membrane type. PVC is not generally compatible with bituminous based products. Alternatively, as shown, the balcony membrane can extend up onto the door sill as one piece.

Air-Barrier Strategies

To maintain continuity of the air barrier, a transition from the door frame to the door opening is required. This is provided by the placement of a membrane flashing lapped onto the door sill and sealed to the door frame, or by extending the balcony membrane onto the door sill and sealing the door frame to the membrane (as shown). At balconies, spray foam is used in between the joists to provide continuity between the balcony membrane and the sheathing membrane below, in some cases via wood framing members.

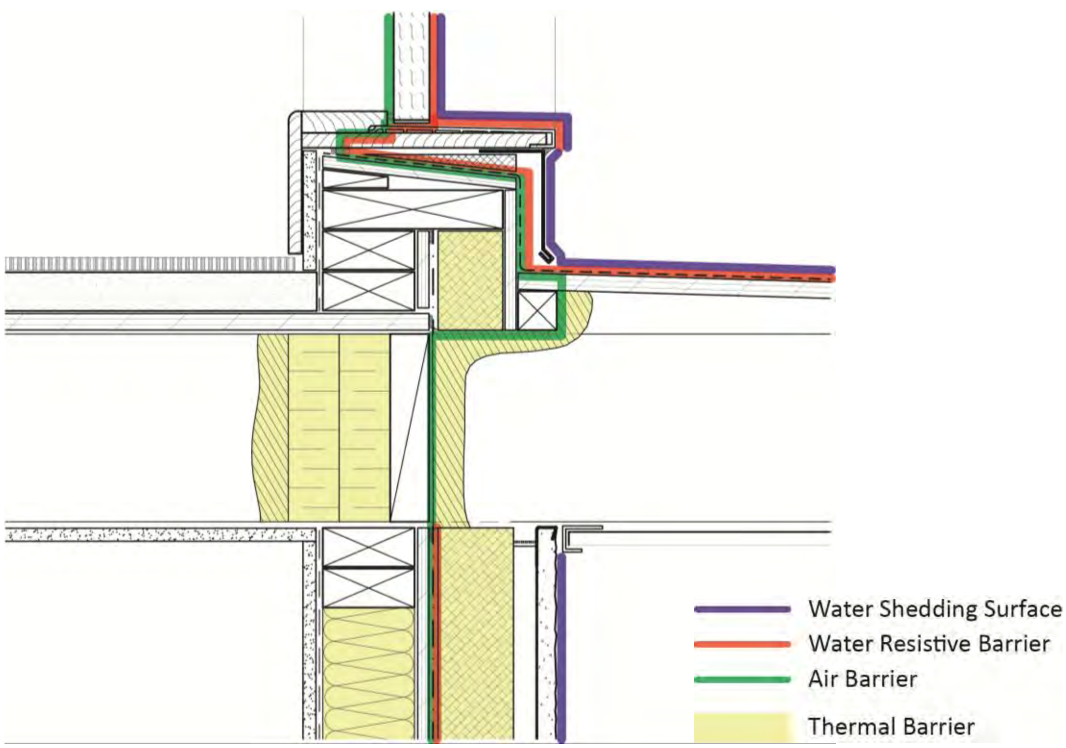
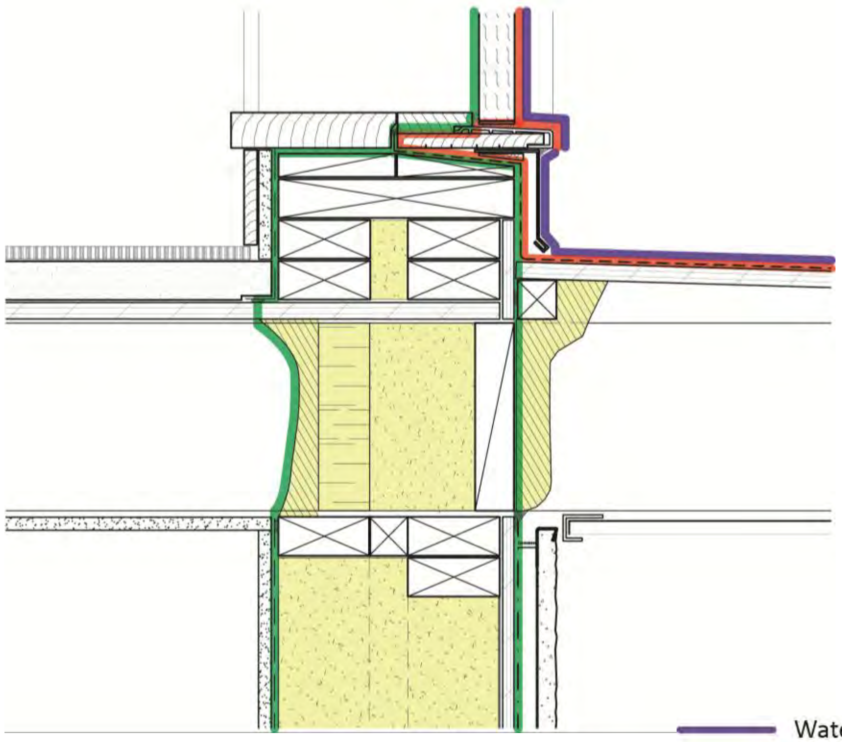


Fig. 5.2.18 Detail 7-SI – Location of Critical Barriers



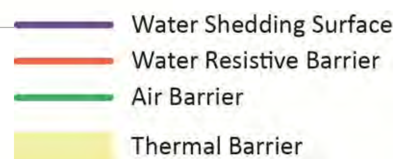


Fig. 5.2.19 Detail 7-DS – Location of Critical Barriers

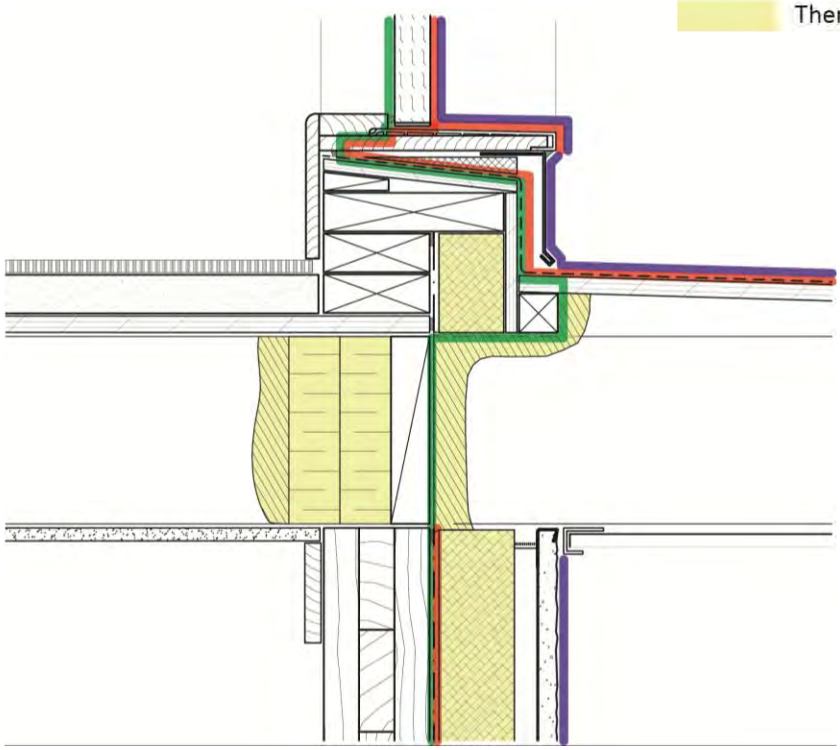
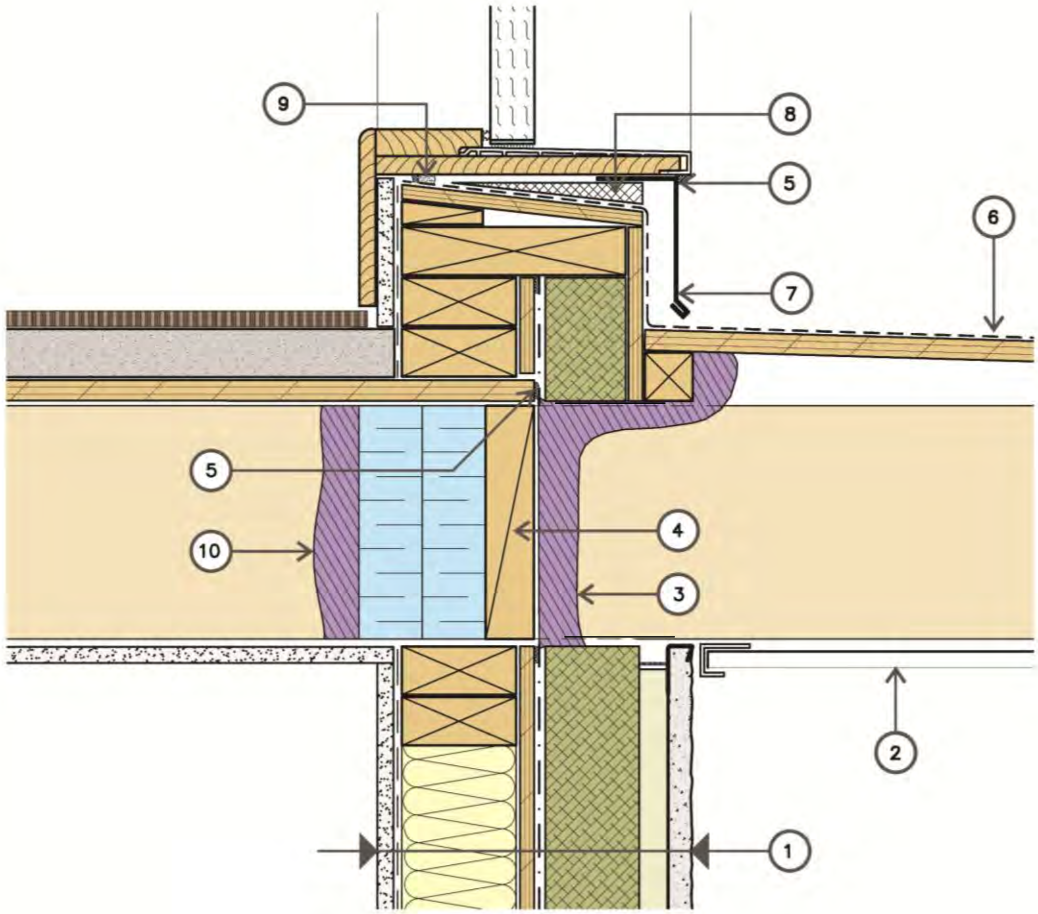


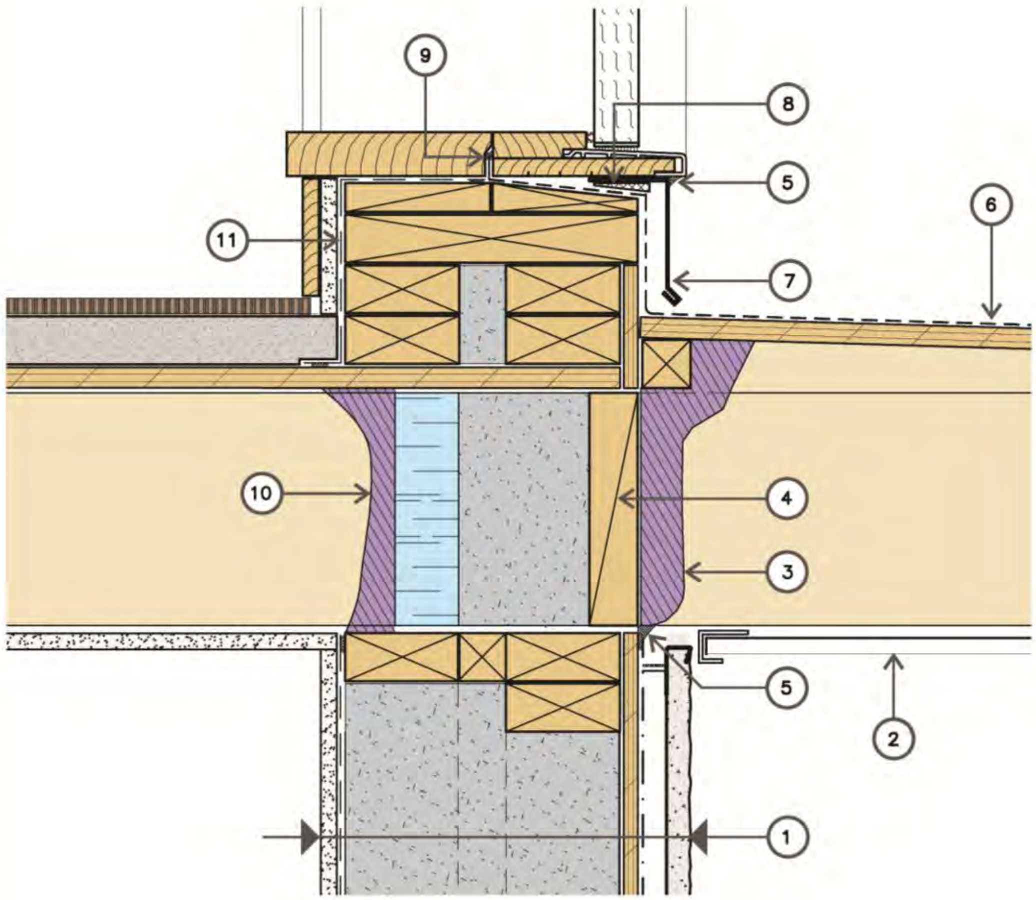
Fig. 5.2.20 Detail 7-MT – Location of Critical Barriers



LEGEND

1. Wall Assembly
   Cladding (stucco with backer board)
   19mm (¾") wood strapping (p.t.)
   76mm (3") mineral wool insulation
   Vapour permeable sheathing membrane
   Sheathing
   Wood framing 38x89mm (2x4) with
   Batt insulation
   Polyethylene
   Gypsum board
2. Vented aluminum soffit
3. Spray-in-place foam air seal over blocking between joists
4. Blocking between joists
5. Sealant
6. Balcony membrane
7. Pre-finished metal flashing
8. Intermittent shims
9. Backer rod and sealant
10. Extruded polystyrene insulation with spray-in-place foam at edges

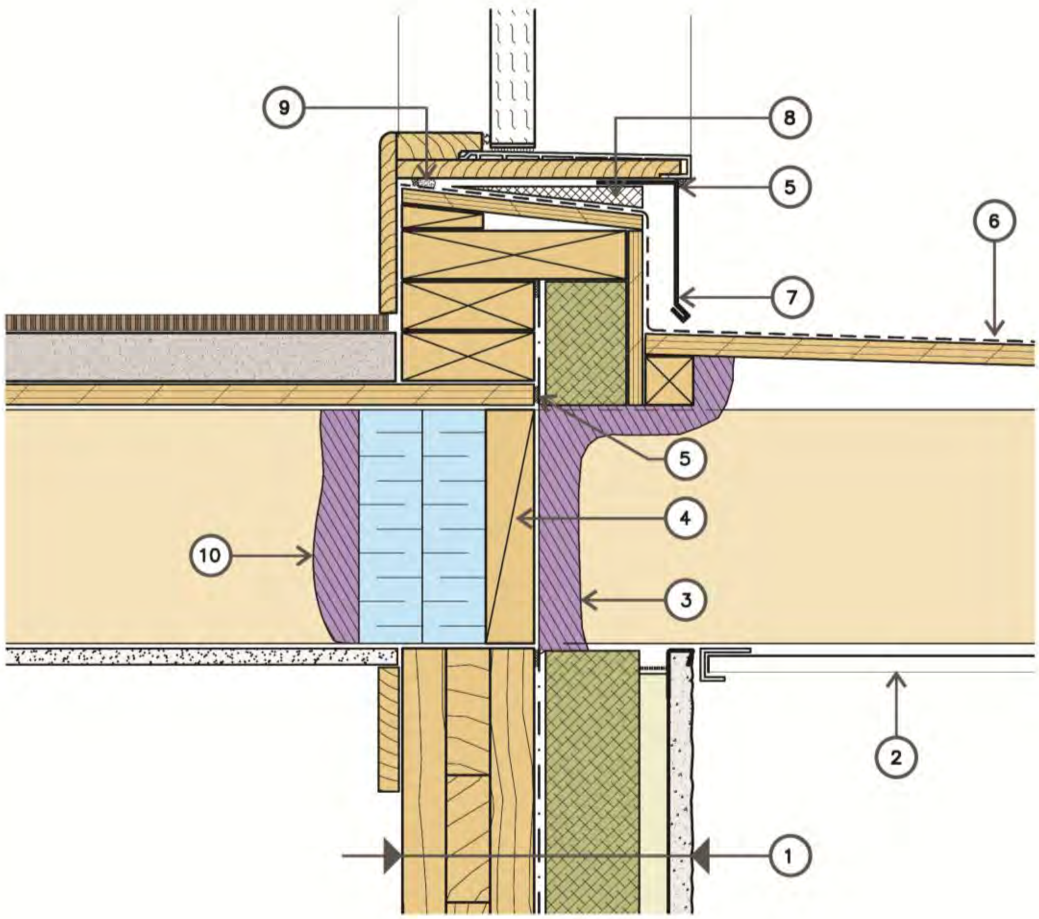
DOOR SILL | DETAIL 7-SI



LEGEND

1. Wall Assembly
   Cladding (stucco with backer board)
   19mm (¾") wood strapping (p.t.)
   Vapour permeable sheathing membrane
   Sheathing
   2 rows of wood framing 38x89mm (2x4) with 38mm (1½") gap (adjustable)
   Cellulose insulation in wall cavity
   Polyethylene
   Gypsum board
2. Vented aluminum soffit panel
3. Spray-in-place foam air seal over blocking between joists
4. Blocking between joists
5. Sealant
6. Balcony membrane
7. Pre-finished metal flashing
8. Intermittent shims
9. Backer rod and sealant
10. Cellulose insulation and extruded polystyrene with spray-in-place foam at edges
11. Polyethylene sealed to framing

DOOR SILL | DETAIL 7-DS



LEGEND

1. Wall Assembly
   Cladding (stucco with backer board)
   19mm (¾") wood strapping (p.t.)
   76mm (3") mineral wool insulation
   Vapour permeable sheathing membrane
   CLT Panel
2. Vented aluminum soffit panel
3. Spray-in-place foam air seal over blocking between joists
4. Blocking between joists
5. Sealant
6. Balcony membrane
7. Pre-finished metal flashing
8. Intermittent shims
9. Backer rod and sealant
10. Extruded polystyrene insulation with spray-in-place foam at edges

DOOR SILL | DETAIL 7-MT

5.2.8 Detail 8: Sloped Roof / Wall Interface

A transition detail is needed where the above-grade wall meets the sloped roof assembly.

At these locations there are a number of specific issues that should be addressed.

Issues

Attic Venting

Placement of the insulation baffles should be based on the venting requirements for the attic space. This is typically 1/300 of the area of the insulated ceiling (based on NRC and IECC). Similar requirements are usually appropriate for larger buildings.

Roof Deck Venting

Where the roof deck is above the insulation, such as in cathedral ceilings (not shown) and exterior insulated sloped roofs (shown), the venting requirements are recommended to be 1/150 of the insulated ceiling.

Roof Wall Interfaces

Sloped-roof-to-wall interfaces are critical where the roof slope runs adjacent to a wall (not shown here). Special attention must be paid to the continuity of critical barriers, especially the water-shedding surface. For example, at the edge of the sloped roof, where a gutter meets a wall, the use of a kickout flashing is needed in order to direct water away from the roof/wall interface and into the gutter, and to stop it from running behind the cladding.

Air-Barrier Strategies - Interior

Where there is an interior air barrier at the ceiling plane, care must be taken to ensure that the air barrier, either the polyethylene (shown here), or, alternatively, the gypsum board, is continuous at all penetrations through the ceiling. Special care is required to seal around penetrations such as pot lights that generate significant heat and leak air. A gypsum board enclosure should be built around all pot-light penetrations and around the polyethylene and insulation carried over the enclosure. Alternatively, low-wattage, airtight pot lights can be used, in which case the polyethylene is sealed to the pot light housing. At the ceiling/wall interfaces, the polyethylene is sealed to the top plate of wall framing on the inside, the sheathing is sealed to the top plate of the wall framing on the outside, and the sheathing membrane is sealed to the outside of the sheathing. More robust continuity can be achieved with the use of spray foam at this interface.

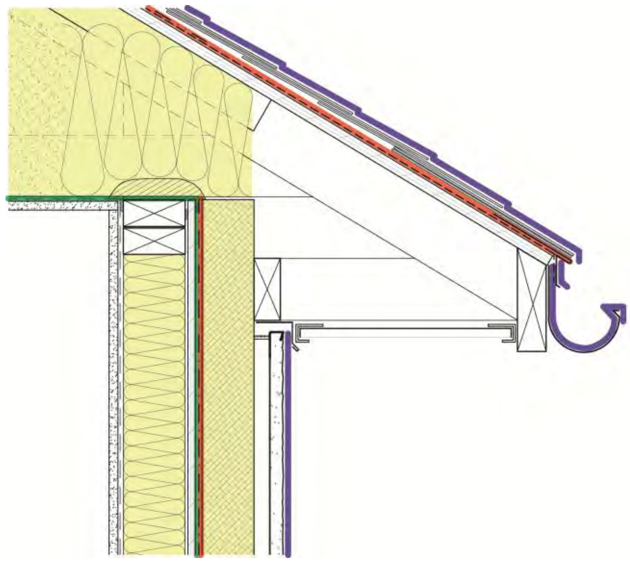


Fig. 5.2.21 Detail 8-SI – Location of Critical Barriers

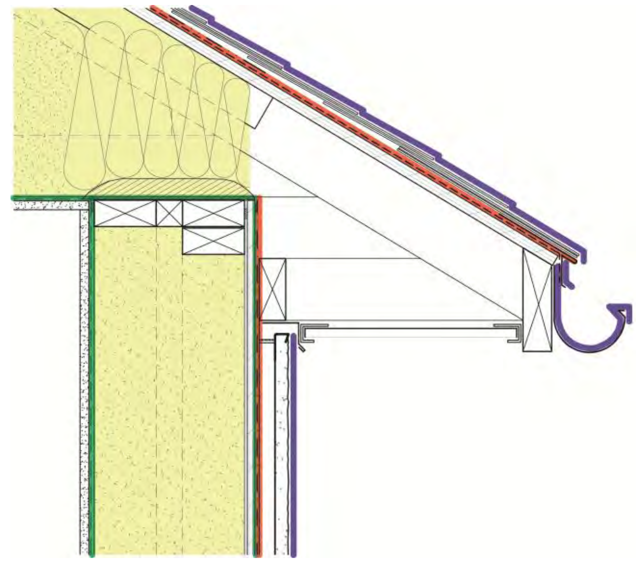


Fig. 5.2.22 Detail 8-DS – Location of Critical Barriers

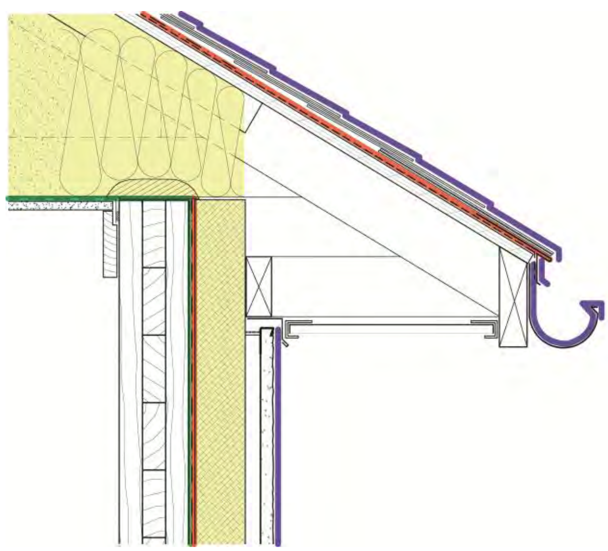


Fig. 5.2.23 Detail 8-MT – Location of Critical Barriers

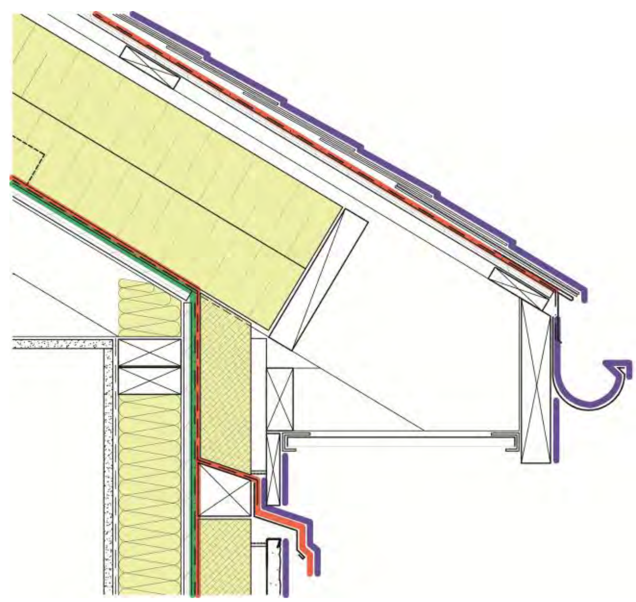
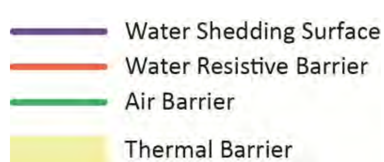
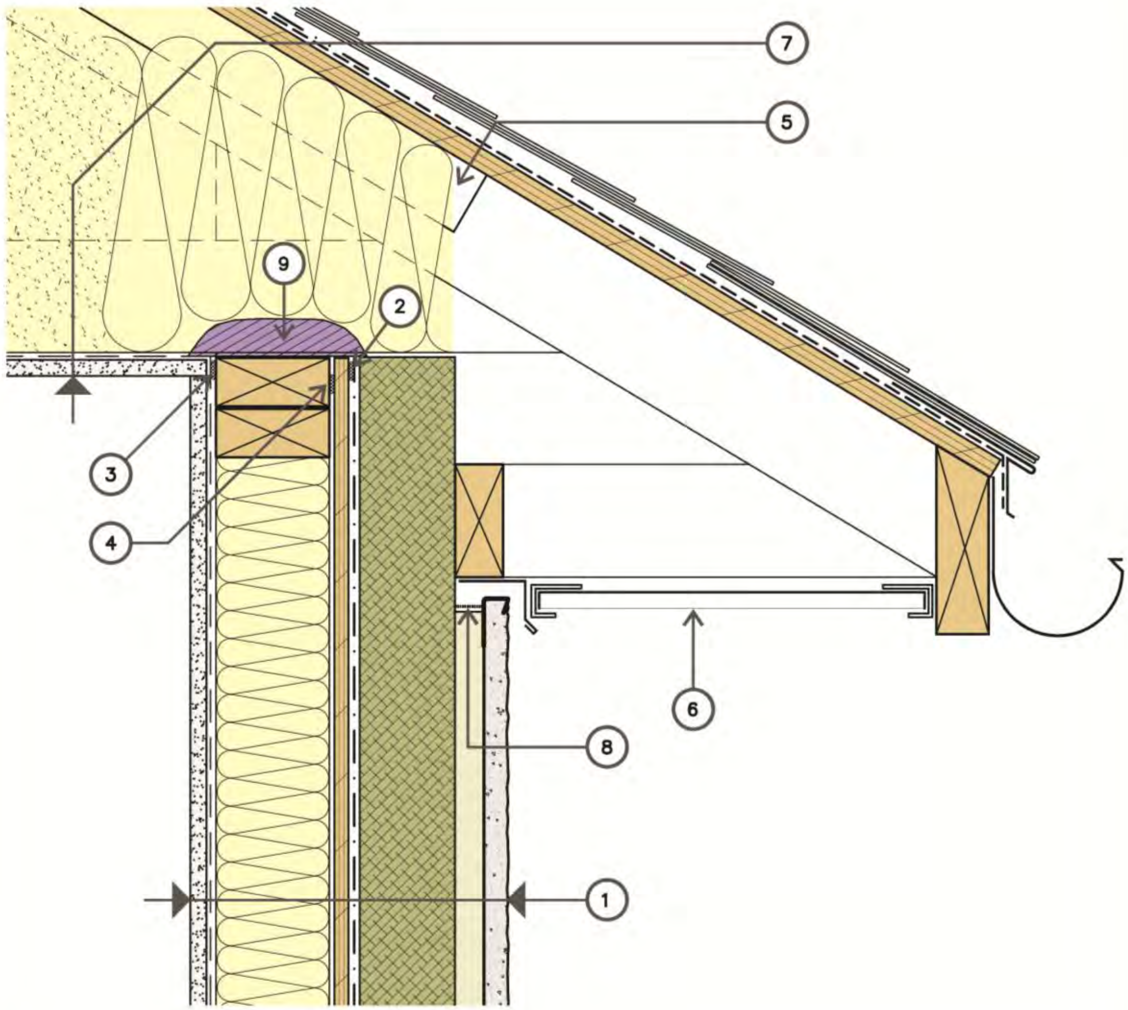


Fig. 5.2.24 Detail 8-EI– Location of Critical Barriers

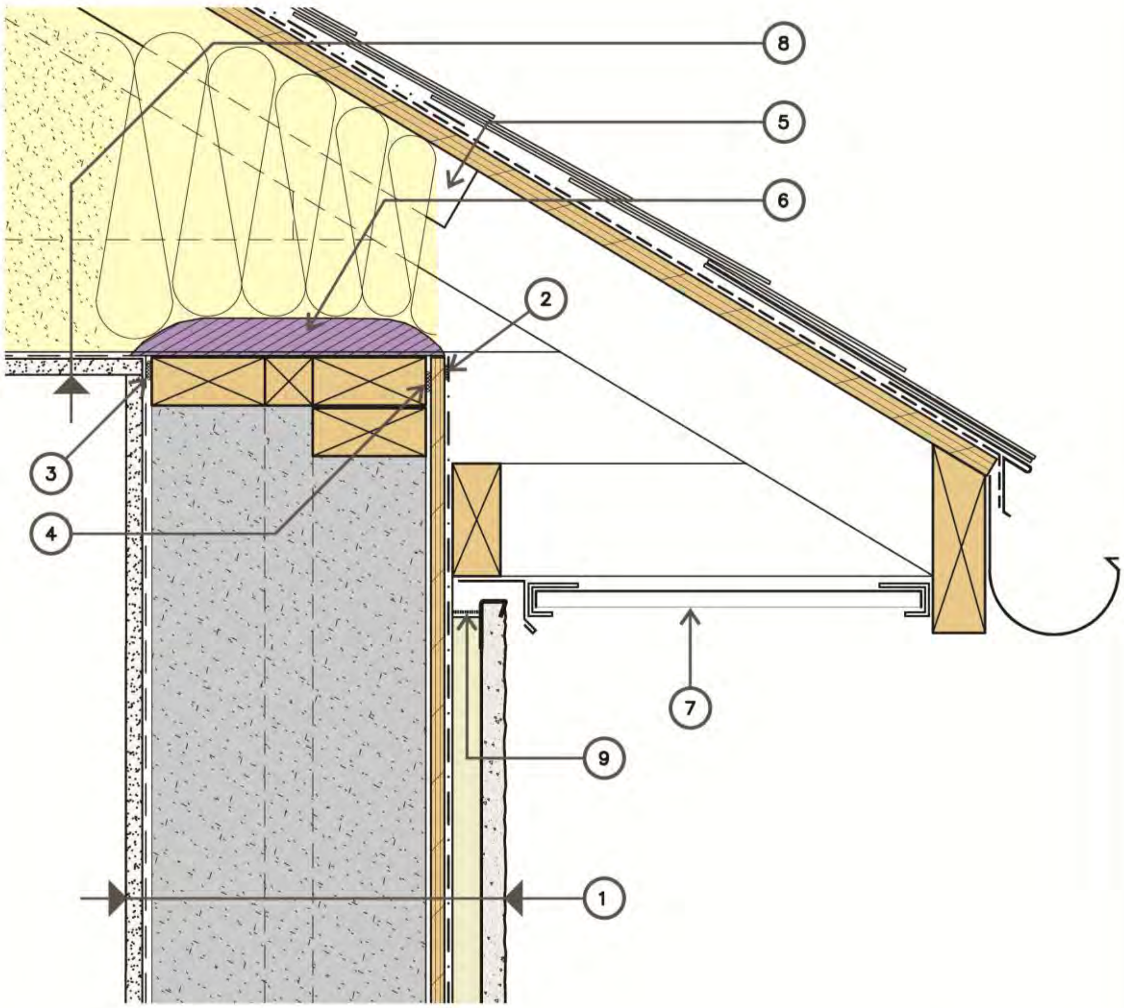




LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (¾") wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x89mm (2x4) with Batt insulation
   - Polyethylene
   - Gypsum board
2. Sealant
3. Acoustic sealant
4. Construction adhesive
5. Baffle
6. Vented aluminium soffit panels
7. Roof Assembly
   - Roofing shingles
   - Waterproof roof membrane
   - Roof sheathing
   - Wood roof framing
   - Loose fill insulation (batts at edges)
   - Polyethylene
   - Gypsum board
8. Insect screen
9. Spray-in-place foam insulation over framing for air barrier continuity

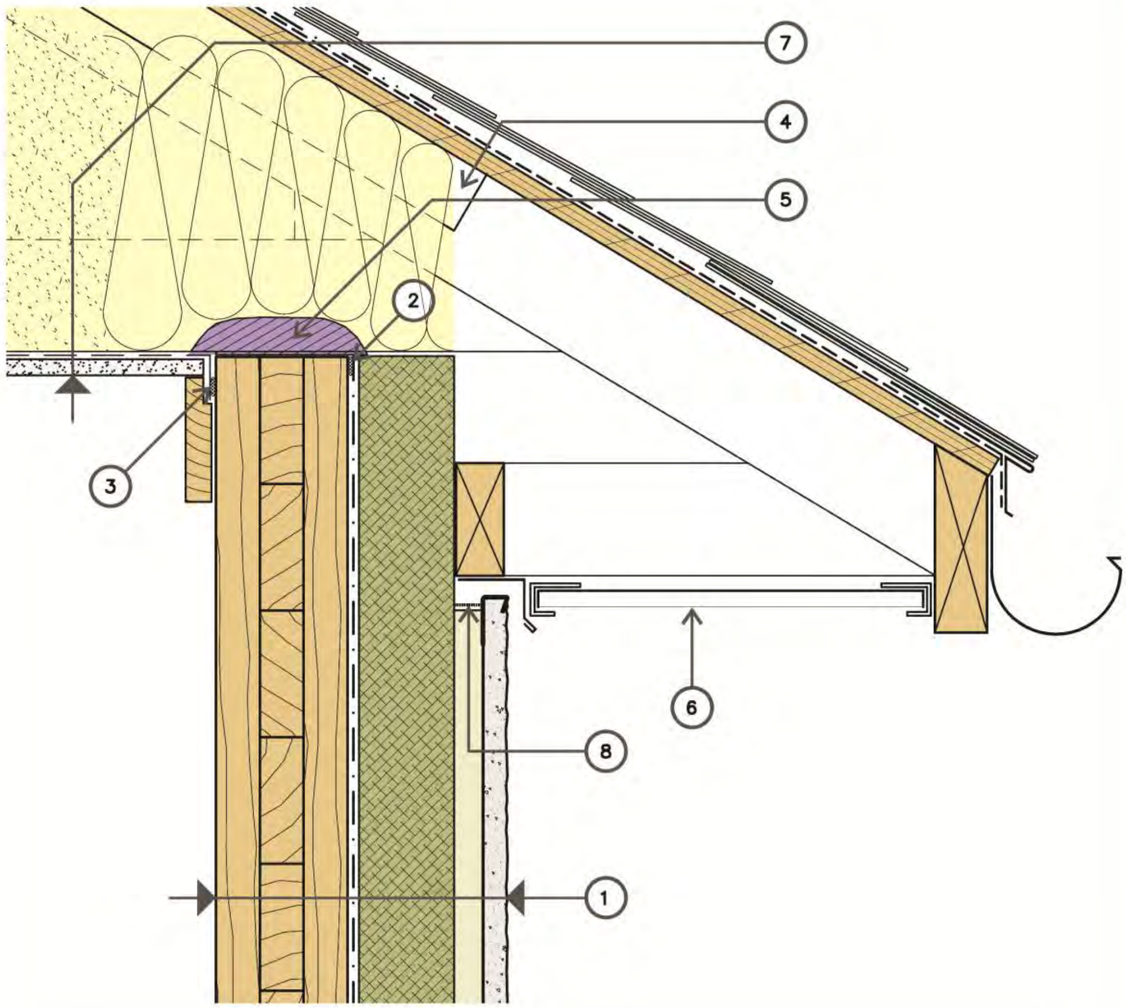
SLOPED ROOF/WALL INTERFACE | DETAIL 8-SI



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm ($\frac{3}{4}$") wood strapping (p.t.)
   - Vapour permeable sheathing membrane
   - Sheathing
   - 2 Rows of wood framing 38x89mm (2x4) with 38mm ($1\frac{1}{2}$") gap (adjustable)
   - Cellulose insulation in wall cavity
   - Polyethylene
   - Gypsum board
2. Sealant
3. Acoustic sealant
4. Construction adhesive
5. Baffle
6. Spray-in-place foam insulation over framing for air barrier continuity
7. Vented aluminum soffit panels
8. Roof Assembly
   - Roofing shingles
   - Waterproof roof membrane
   - Roof sheathing
   - Wood roof framing at attic space
   - Loose fill insulation (batts at roof edges)
   - Polyethylene
   - Gypsum board
9. Insect screen

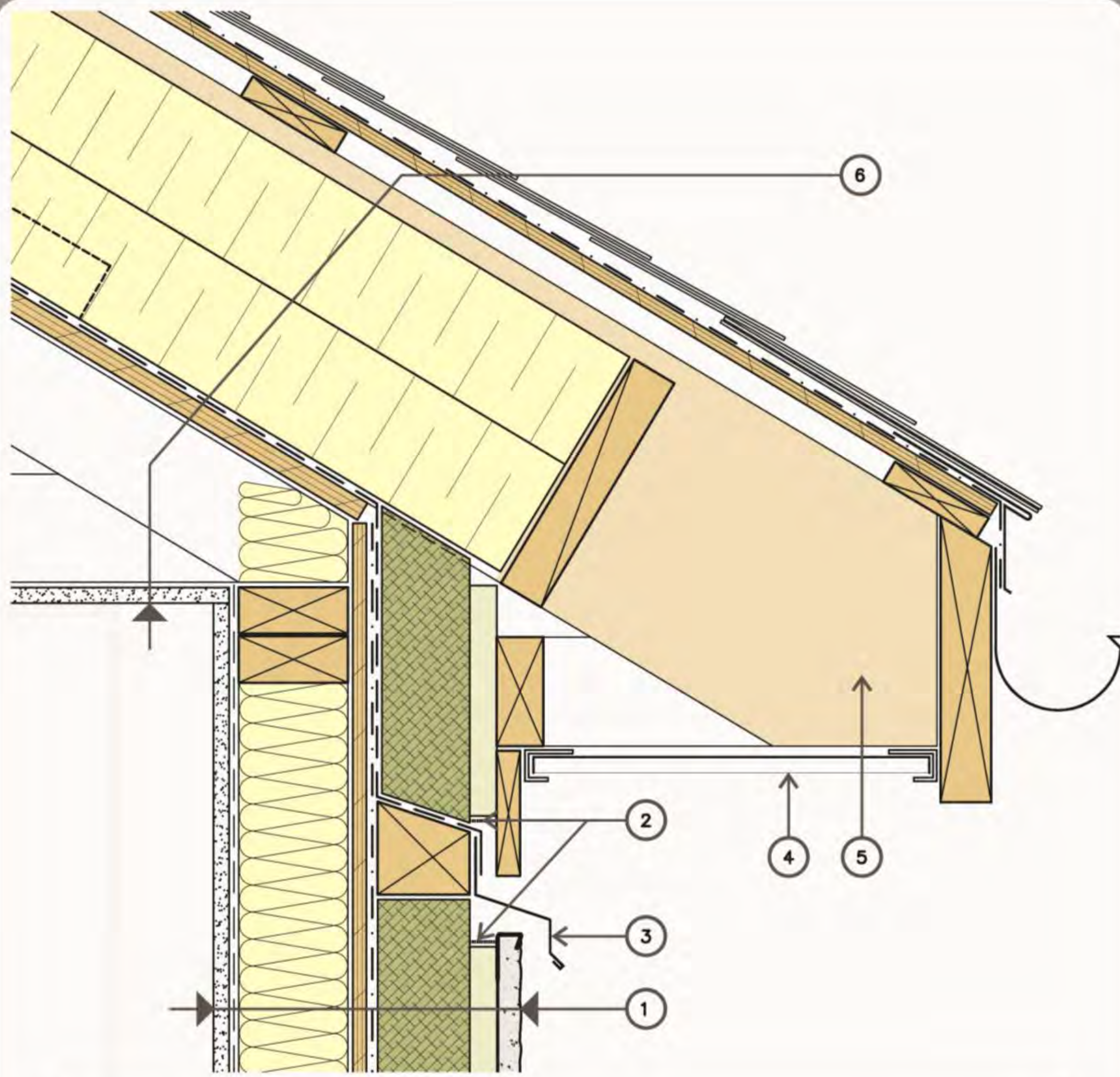
SLOPED ROOF/WALL INTERFACE | DETAIL 8-DS



LEGEND

1. Wall Assembly
   Cladding (stucco with backer board)
   19mm (¾") wood strapping (p.t.)
   76mm (3") mineral wool insulation
   Vapour permeable sheathing membrane
   CLT Panel
2. Sealant
3. Acoustic sealant
4. Baffle
5. Spray-in-place foam insulation over top of panel for air barrier continuity
6. Vented aluminum soffit panels
7. Roof Assembly
   Roofing shingles
   Waterproof roof membrane
   Roof sheathing
   Wood roof framing at attic space
   Loose fill insulation (batts at roof edges)
   Polyethylene
   Gypsum board
8. Insect screen

SLOPED ROOF/WALL INTERFACE | DETAIL 8-MT



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (¾") wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x89mm (2x4) with Batt insulation
   - Polyethylene
   - Gypsum board
2. Insect screen
3. Pre-finished metal flashing on wood blocking
4. Vented aluminium soffit
5. Overhang joist (extends 4' up roof)
6. Roof Assembly
   - Roofing shingles
   - Roof membrane
   - Roof sheathing
   - 19mm (¾") wood cross strapping
   - Overhang joist 38x235mm (2x12)
   - 19mm (¾") wood strapping
   - 2 layers 102mm (4") offset polyiso insulation
   - Self adhered membrane
   - Sheathing
   - Wood roof framing
   - Gypsum board

SLOPED ROOF/WALL INTERFACE | DETAIL 8-EI

5.2.9 Detail 9: Low Sloped Roof / Wall Interface

A transition detail is needed where the above-grade wall meets the low sloped roof assembly.

At these locations there are a number of specific issues that should be addressed.

Issues

Insulation Combination

Mineral wool is used on the top portion of the roof insulation is order to keep the temperature-sensitive polyisocyanurate cool. This serves to maintain dimensional stability for the roofing membrane, and helps to maintain the high in-service R-value of the polyisocyanurate insulation.

Membrane Flashing

The roofing membrane should be connected from the parapet wall to the sheathing membrane on the wall. This can be provided by a self-adhered membrane lapped over the sheathing membrane and onto the parapet wall.

Air-Barrier Strategies

To maintain continuity of the air barrier, a transition from the roof assembly to the wall assembly can be provided through the parapet. The self-adhered membrane is lapped up the parapet wall, and spray-in-place foam provides continuity through the wall to the exterior sheathing membrane via some framing members. In a double-stud wall assembly, spray foam on the interior of the framing provides continuity between the self-adhered membrane and the polyethylene via some framing members.

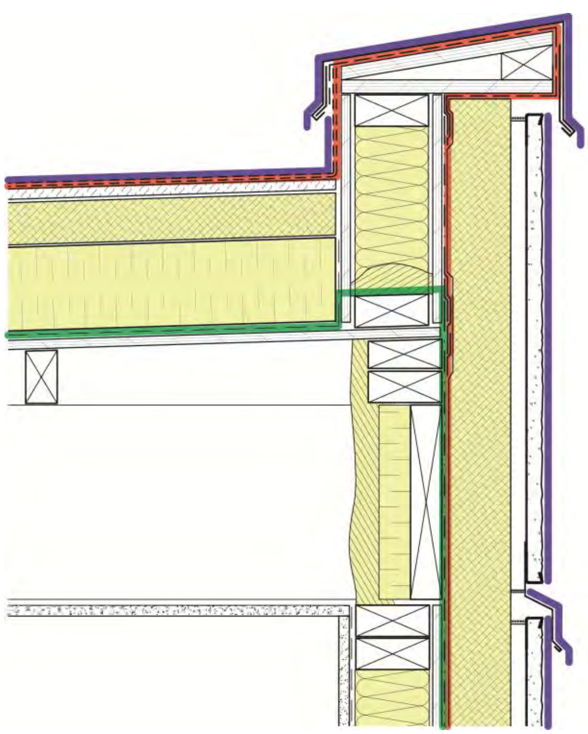


Fig. 5.2.25 Detail 9-SI – Location of Critical Barriers

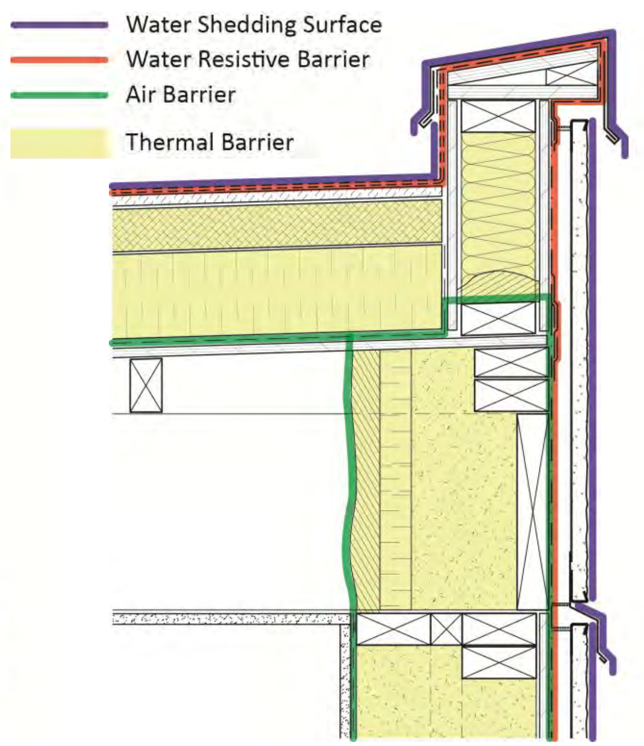


Fig. 5.2.26 Detail 9-DS – Location of Critical Barriers

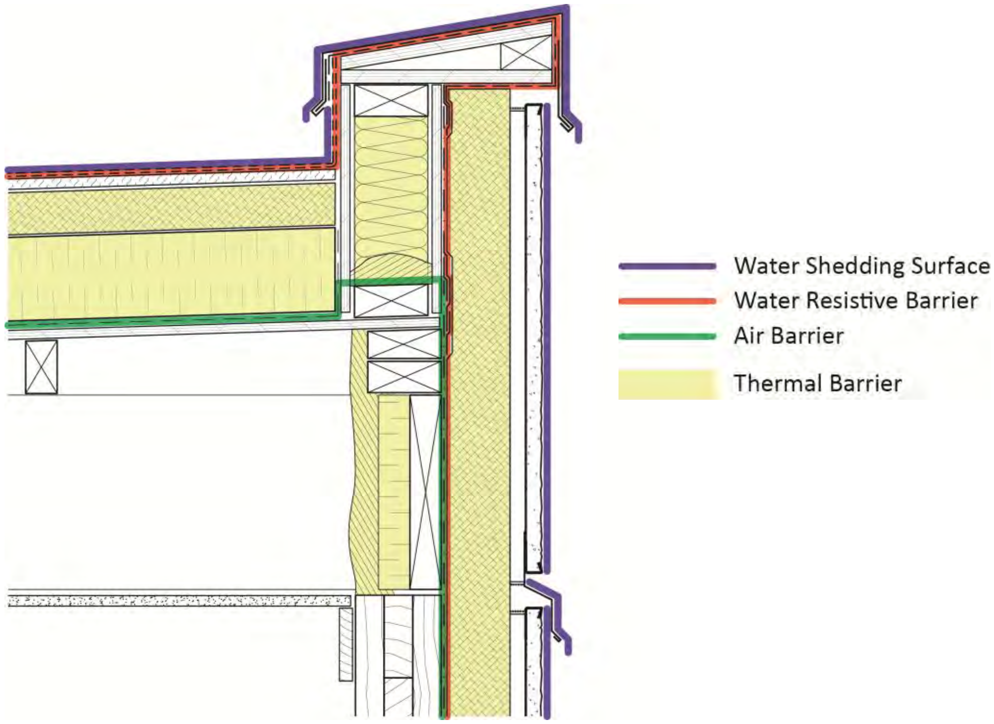
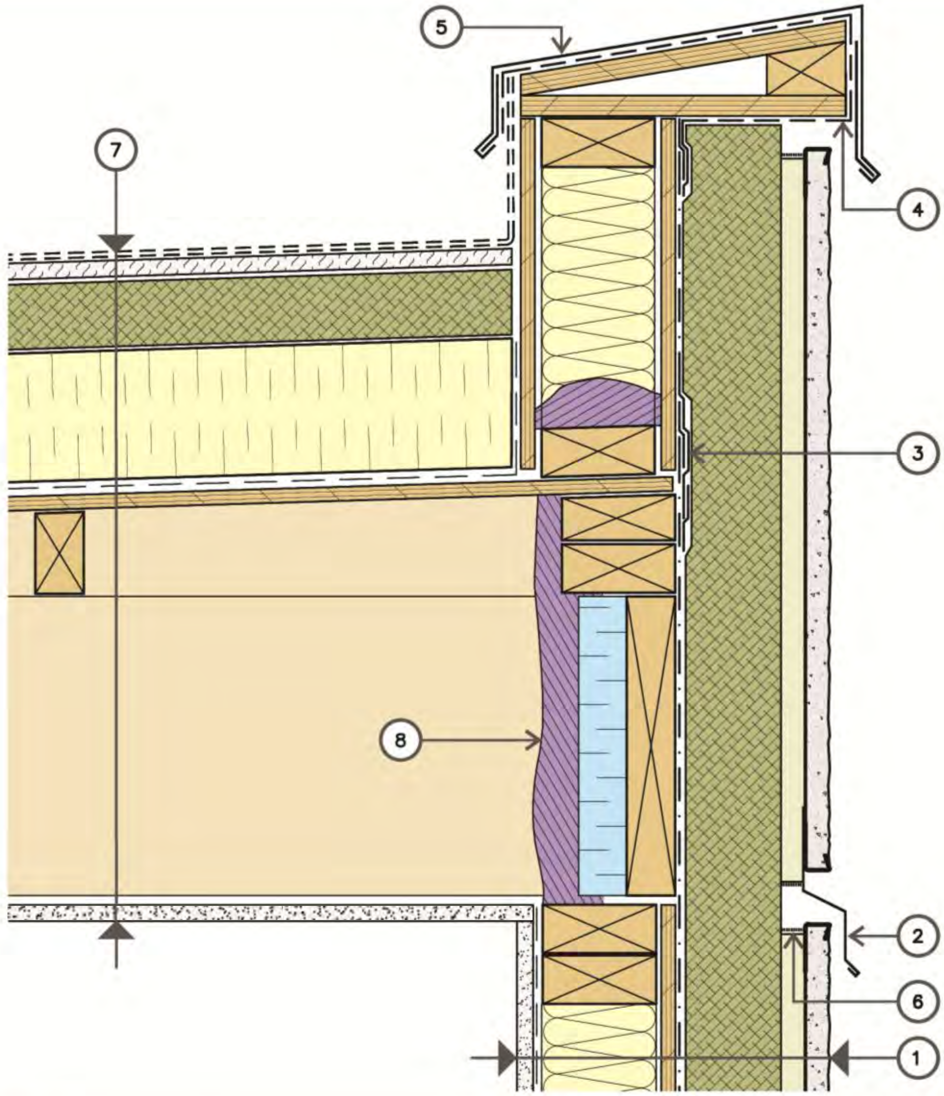


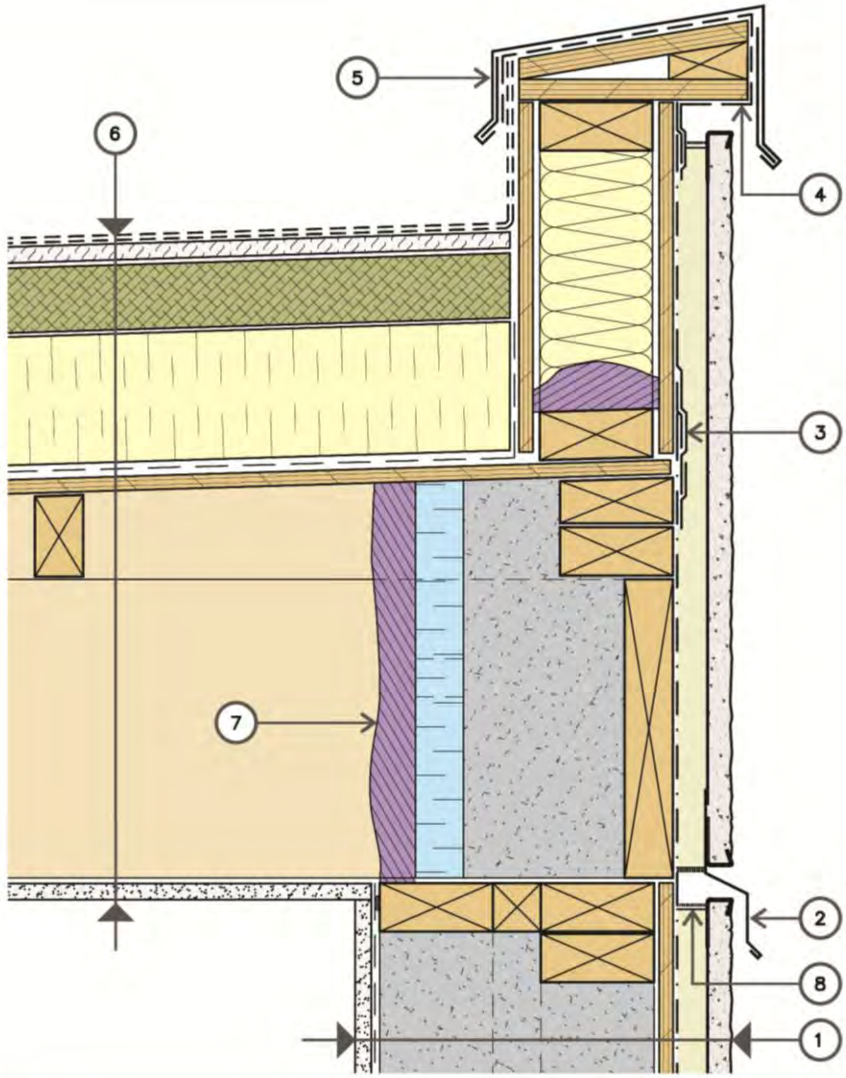
Fig. 5.2.27 Detail 9-MT – Location of Critical Barriers



LEGEND

1. Wall Assembly
   Cladding (stucco with backer board)
   19mm (¾") wood strapping (p.t.)
   76mm (3") mineral wool insulation
   Vapour permeable sheathing membrane
   Sheathing
   Wood framing 38x89mm (2x4) with
   Batt insulation
   Polyethylene
   Gypsum Board
2. Cladding transition flashing
3. Sheathing membrane lapped and taped
4. Foil faced self adhered membrane
5. Metal cap flashing
6. Insect screen
7. Roof Assembly
   Roof membrane
   Protection board
   51mm (2") mineral fibre insulation
   102mm (4") Rigid insulation
   Self adhered membrane
   Sheathing
   Cross purlins as required to provide roof slope
   Wood roof framing
   Gypsum board
8. Extruded polystyrene insulation and
   spray-in-place foam at edges

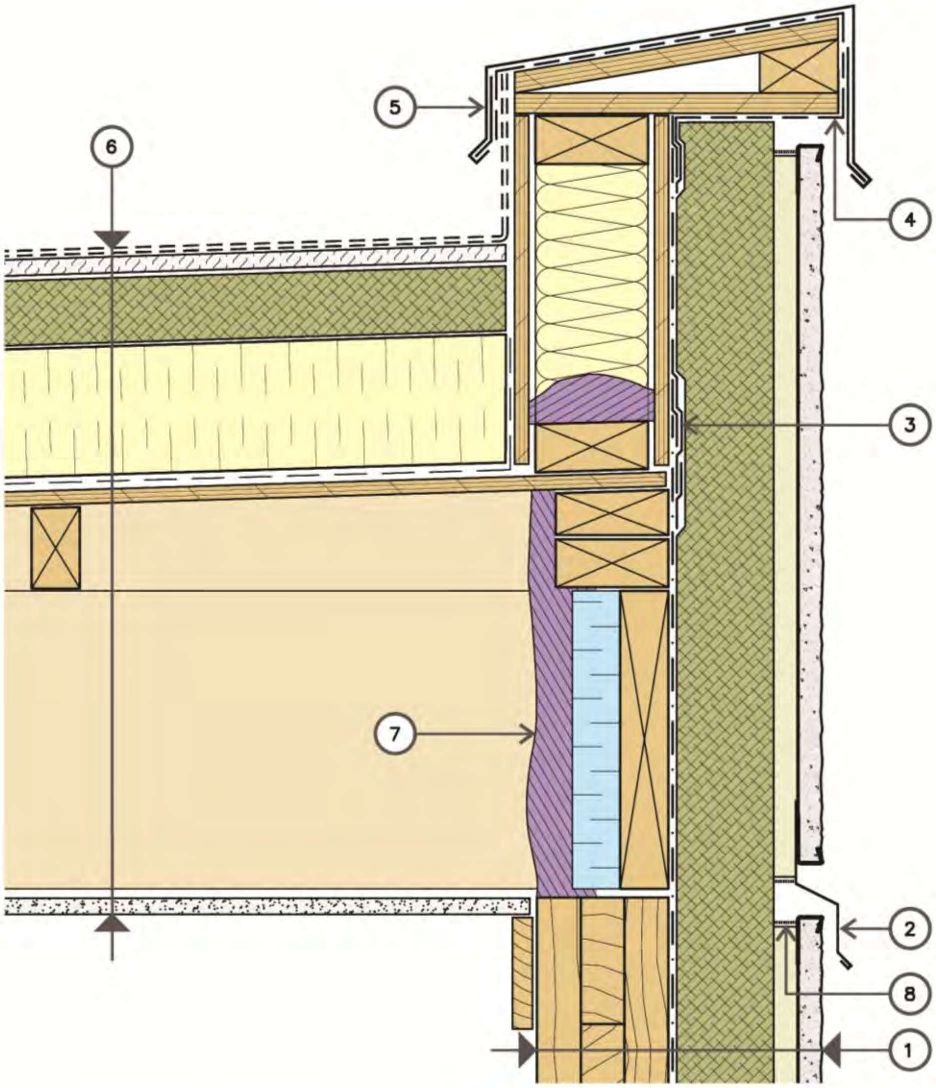
LOW SLOPE ROOF/WALL INTERFACE | DETAIL 9-SI



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (¾") wood strapping (p.t.)
   - Vapour permeable sheathing membrane
   - Sheathing
   - 2 Rows of wood framing 38x89mm (2x4) with 38mm (1½") gap (adjustable)
   - Cellulose Insulation
   - Polyethylene
   - Gypsum board
2. Cladding transition flashing
3. Sheathing membrane lapped and taped
4. Foil faced self adhered membrane
5. Metal cap flashing
6. Roof Assembly
   - Roof membrane
   - Protection board
   - 51mm (2") mineral fibre insulation
   - 102mm (4") Rigid insulation
   - Self adhered membrane
   - Sheathing
   - Cross purlins as required to provide roof slope
   - Wood roof framing
   - Gypsum board
7. Cellulose insulation and extruded polystyrene with spray-in-place foam at edges
8. Insect screen

LOW SLOPE ROOF/WALL INTERFACE | DETAIL 9-DS



LEGEND

1. Wall Assembly
   Cladding (stucco with backer rod)
   19mm (¾") wood strapping (p.t.)
   76mm (3") mineral wool insulation
   Vapour permeable sheathing membrane
   CLT Panel
2. Cladding transition flashing
3. Sheathing membrane lapped and taped
4. Foil faced self adhered membrane
5. Metal cap flashing
6. Roof Assembly
   Roof membrane
   Protection board
   51mm (2") mineral fibre insulation
   102mm (4") Rigid insulation
   Self adhered membrane
   Sheathing
   Cross purlins as required to provide roof slope
   Wood roof framing
   Gypsum board
7. Extruded polystyrene insulation and spray-in-place foam at edges
8. Insect screen

LOW SLOPE ROOF/WALL INTERFACE | DETAIL 9-MT

5.2.10 Detail 10: Balcony/Wall Interface

A transition detail is needed where the balcony intersects the above-grade walls of two different floor levels.

At these locations there are a number of specific issues that should be addressed.

In this detail, and in the next three, only the split insulation detail is shown. The other types of details (double stud, CLT) can be applied in these locations using similar construction detailing and concepts from the details previously described.

Cladding Height

Whenever possible, the bottom of the exterior insulation and cladding should be elevated above the drainage surface. The higher the materials are above the drainage surface, the less the potential for moisture damage as a result of snow melt, water backup, and splashing from the water-shedding surface. This does, however, need to be balanced with considerations for the thermal bridging caused by this gap in the insulation continuity.

Metal Flashing

The pre-finished metal flashing should be kept a minimum of 12 mm (½ inch) above the membrane surface to reduce the potential for corrosion of the flashing.

Air-Barrier Strategies

To maintain continuity of the air barrier, a transition from the wall above to the wall below is required. This is provided by lapping and taping the sheathing membrane onto the drainage material. At balconies, spray foam is used in between the joists to provide continuity between the balcony membrane and the sheathing membrane below via some wood framing members.

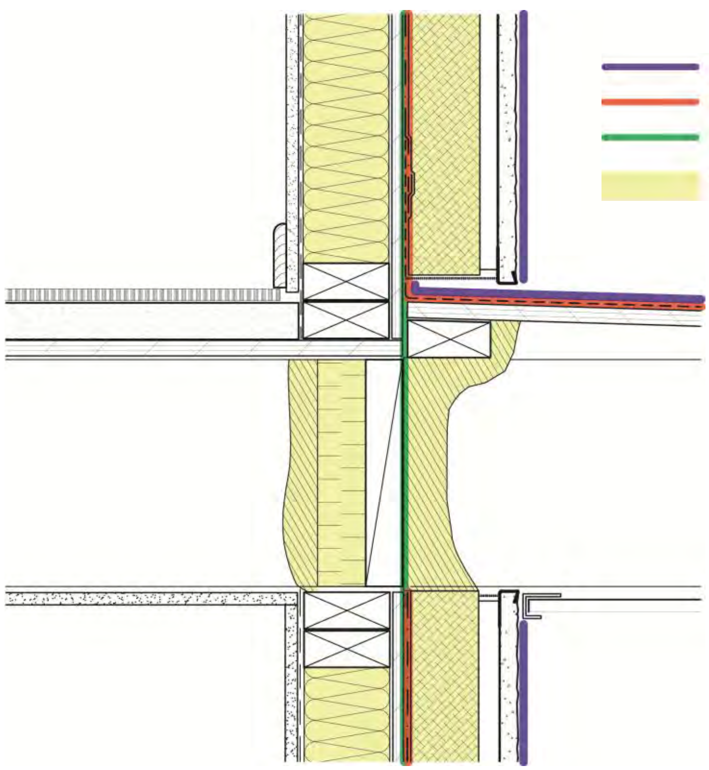
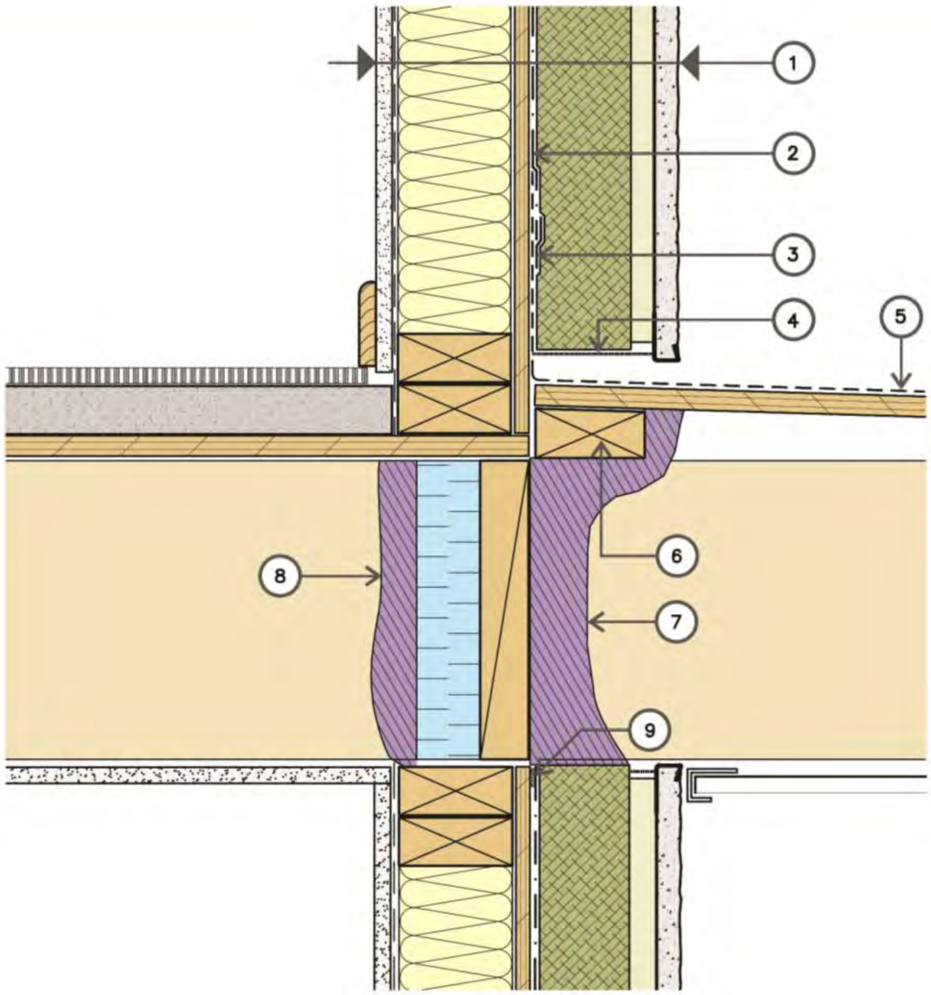


Fig. 5.2.28 Detail 10-SI – Location of Critical Barriers



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (¾") wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x89mm (2x4) with
   - Batt insulation
   - Polyethylene
   - Gypsum board
2. Sheathing membrane lapped over deck membrane
3. Tape
4. Perforated metal insect screen
5. Deck membrane
6. Cross purlins to provide slope
7. Spray-in-place foam over blocking between joists
8. Extruded polystyrene insulation with spray-in-place foam at edges
9. Sealant

BALCONY / WALL INTERFACE | DETAIL 10-SI

5.2.11 Detail 11: Wall Exhaust Vent

A transition detail is needed where exhaust vents penetrate the wall assembly.

At these locations there are a number of specific issues that should be addressed.

Issues

Moisture Protection for Vents

Exhaust-vent detailing must address two potential moisture sources. Detailing to prevent ingress of rainwater incorporates flashing and the use of sealants. Exhaust vents, particularly from clothes dryers, may also be a source of interior moisture. Significant problems can be caused if hot, humid interior air leaks from ducts, grills, or the connection to exhaust vents, and condenses within wall, floor, or balcony assemblies. Care must be taken to ensure that joints in ducts, between ducts and exhaust hoods, and at wall-assembly penetrations are airtight.

Flashing

It may be desirable to integrate the vent flashing with the cross-cavity flashing that typically occurs at the rim-joist location. The cross-cavity flashing, which is usually placed at the level of the wall plates below the joists, may instead be positioned at the top of the rim joist above the exhaust.

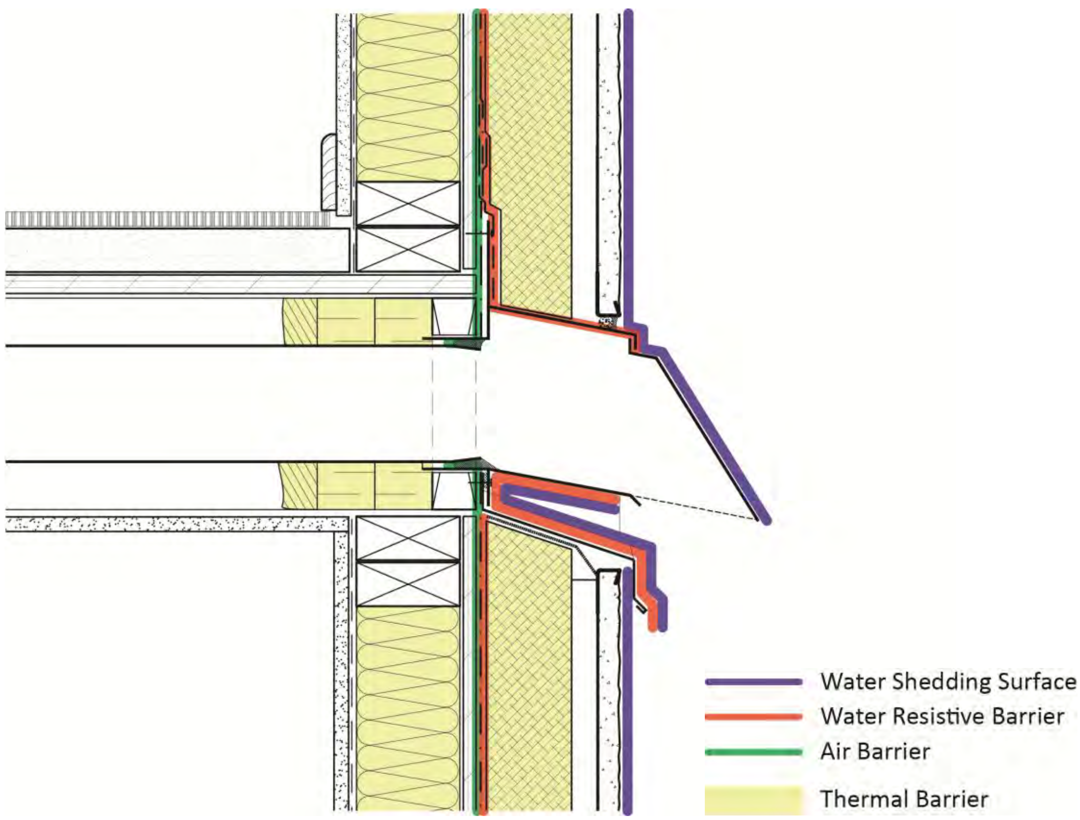
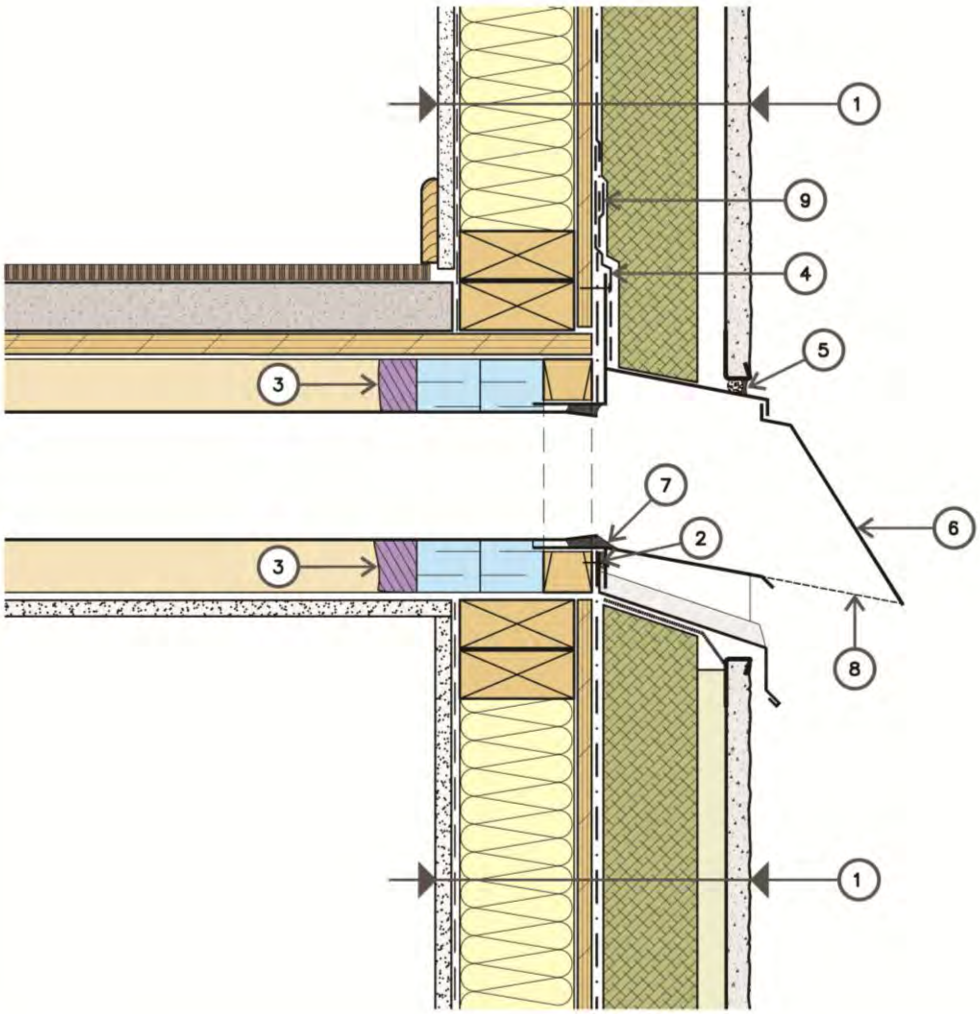


Fig. 5.2.29 Detail 11-SI – Location of Critical Barriers



LEGEND

1. Wall Assembly
   - Cladding (stucco with backer board)
   - 19mm (1¾") Wood strapping (p.t.)
   - 76mm (3") mineral wool insulation
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x89mm (2x4) with
   - Batt insulation
   - Polyethylene
   - Gypsum board
2. Sealant
3. Extruded polystyrene insulation with spray-in-place foam at edges and penetration
4. Self adhered membrane
5. Backer rod and sealant at top and sides of vent
6. Two-piece exhaust vent with 3" flange at top and sides
7. Sealant all around annular space
8. Removable screen
9. Tape

WALL EXHAUST VENT | DETAIL 11-SI

5.2.12 Detail 12: Exterior Electrical Outlet

Issues

Location of Fixtures

Where possible, fixtures and receptacles should be located in protected areas where the potential for wetting of the adjoining wall surfaces is reduced.

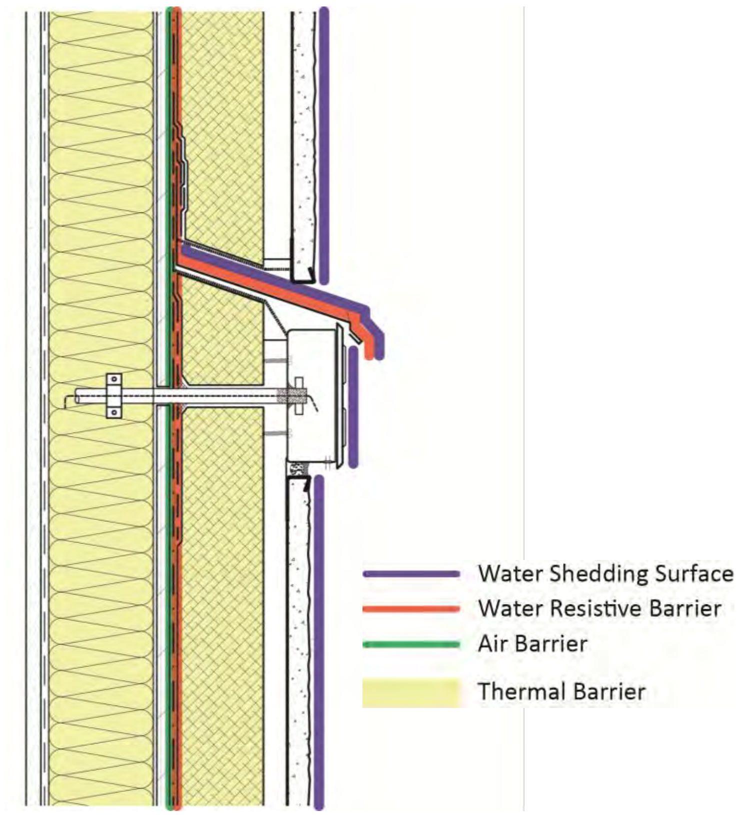
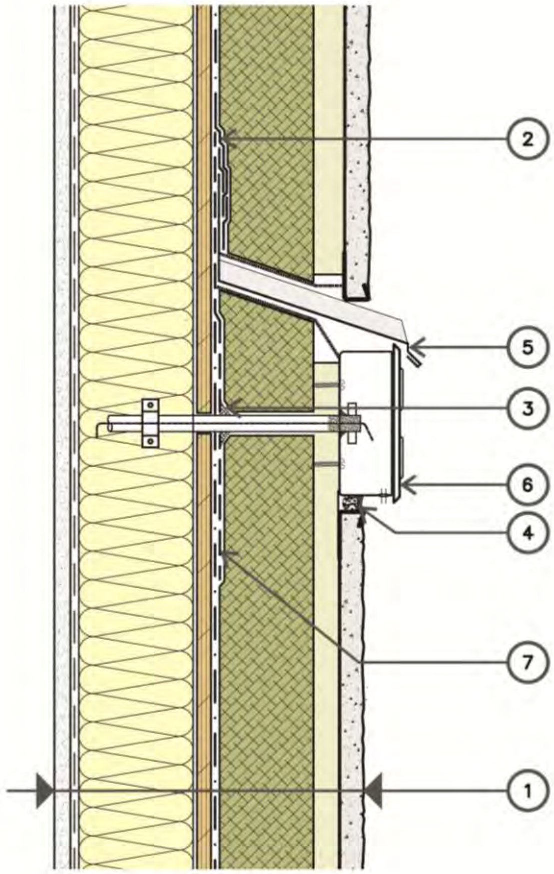


Fig. 5.2.30 Detail 12-SI – Location of Critical Barriers



1. Wall Assembly
   Cladding (stucco with backer board)
   19mm (¾") wood strapping (p.t.)
   76mm (3") mineral wool insulation
   Vapour permeable sheathing membrane
   Sheathing
   Wood framing 38x89 mm (2x4)
   Batt insulation
   Polyethylene
   Gypsum board
2. Permeable sheathing membrane lapped and taped over flashing
3. Sealant
4. Backer rod and sealant at bottom and sides
5. Pre-finished metal flashing with end dams and end closures
6. Weatherproof thin profile electrical box with cover plate, gasket, and rigid conduit pipe clamped to stud end of pipe filled with expanding foam, drained at bottom of box
7. Foil-faced self adhered membrane 150x230mm (6"x9")

EXTERNAL ELECTRICAL OUTLET | DETAIL 12-SI

5.2.13 Detail 13: Hose Bib

Issues

Location of Pipes

Where possible, pipe penetrations should be located in protected areas where the potential for wetting of the adjoining wall surfaces is reduced.

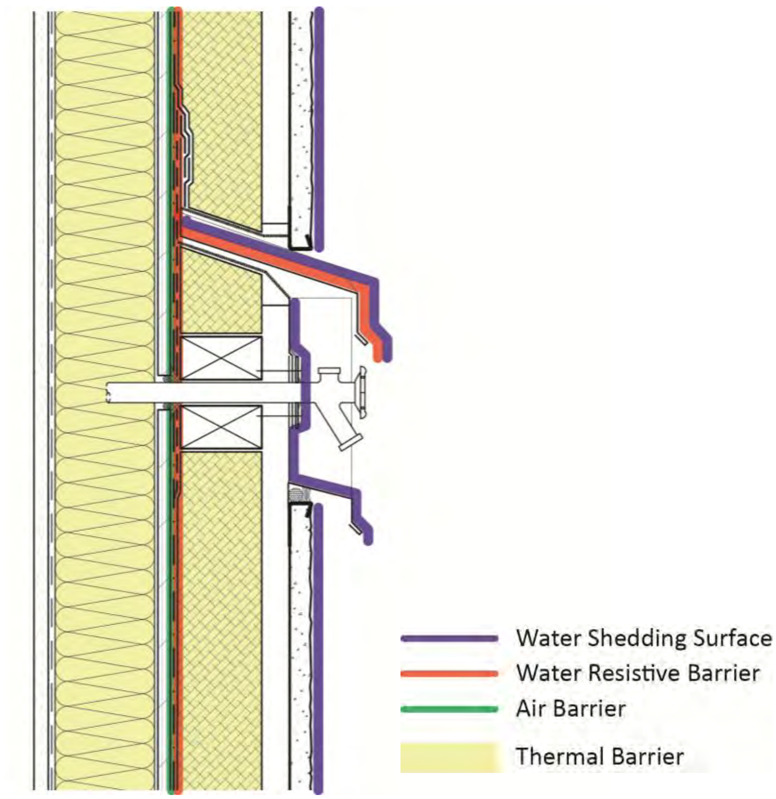
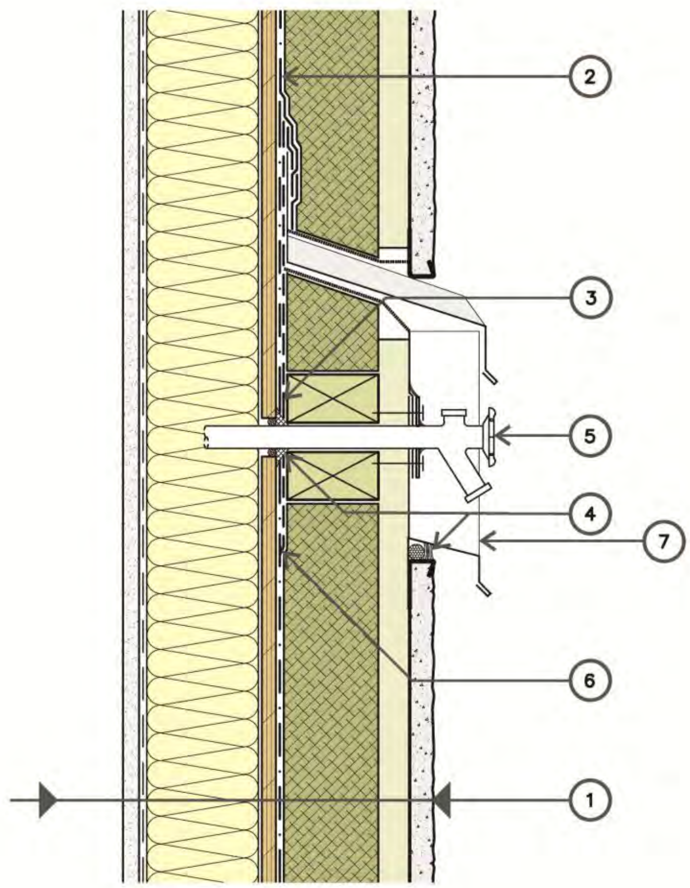


Fig. 5.2.31 Detail 13-SI – Location of Critical Barriers



LEGEND

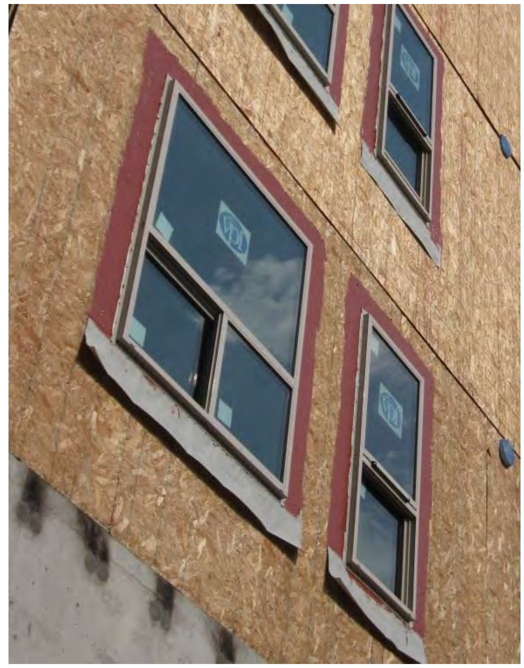
1. Wall Assembly
   Cladding (stucco with backer board)
   19mm (¾") wood strapping (p.t.)
   76 mm (3") mineral wool insulation
   Vapour permeable sheathing membrane
   Sheathing
   Wood framing 38x89mm (2x4) with
   Batt insulation
   Polyethylene
   Gypsum board
2. Vapour permeable sheathing membrane lapped and taped over flashing
3. Foil-faced self adhered membrane sealed at all four sides
4. Backer rod and sealant all around
5. Hose bib with pipe secured to framing (Gas line detail similar)
6. Sealant
7. Prefinished metal housing box

HOSE BIB | DETAIL 13-SI

5.3 Three-Dimensional Sequencing Drawings

Three-dimensional sequencing drawings are provided in this chapter. The drawings are listed by title in Table 5.3.1, which also provides the corresponding section number in this chapter.

These details show, graphically, how to construct certain complex details that require certain sequencing to maintain critical barrier continuity and correct lapping of membranes and tapes. Liquid membranes, which are not shown in the sequencing drawings, can be used as a substitute for self-adhered membranes in window rough openings. They serve to simplify the detailing process by reducing the number of pieces required to achieve continuity and correct lapping. In addition, with the use of self-adhered vapour-permeable membranes, staples and tapes can be eliminated.

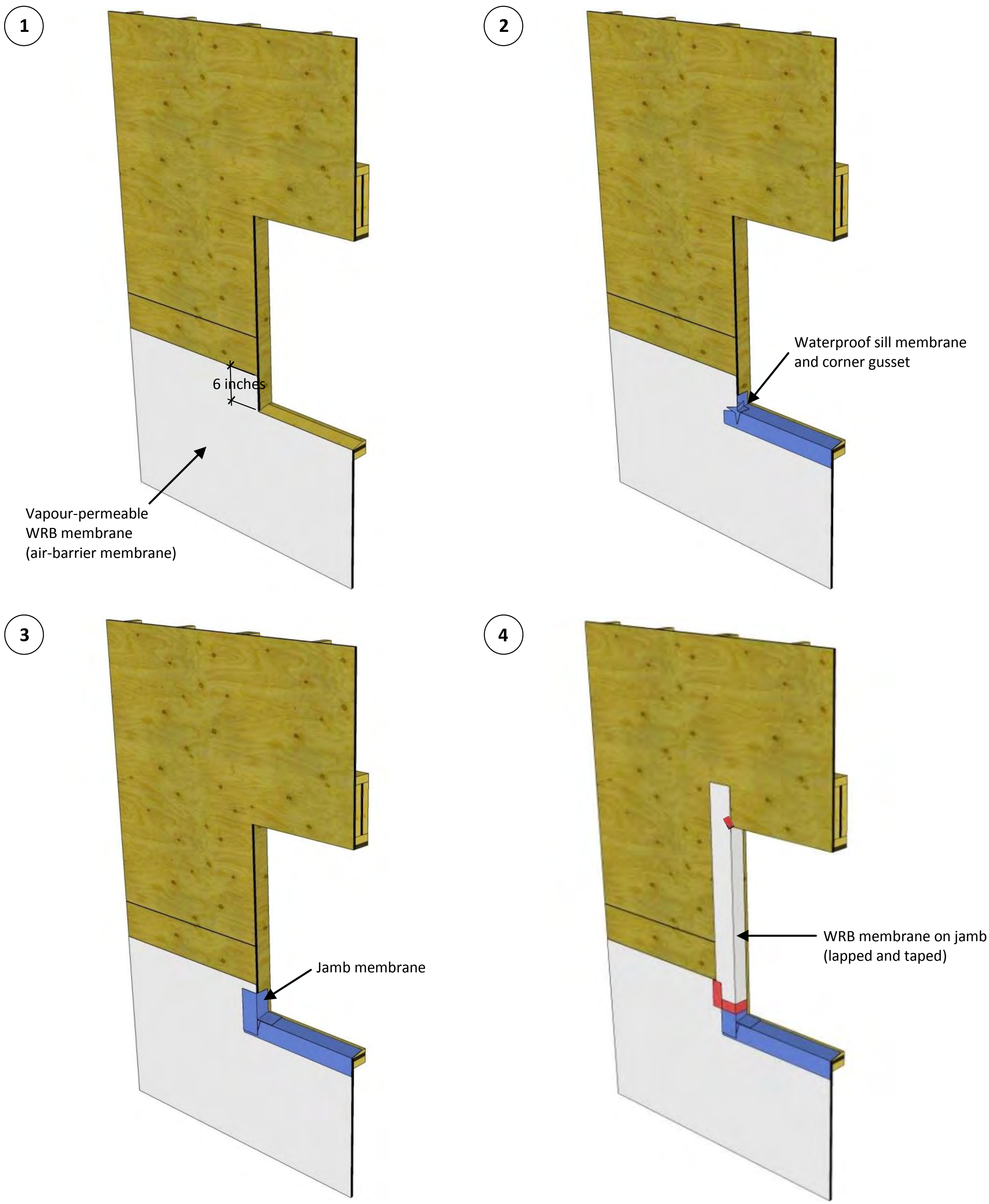


Liquid membrane used in the window rough opening to simplify sequencing and detailing.

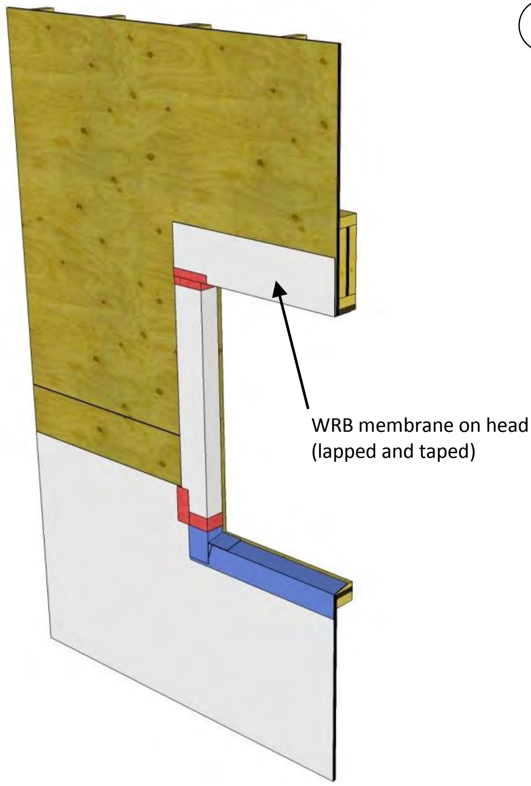
Table 5.3.1 List of three-dimensional sequencing drawings.

Sequencing drawings, no. in this chapter	Title	Section no. in this chapter
Sequence 1	Drawings for Window Installation: Traditional 2x4 or 2x6 Stud Wall, Sealed Sheathing Membrane, Air-Barrier Approach	5.3.1
Sequence 2	Drawings for Window Installation: Double-Stud Wall, Sealed Sheathing Membrane, Air-Barrier Approach	5.3.2
Sequence 3	Drawings for Window Installation (Innie Window): Split-insulation, Sealed Sheathing Membrane, Air-Barrier Approach	5.3.3
Sequence 4	Drawings for Window Installation (Outie Window): Split-Insulation, Self-Adhered Sheathing Membrane, Air-Barrier Approach	5.3.4
Sequence 5	Drawings for Window Installation (Innie Window): CLT, Exterior Insulation, Sealed Sheathing Membrane, Air-Barrier Approach	5.3.5

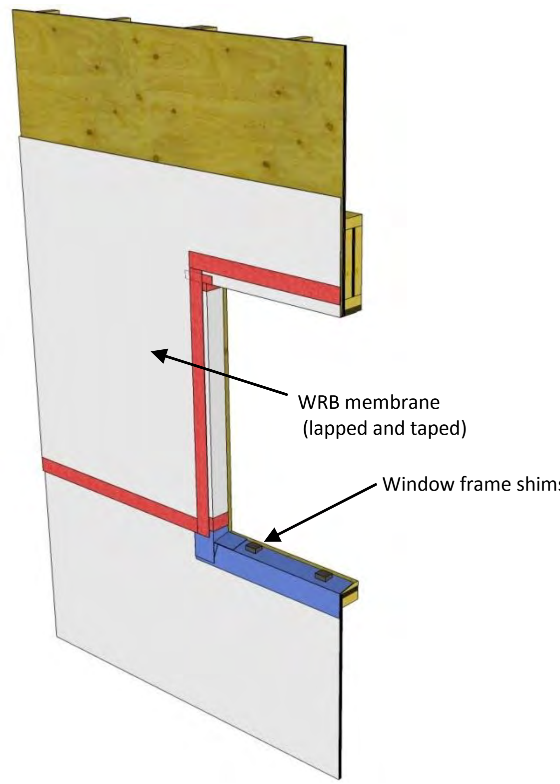
5.3.1 Sequence 1 — Drawings for Window Installation: Traditional 2x4/2x6 Stud Wall, Sealed Sheathing Membrane, Air-Barrier Approach



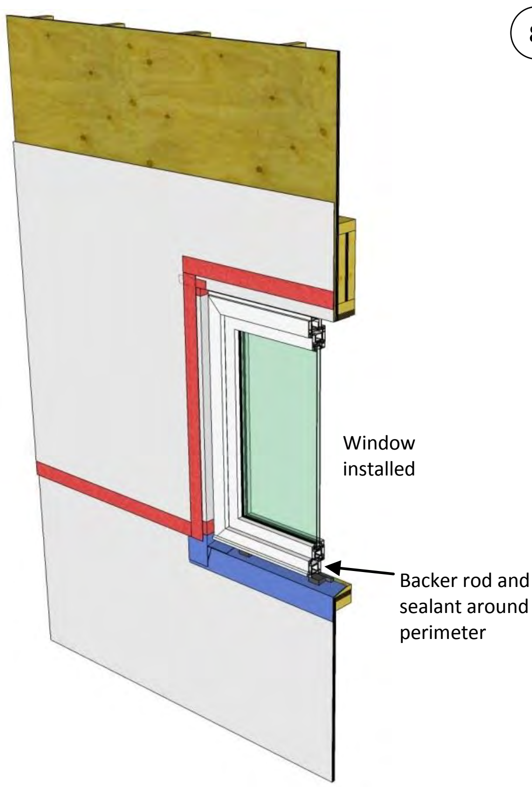
5


WRB membrane on head
(lapped and taped)

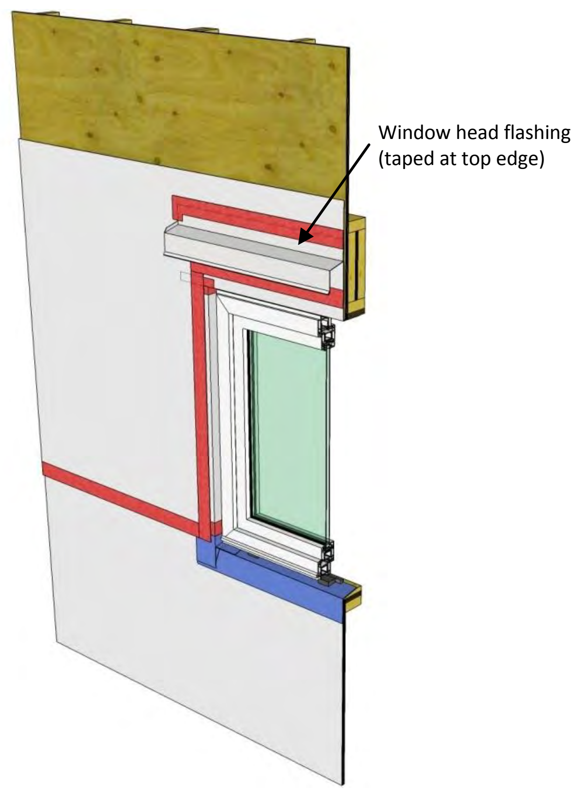
6


WRB membrane
(lapped and taped)
Window frame shims

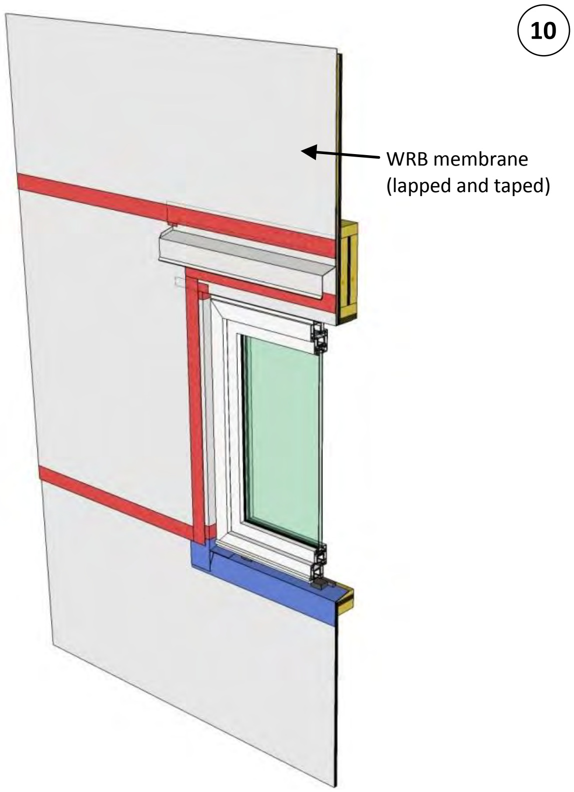
7


Window
installed
Backer rod and
sealant around
perimeter

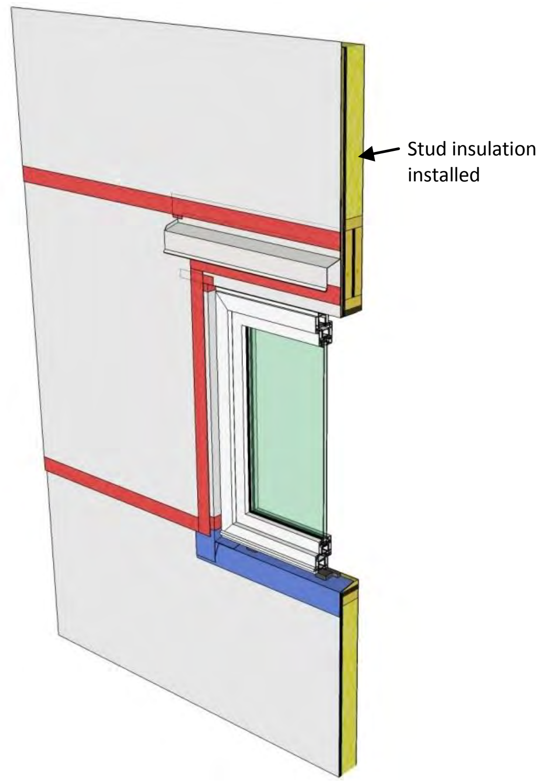
8


Window head flashing
(taped at top edge)

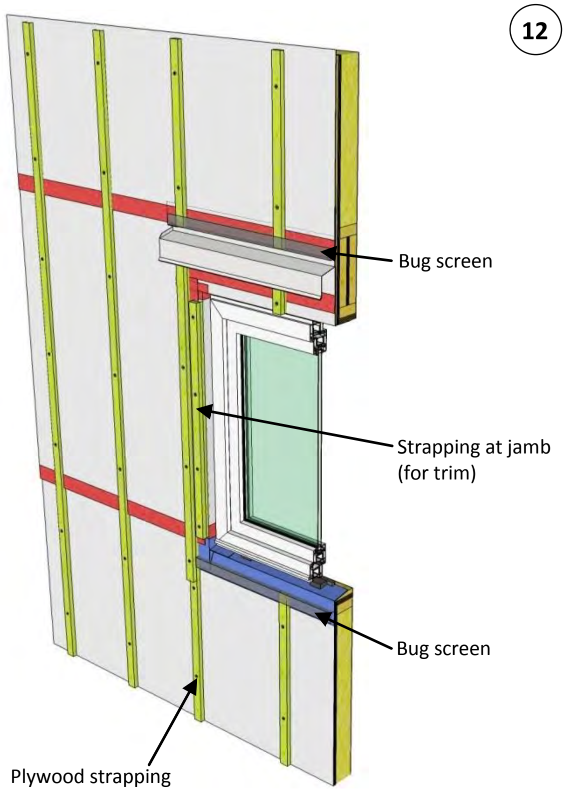
9


WRB membrane
(lapped and taped)

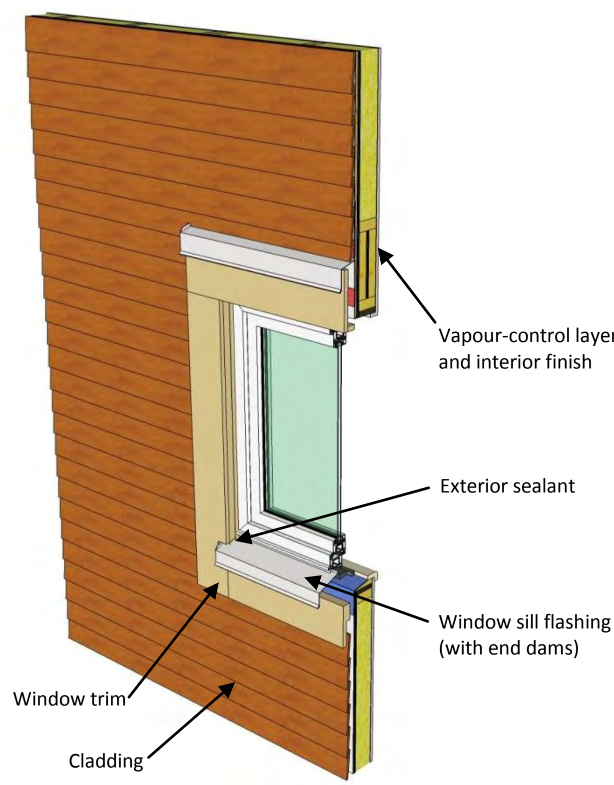
10


Stud insulation
installed

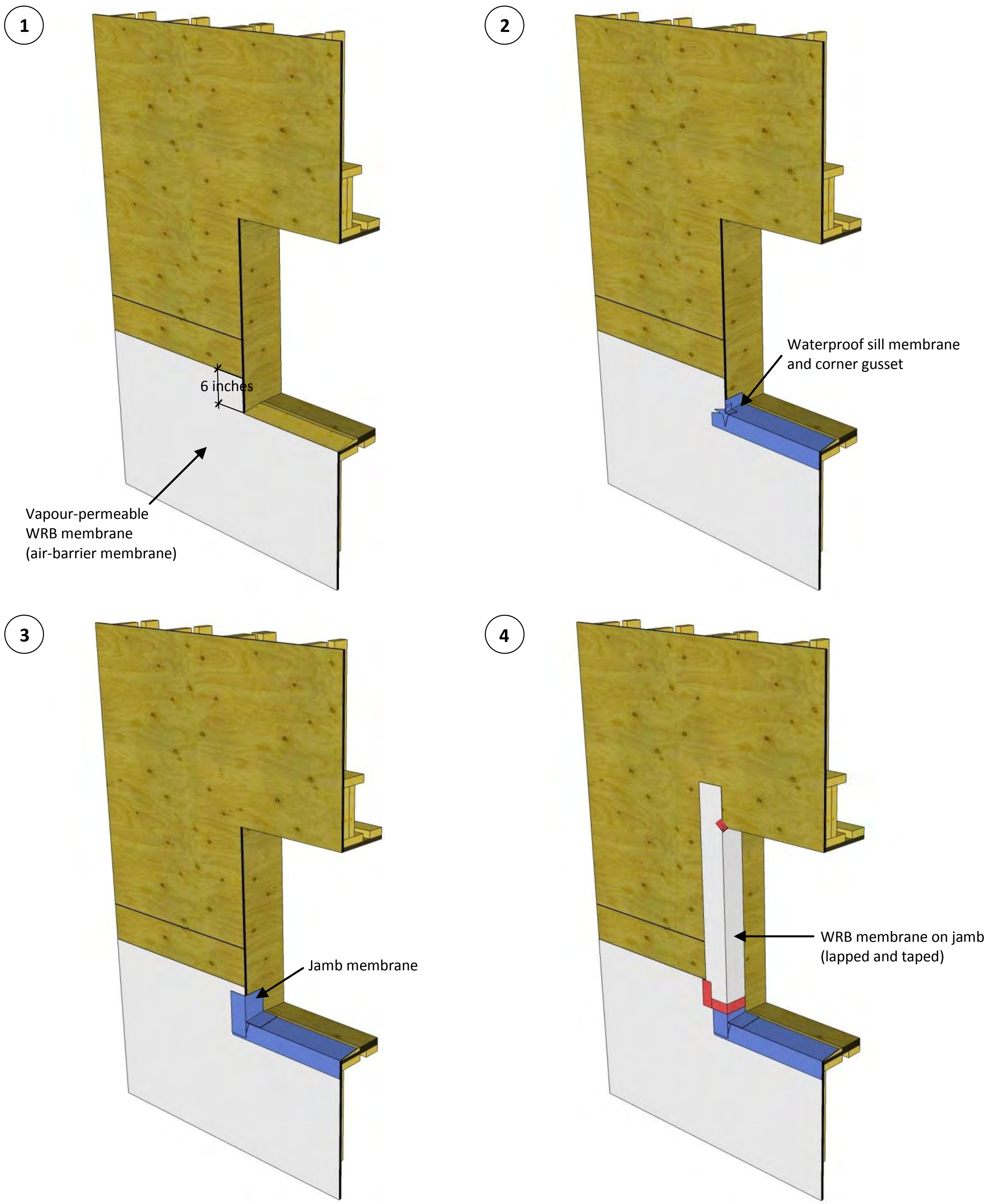
11


Bug screen
Strapping at jamb
(for trim)
Bug screen
Plywood strapping

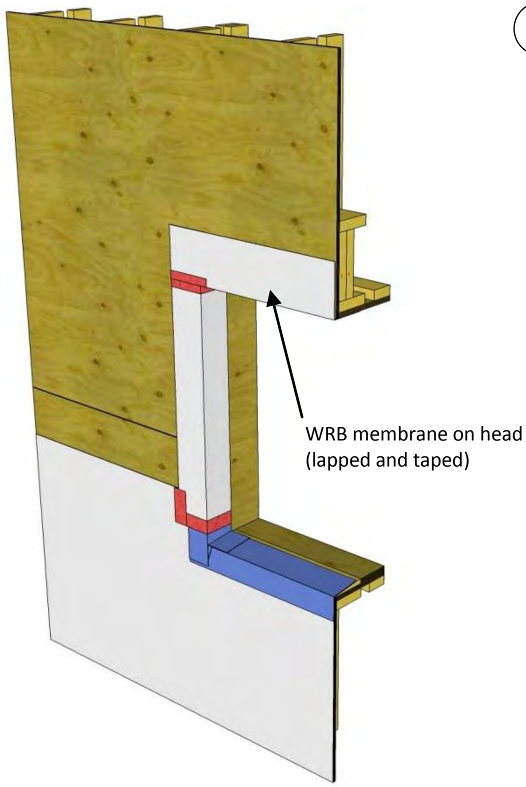
12


Vapour-control layer
and interior finish
Exterior sealant
Window sill flashing
(with end dams)
Window trim
Cladding

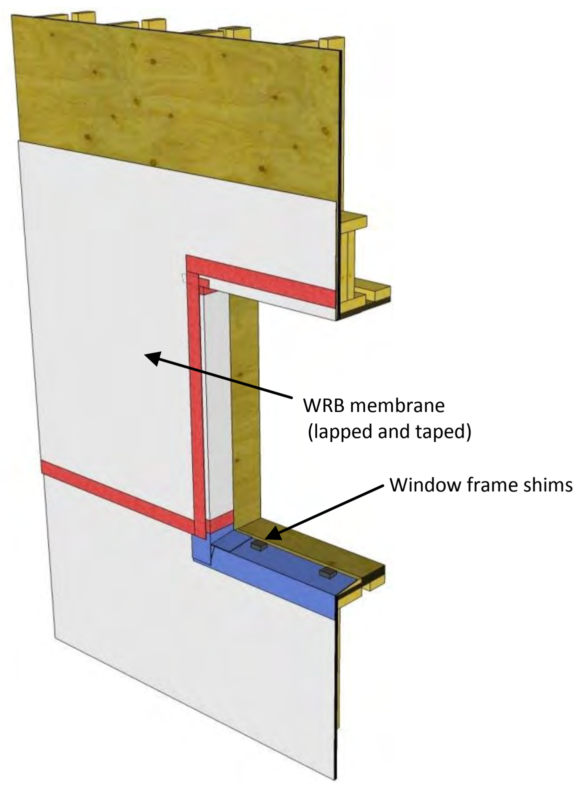
5.3.2 Sequence 2 — Drawings for Window Installation: Double-Stud Wall, Sealed Sheathing Membrane, Air-Barrier Approach



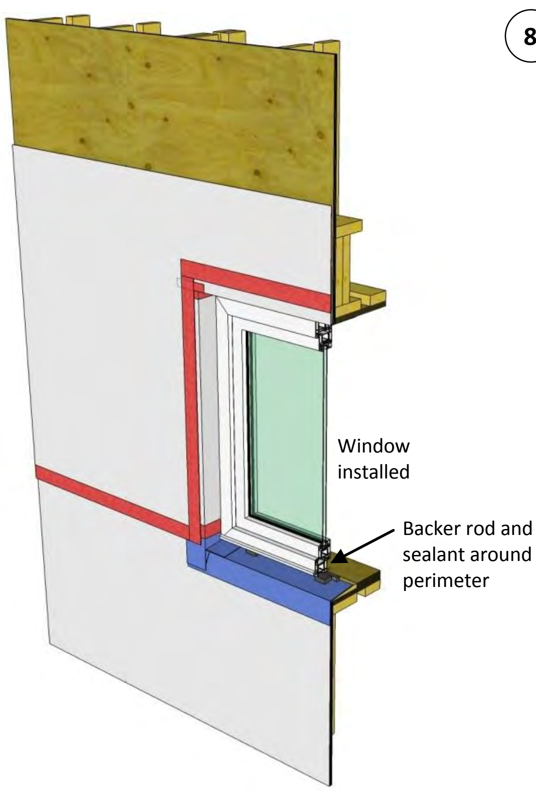
5


WRB membrane on head
(lapped and taped)

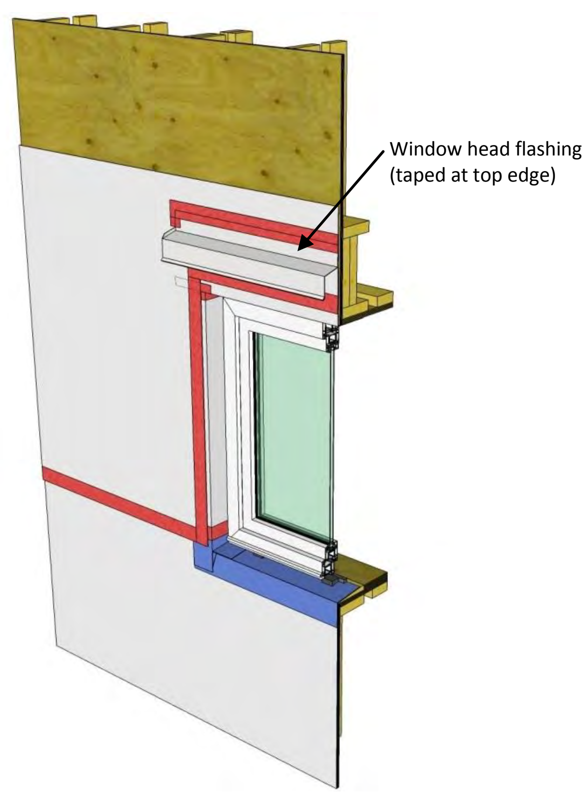
6


WRB membrane
(lapped and taped)
Window frame shims

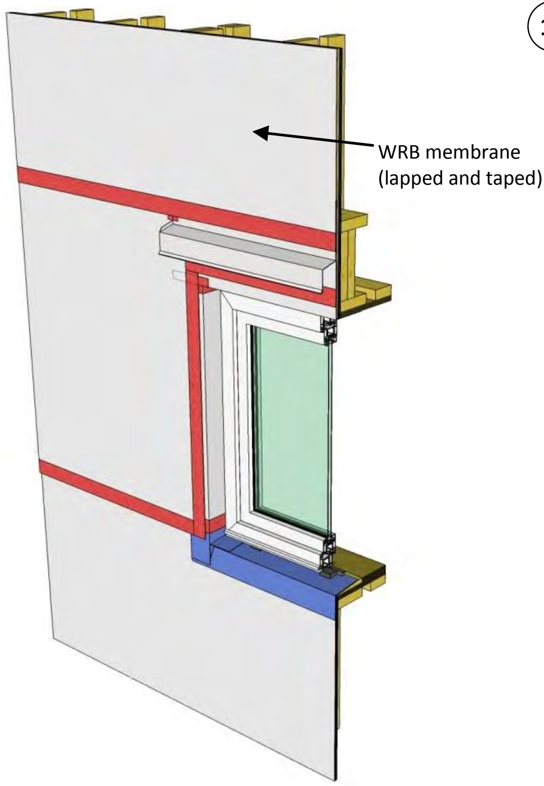
7


Window
installed
Backer rod and
sealant around
perimeter

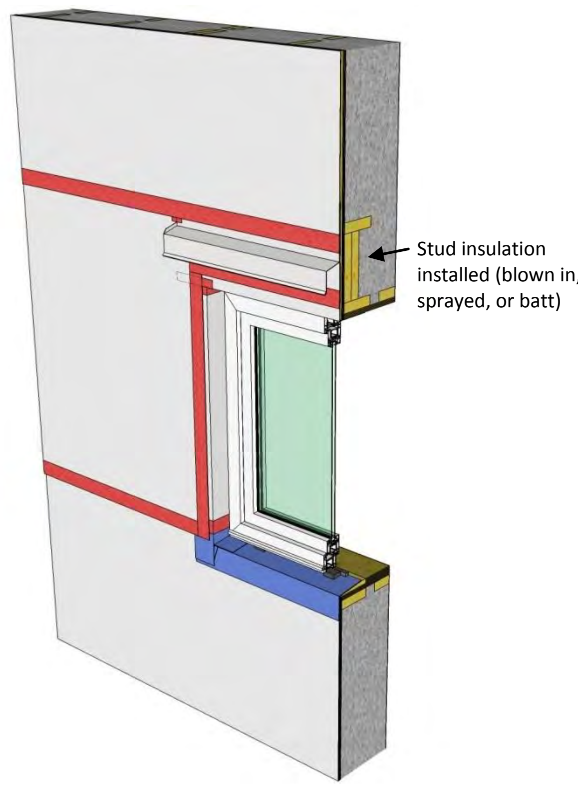
8


Window head flashing
(taped at top edge)

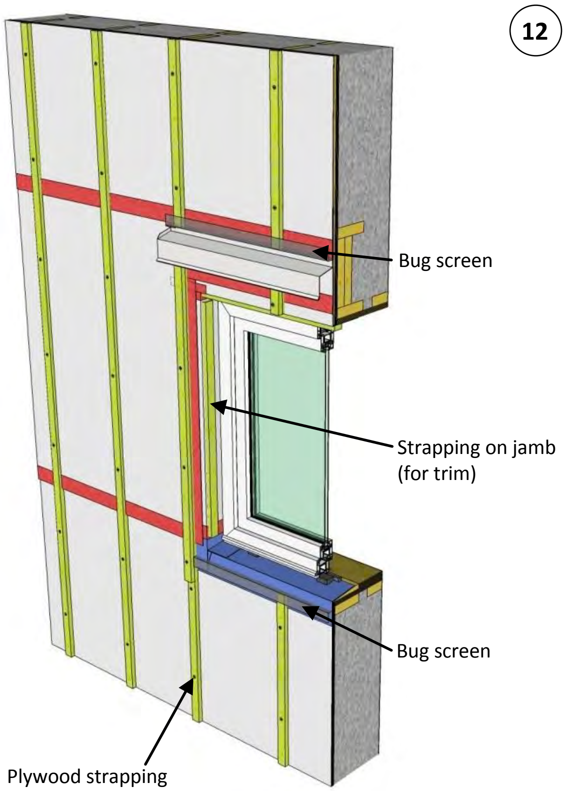
9


WRB membrane
(lapped and taped)

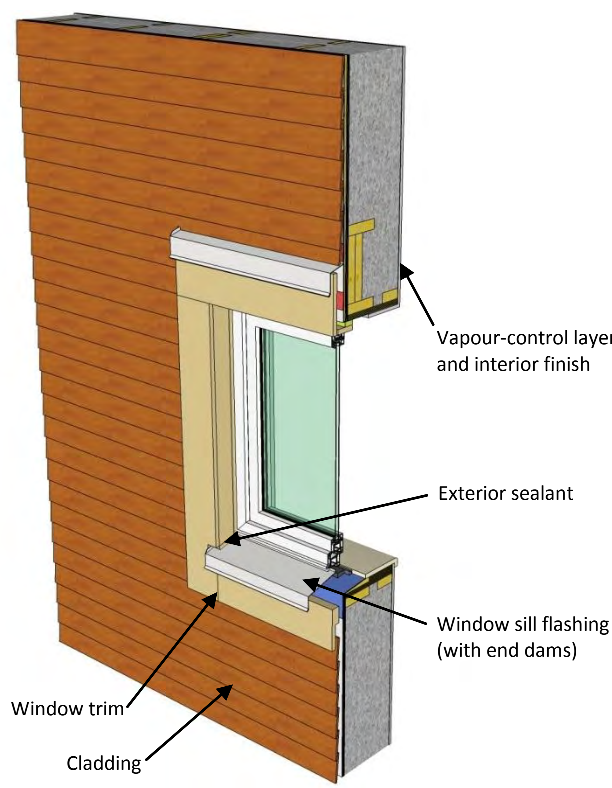
10


Stud insulation
installed (blown in,
sprayed, or batt)

11

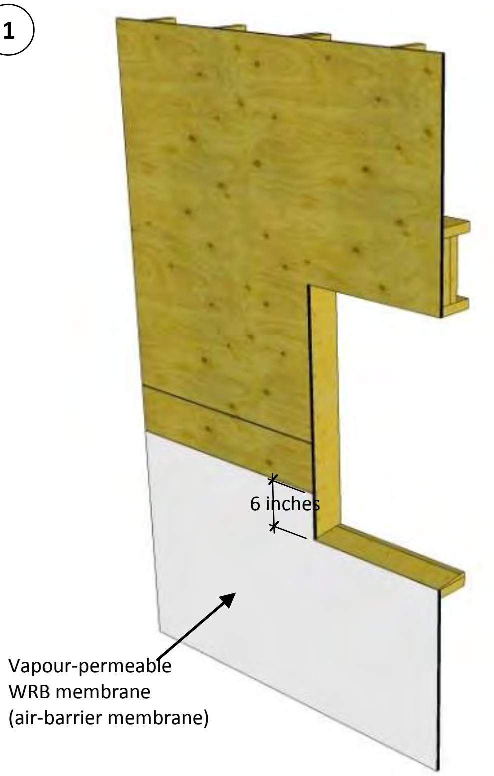

Bug screen
Strapping on jamb
(for trim)
Bug screen
Plywood strapping

12


Vapour-control layer
and interior finish
Exterior sealant
Window sill flashing
(with end dams)
Window trim
Cladding

5.3.3 Sequence 3 — Drawings for Window Installation (Innie Window): Split Insulation, Sealed Sheathing Membrane, Air-Barrier Approach

1



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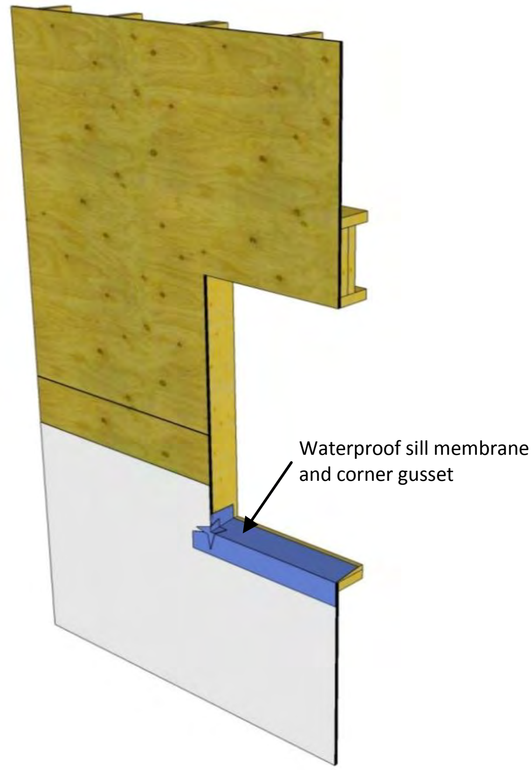

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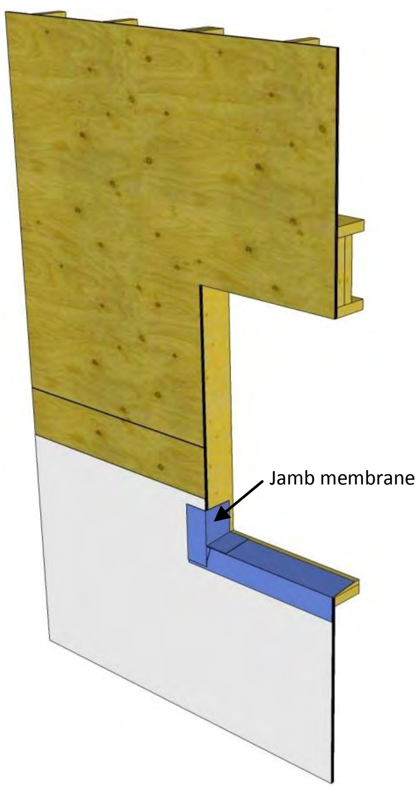

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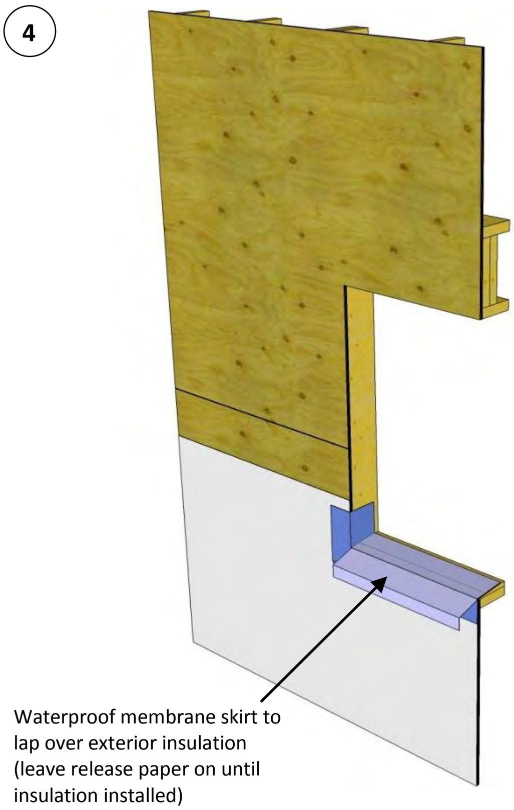

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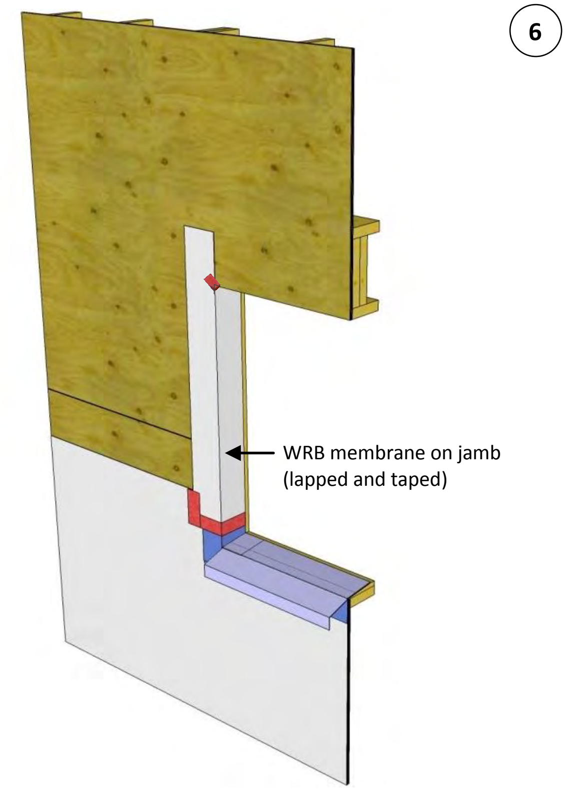
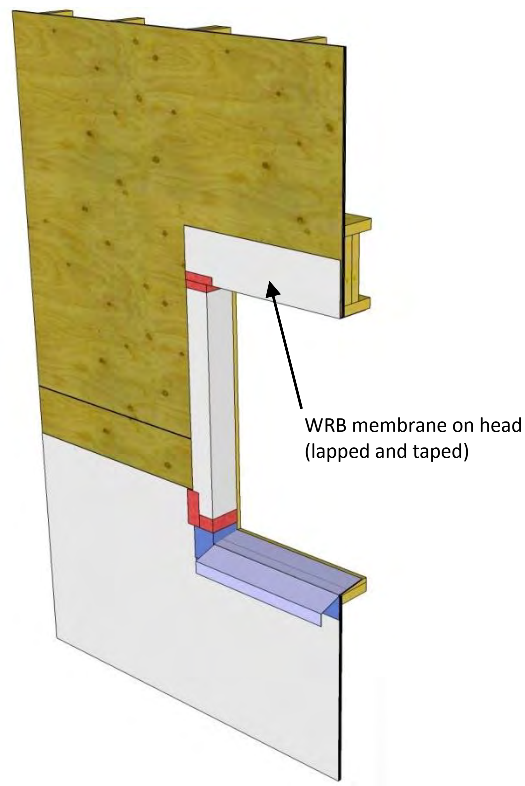
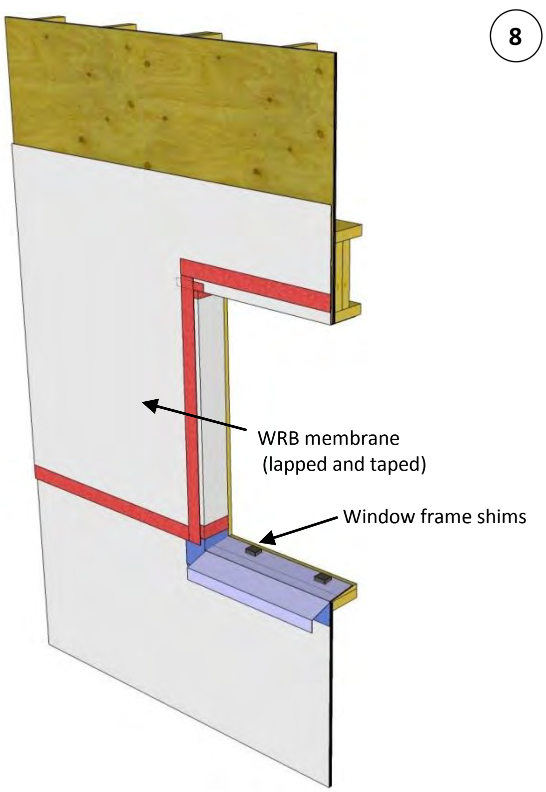

WRB membrane on jamb
(lapped and taped)

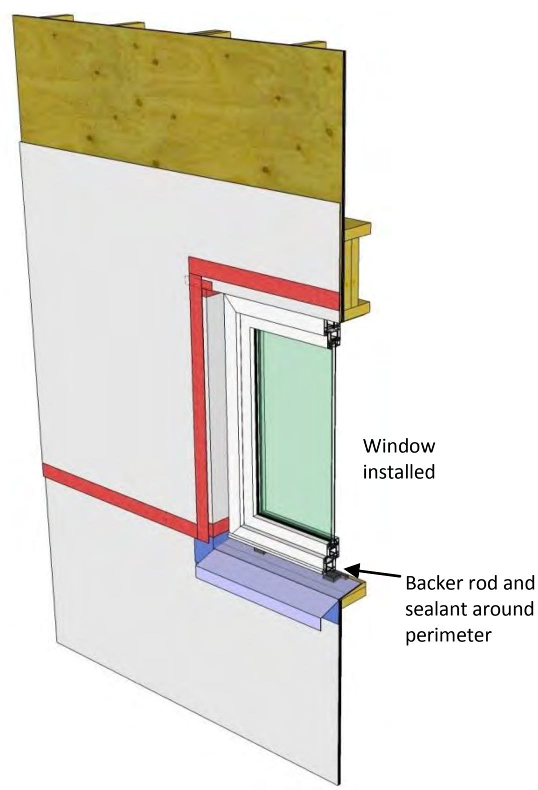
6


WRB membrane on head
(lapped and taped)

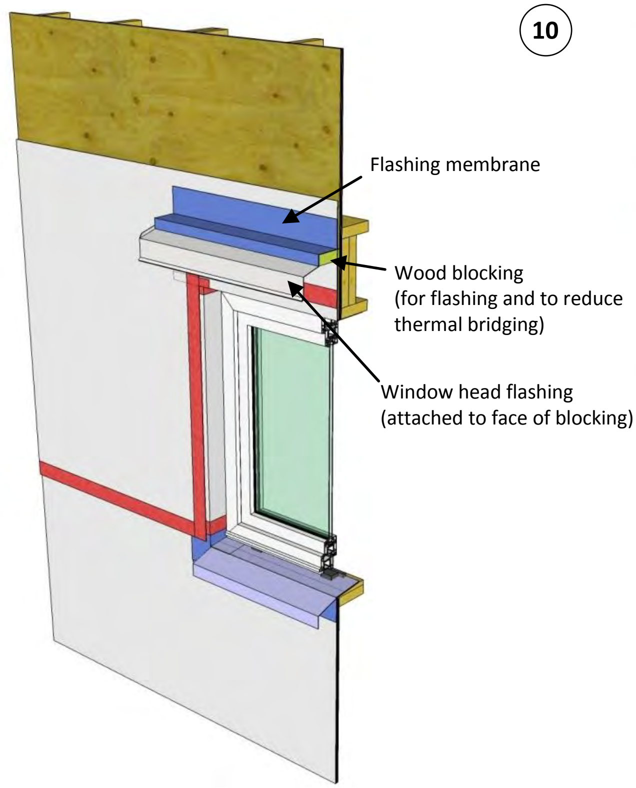
7


WRB membrane
(lapped and taped)
Window frame shims

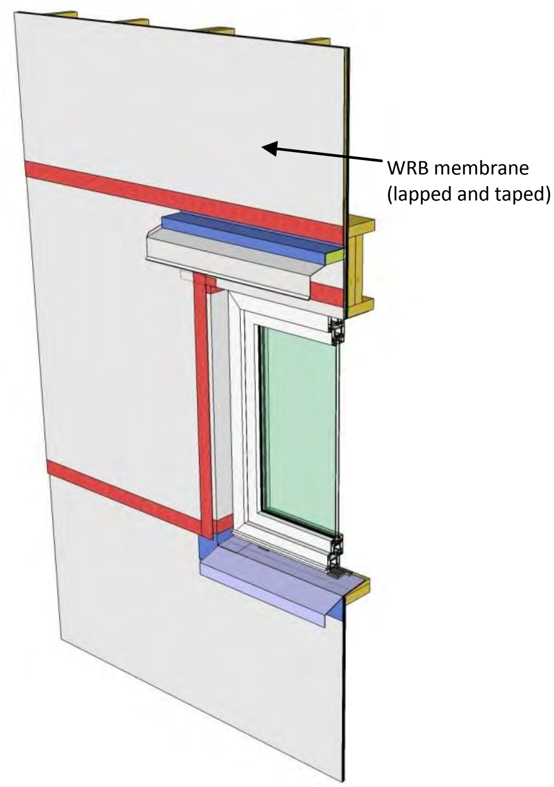
8


Window
installed
Backer rod and
sealant around
perimeter

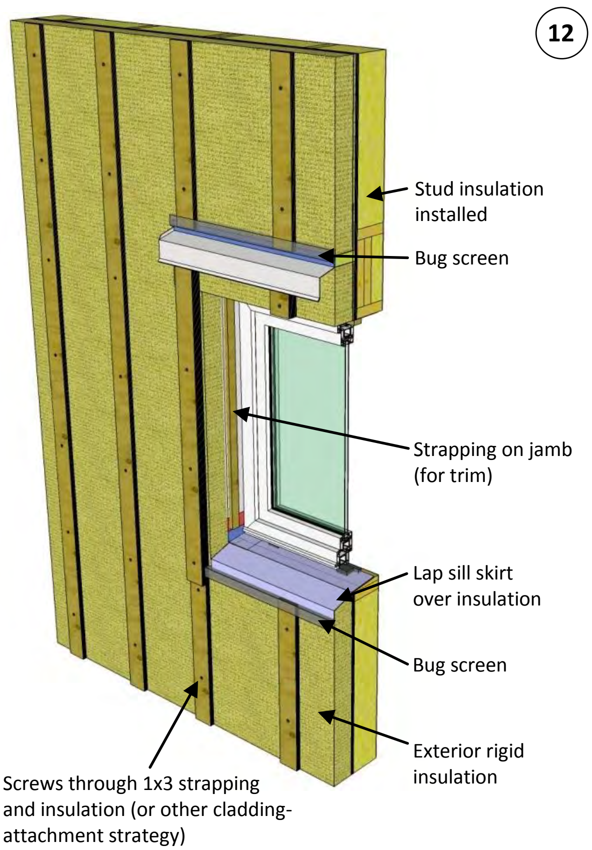
9


Flashing membrane
Wood blocking
(for flashing and to reduce
thermal bridging)
Window head flashing
(attached to face of blocking)

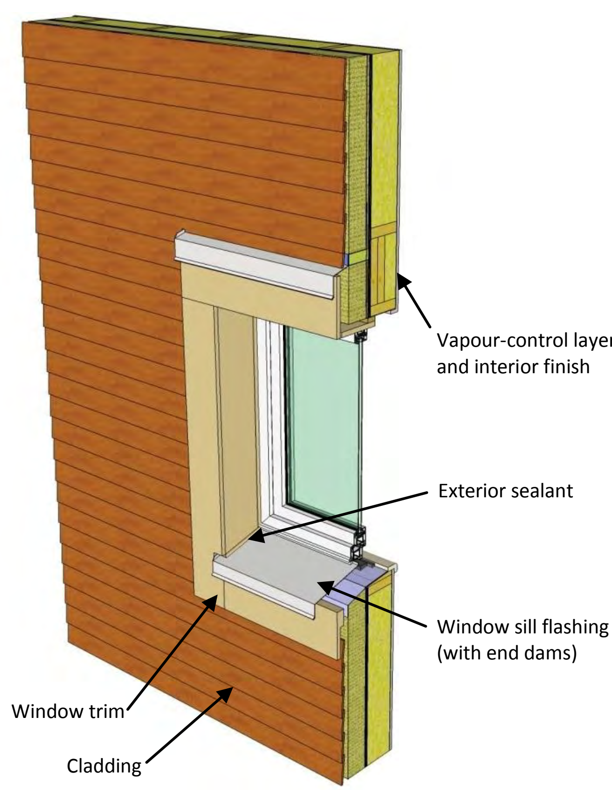
10


WRB membrane
(lapped and taped)

11

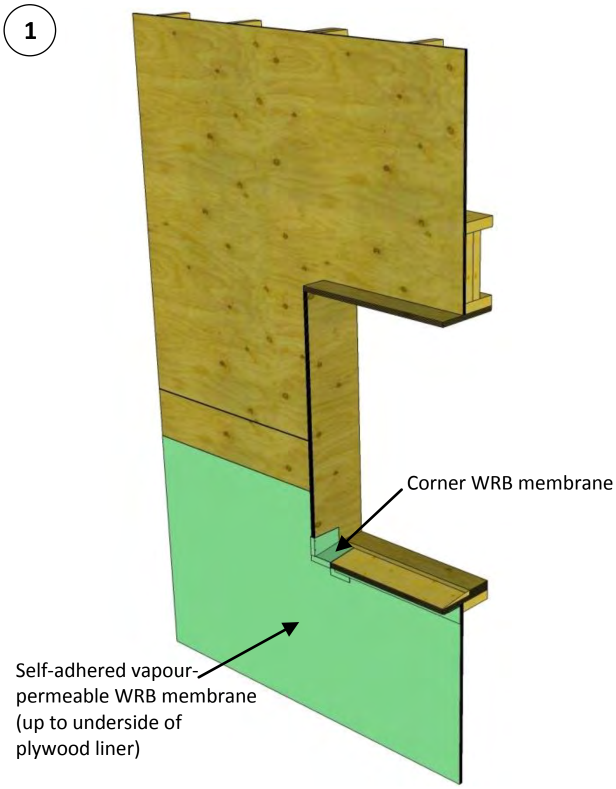

Stud insulation
installed
Bug screen
Strapping on jamb
(for trim)
Lap sill skirt
over insulation
Bug screen
Exterior rigid
insulation
Screws through 1x3 strapping
and insulation (or other cladding-
attachment strategy)

12


Vapour-control layer
and interior finish
Exterior sealant
Window sill flashing
(with end dams)
Window trim
Cladding

5.3.4 Sequence 4 — Drawings for Window Installation (Outie Window): Split Insulation, Self-Adhered Sheathing Membrane, Air-Barrier Approach

1



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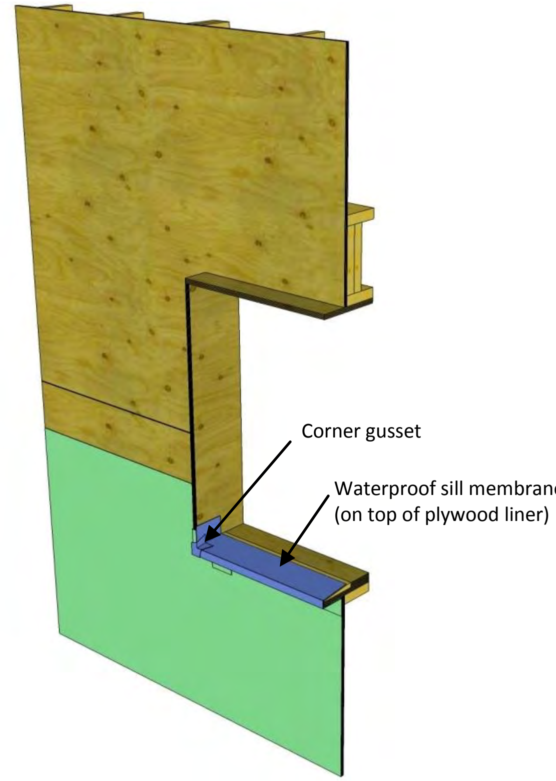

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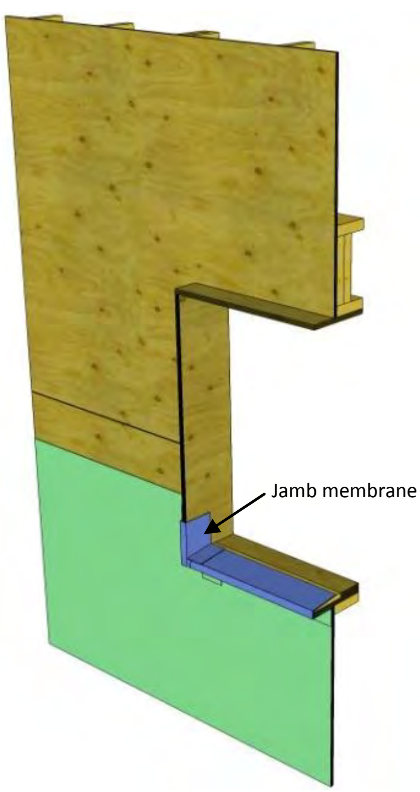
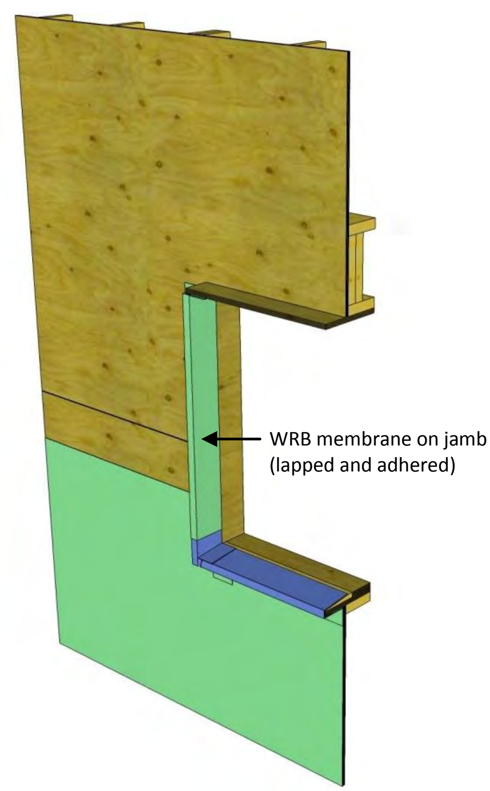
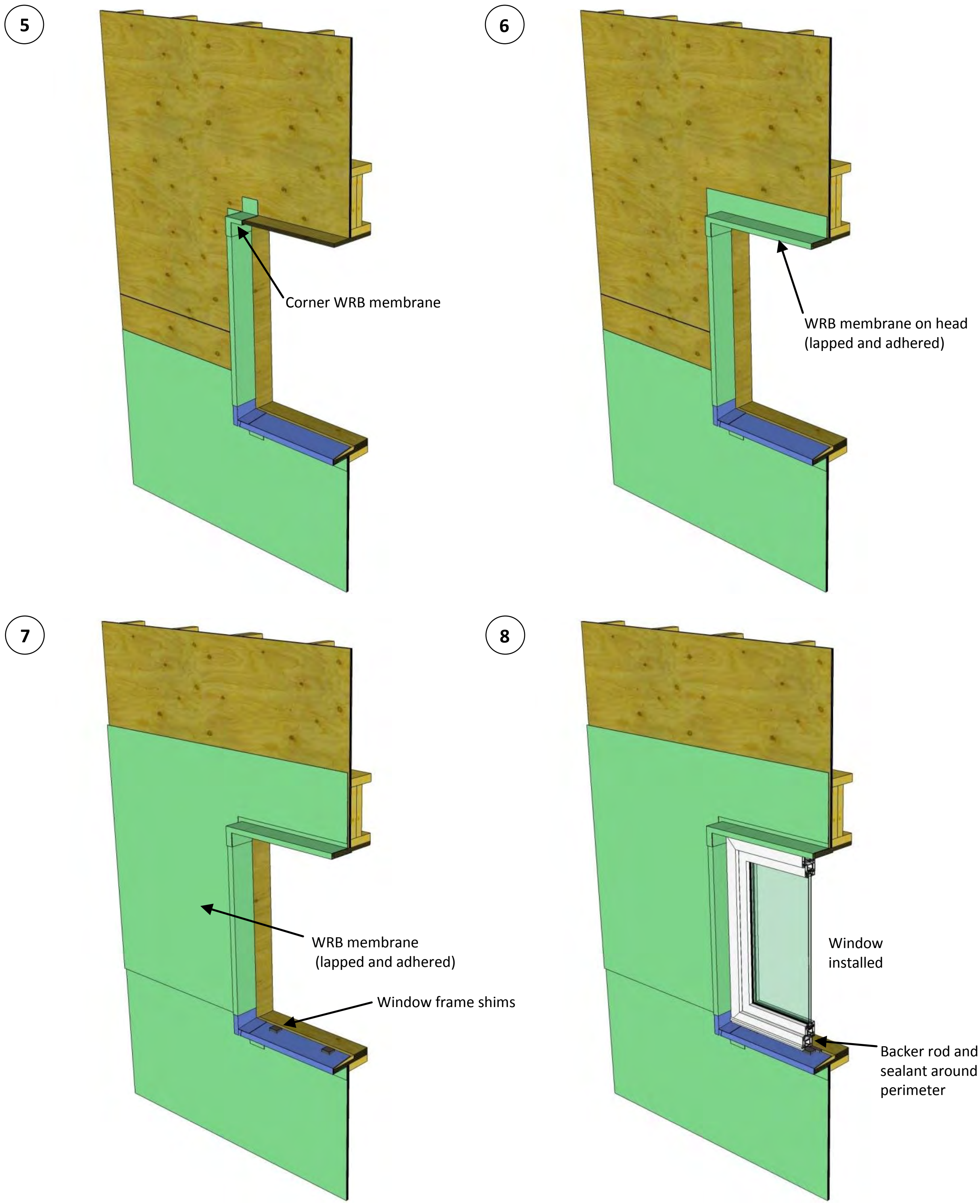
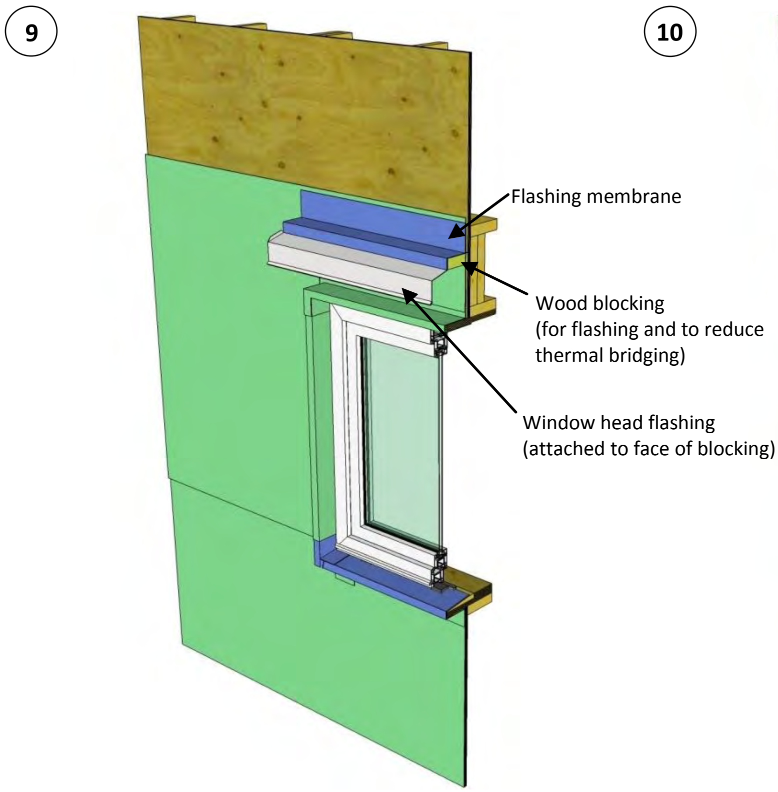
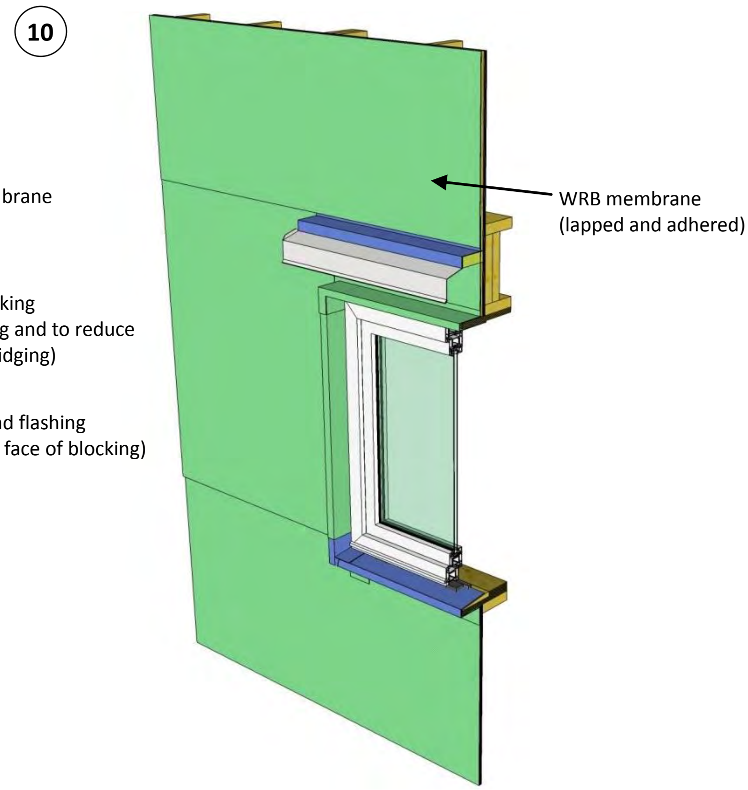


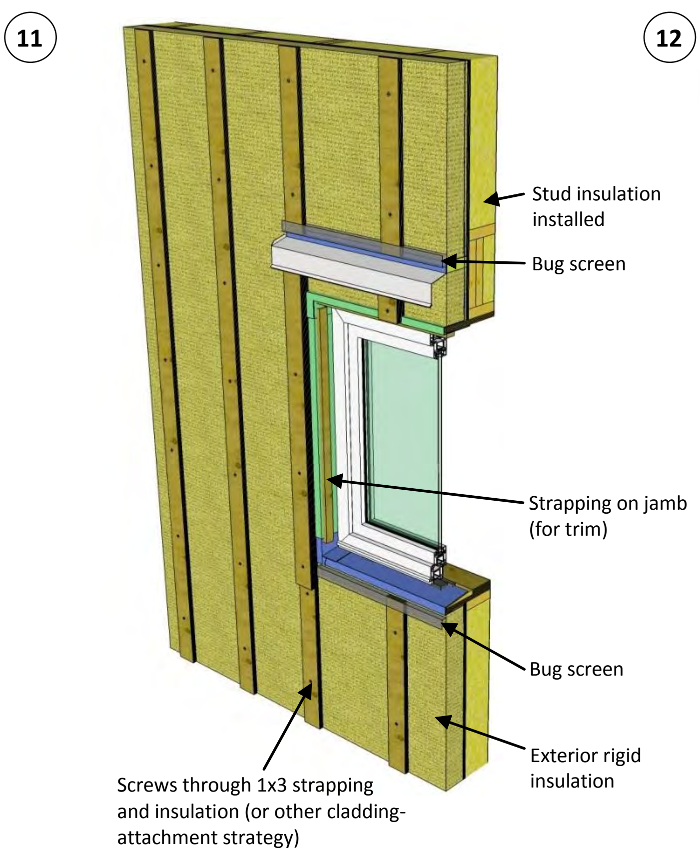
4

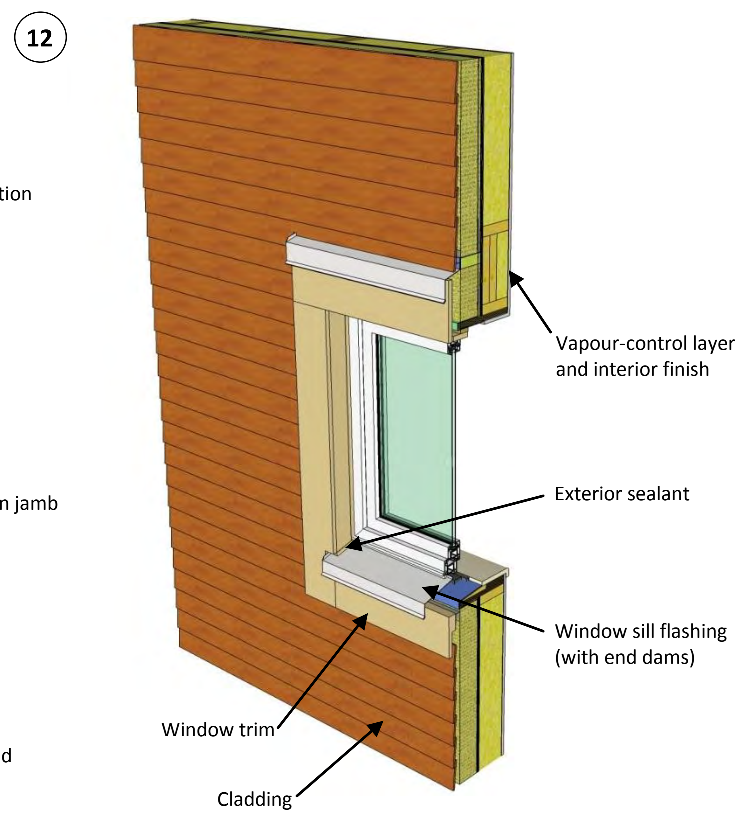



5
Corner WRB membrane
6
WRB membrane on head
(lapped and adhered)
7
WRB membrane
(lapped and adhered)
Window frame shims
8
Window
installed
Backer rod and
sealant around
perimeter

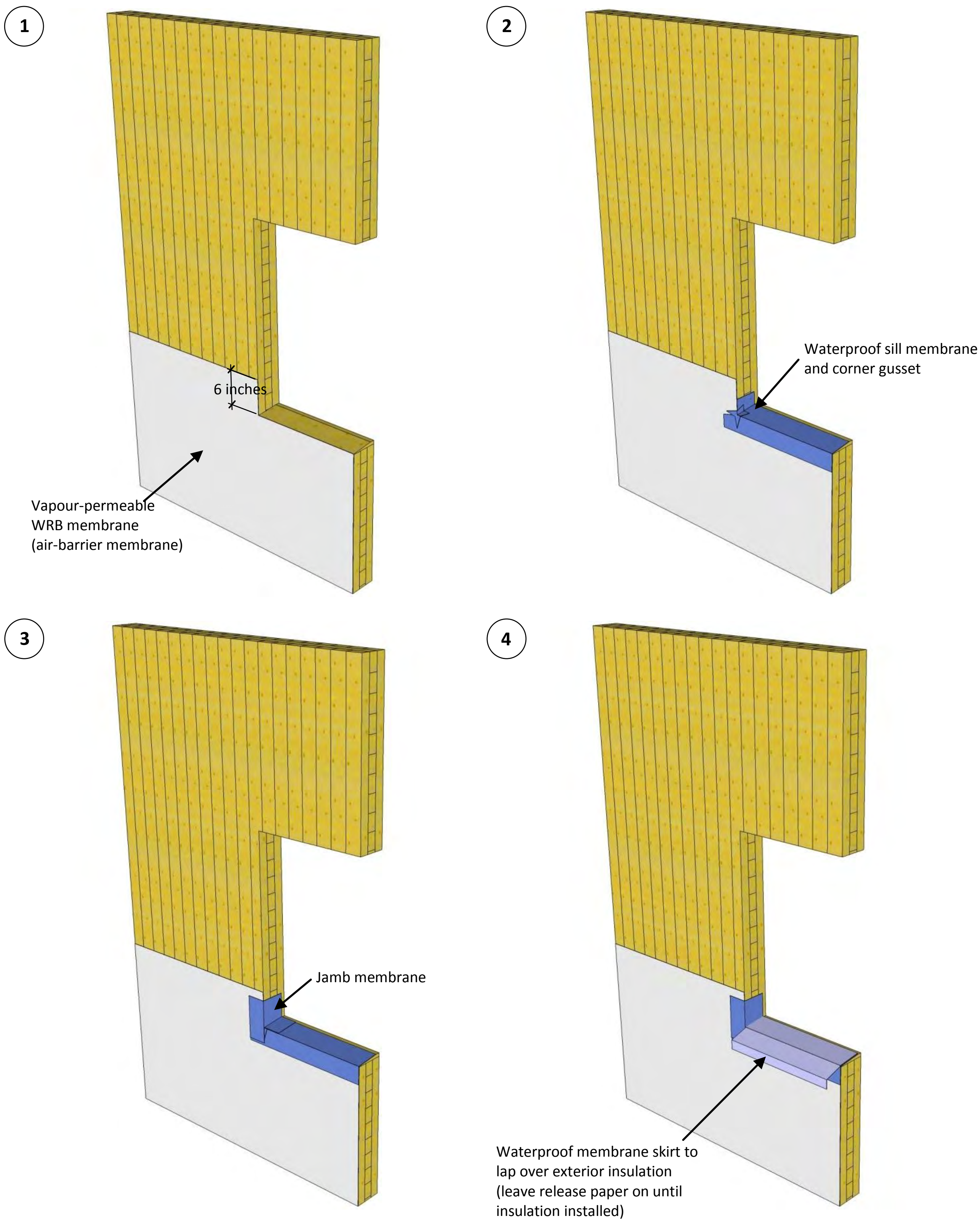

9
Flashing membrane
Wood blocking
(for flashing and to reduce
thermal bridging)
Window head flashing
(attached to face of blocking)


10
WRB membrane
(lapped and adhered)


11
Stud insulation
installed
Bug screen
Strapping on jamb
(for trim)
Bug screen
Exterior rigid
insulation
Screws through 1x3 strapping
and insulation (or other cladding-
attachment strategy)


12
Vapour-control layer
and interior finish
Exterior sealant
Window sill flashing
(with end dams)
Window trim
Cladding

5.3.5 Sequence 5 — Drawings for Window Installation (Innie Window): CLT, Exterior Insulation, Sealed Sheathing Membrane, Air-Barrier Approach



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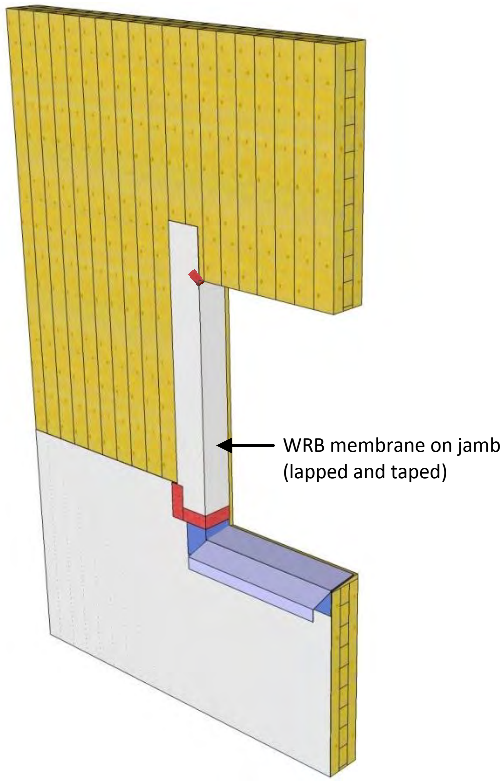
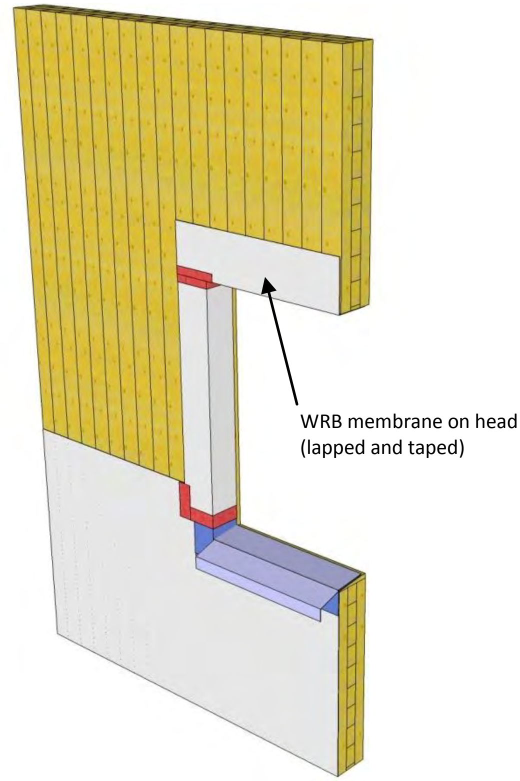
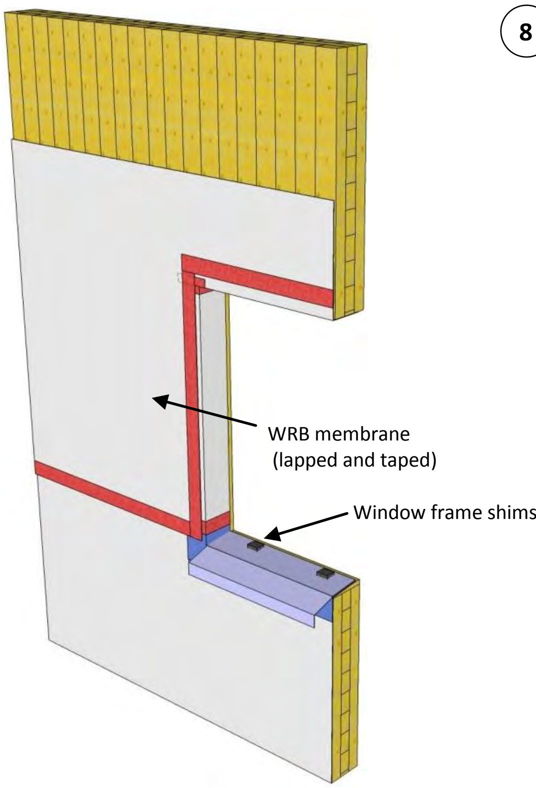

WRB membrane on jamb
(lapped and taped)

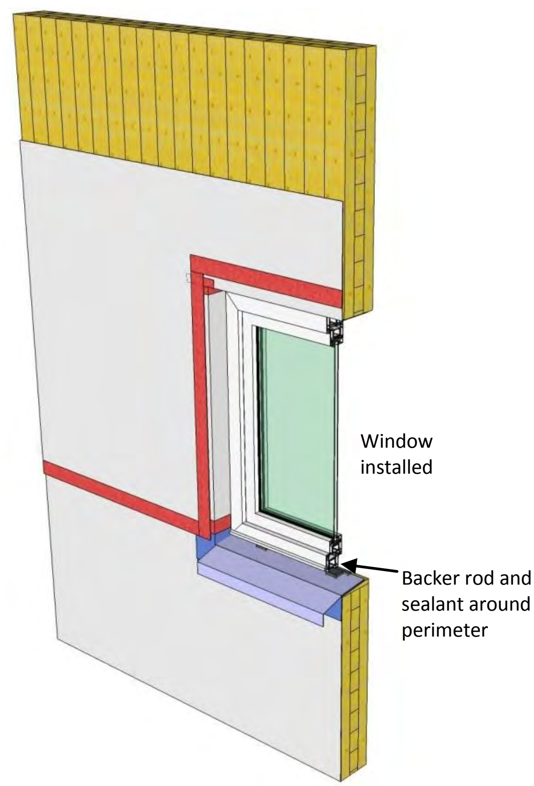
6


WRB membrane on head
(lapped and taped)

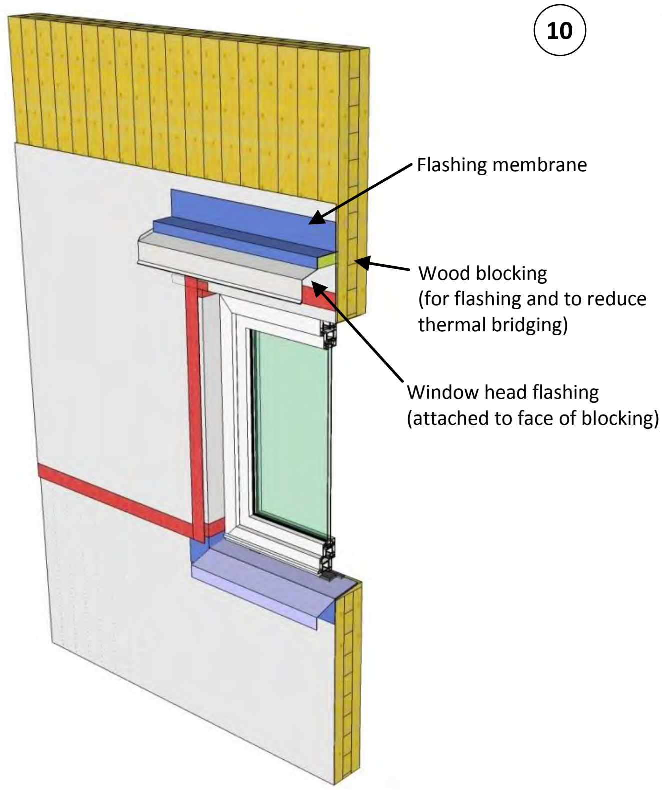
7


WRB membrane
(lapped and taped)
Window frame shims

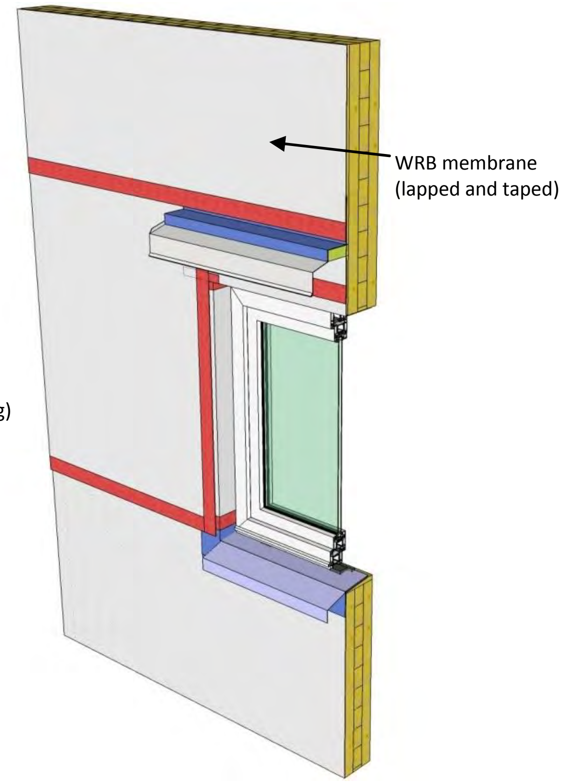
8


Window
installed
Backer rod and
sealant around
perimeter

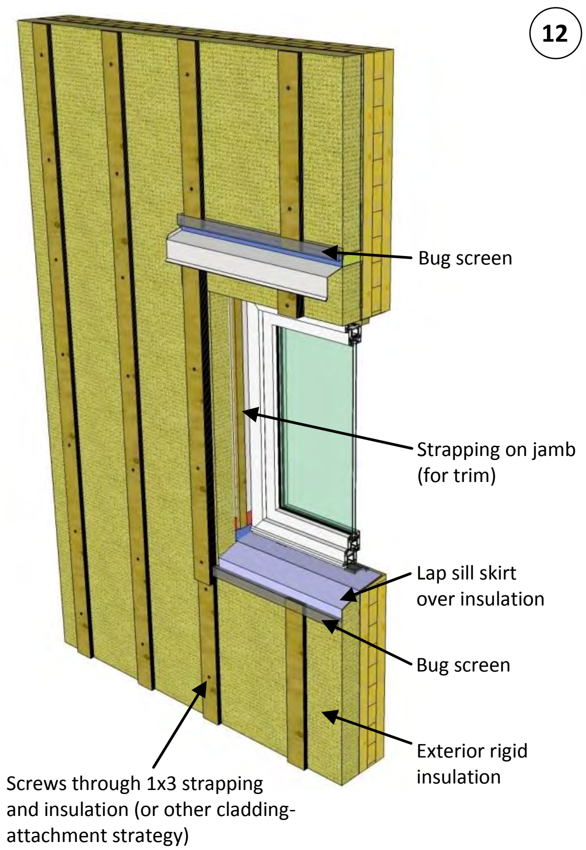
9


Flashing membrane
Wood blocking
(for flashing and to reduce
thermal bridging)
Window head flashing
(attached to face of blocking)

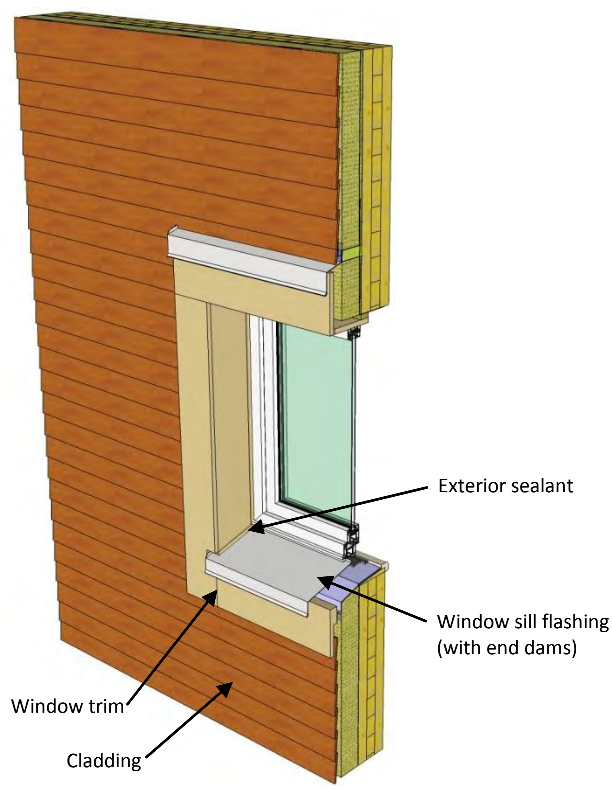
10


WRB membrane
(lapped and taped)

11


Bug screen
Strapping on jamb
(for trim)
Lap sill skirt
over insulation
Bug screen
Exterior rigid
insulation
Screws through 1x3 strapping
and insulation (or other cladding-
attachment strategy)

12


Exterior sealant
Window sill flashing
(with end dams)
Window trim
Cladding

CHAPTER 6: FURTHER READING, REFERENCES, and GLOSSARY of TERMS

RECOMMENDED FURTHER READING

Builder and Design Guides – Residential Construction including Wood-frame MURBs

Building Enclosure Design Guide: Wood-Frame Multi-Unit Residential Buildings. Homeowner Protection Office, Branch of BC Housing. 2011. Available at: hpo.bc.ca.

Building Envelope Guide for Houses – Part 9 Residential Construction. Homeowner Protection Office, Branch of BC Housing. 2008. Available at: hpo.bc.ca.

Builder's Guide for Cold Climates. Joseph Lstiburek. Building Science Press. 2006. Available at: buildingsciencepress.com.

Builder's Guide for Hot/Humid Climates. Joseph Lstiburek. Building Science Press. 2005. Available at: buildingsciencepress.com.

Builder's Guide for Hot-Dry/Mixed-Dry Climates. Joseph Lstiburek. Building Science Press. 2004. Available at: buildingsciencepress.com.

Builder's Guide for Mixed-Humid Climates. Joseph Lstiburek. Building Science Press. 2006. Available at: buildingsciencepress.com

Build America Climate Specific Publications for North American Climate Zones. Various Publications and Dates. Best Practices, Handbook, Builders Challenge Guides, and Case Studies are available for download at: eere.energy.gov/buildings/building_america/climate_specific_publications.html.

Canadian Wood-Frame House Construction. CMHC-SCHL. 2007. Available at: chmc-schl.gc.ca

Cross-Laminated Timber (CLT) Handbook (Canadian Edition). FPInnovations. 2011.

Cross-Laminated Timber (CLT) Handbook (US Edition). FPInnovations and Binational Softwood Lumber Council. 2013.

Building Science/Wood Science Resources

Building Science for Building Enclosures. John Straube and Eric Burnett. Building Science Press. 2005. Available at: buildingsciencepress.com.

Building Science for a Cold Climate. Neil Hutcheon and Gustav Handegord. National Research Council of Canada, 1983. Available at: nrc-cnrc.gc.ca/eng/ibp/irc/catalogue/cold-climate.html.

Moisture Control Handbook. Joseph Lstiburek and John Carmody. 1999. Building Science Press. Available at: buildingsciencepress.com.

Durability Website, durable-wood.com, Canadian Wood Council and FPInnovations.

FPL. Wood Handbook—Wood as an Engineering Material. Gen. Tech. Rep. FPL-GTR-113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 2010. Available at http://www.fpl.fs.fed.us/products/publications.

Building Codes, Energy Codes and Energy Standards

ASHRAE Standard 90.1 "Energy Standard for Buildings except Low-Rise Residential Buildings" I-P and S-I Editions. Various Dates up to 2010. ANSI/ASHRAE/IESNA. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Available at: ashrae.org. Free online preview at: ashrae.org/standards-research--technology/standards—guidelines.

ASHRAE Standard 189.1 "Standard for the Design of High-Performance Green Buildings except Low-Rise Residential Buildings. 2009 and 2011. ANSI/ASHRAE/USGBC/IES. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Available at: ashrae.org. Free online preview at: ashrae.org/standards-research--technology/standards—guidelines.

International Energy Conservation Code® (IECC). Various Dates up to 2012. International Code Council®. Available at: iccsafe.org.

National Building Code of Canada (NBC). Various Dates up to 2010. NRC-CRNC. Available at: nationalcodes.nrc.gc.ca/eng/nbc/index.shtml.

National Energy Code for Buildings (NECB). 1997 and 2011. NRC-CRNC. Available at: nationalcodes.nrc.gc.ca/eng/necb/index.shtml.

Other Building Science Research Organizations

- American Wood Council

  awc.org
- APA – The Engineered Wood Association

  apawood.org
- American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)
  ashrae.org
- Building Science Corporation
  buildingscience.com
- Canada Mortgage and Housing Corporation
  cmhc-schl.gc.ca
- Canadian Wood Council
  cwc.ca
- FPInnovations
  fpinnovations.ca
- Homeowner Protection Office, Branch of BC Housing
  hpo.bc.ca
- National Research Council of Canada
  Construction Codes in Canada
  nationalcodes.nrc.gc.ca/eng/code_adoption.shtml
- National Research Council of Canada
  nrc.ca
- Oak Ridge National Laboratory
  ornl.gov/sci/ees/etsd/btric/

- US Department of Energy – Energy Efficient and Renewable Energy
  Building Energy Codes Program
  energycodes.gov
- US Department of Energy – Energy Efficiency and Renewable Energy
  Building America Program
  www1.eere.energy.gov/buildings/building_america
- US Forest Products Laboratory
  fpl.fs.fed.us
- Building Science Corporation
  buildingscience.com

Building Enclosure Design and Analysis Software

- HEAT3, Blocon
  buildingphysics.com
- hygIRC

  archive.nrc-cnrc.gc.ca/eng/projects/irc/hygirc.html
- THERM, LBNL
  windows.lbl.gov/software/therm/therm.html
- WUFI, Fraunhofer IBP
  wufi.de, wufi-pro.com

Current Building Research and Case Studies Related to Wood-frame MURBs

The Case for Tall Wood Buildings – How Mass Timber Offers a Safe, Economical, and Environmentally Friendly Alternative for Tall Building Structures. Michael Green. 2012. Available at: cwc.ca.

Mid-Rise Wood-frame Construction. CWC Woodworks. Available online: woodworks.org/woodBenefits/mid-rise-construction.aspx.

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Advanced Framing Construction Guide, The Engineered Wood Association. apawood.org. 2012.

APEGBC Technical Practice Bulletin: Structural, Fire Protection and Building Envelope Professional Engineering Services for 5 and 6 Storey Wood Frame Residential Building Projects, Association of Professional Engineers and Geoscientists of British Columbia, 2009.

ASHRAE Handbook – Fundamentals (2009), The American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2009.

ASHRAE Standard 62.1 – Ventilation for Acceptable Indoor Air Quality, The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Various.

ASHRAE Standard 90.1 – The Energy Standard for Buildings except Low-Rise Residential Buildings (1998, 2001, 2004, 2007, 2010), The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Various.

*ASHRAE Standard 189.1 – Standard for the Design of High-Performance Green Buildings except Low-Rise Residential Building*s (2009, 2011), The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Various.

Best Practice Guide Building Technology: Wood-Frame Envelopes in the Coastal Climate of British Columbia, Canada Mortgage and Housing Corporation, 2001.

Best Practice Guide: Exterior Insulation and Finish Systems, Canada Mortgage and Housing Corporation, 2004.

Best Practice Guide: Flashings, Canada Mortgage and Housing Corporation, 1998.

Best Practice Guide: Brick Veneer Steel Stud, Canada Mortgage and Housing Corporation, 1996.

Best Practice Guide: Windows, Canada Mortgage and Housing Corporation, to be published later in 2012.

Building America Best Practices Series: Volumes 1-5, Builders and Buyers Handbook for Improving New Home Efficiency, Comfort, and Durability. Building America US Department of Energy. 2005.

Building Enclosure Design Guide: Wood-Frame Multi-Unit Residential Buildings. Homeowner Protection Office, Branch of BC Housing, 2011.

Building Energy Codes 101 – An Introduction. US Department of Energy – Energy Efficient and Renewable Energy. February 2010. Available online. www.energycodes.gov.

Building Science for Building Enclosures, Straube, John and Burnett, Eric, 2005.

CAN/CSA O86-09: *Engineering Design in Wood.* Canadian Standard Association. 2009.

The Case for Tall Wood Buildings – How Mass Timber Offers a Safe, Economical, and Environmentally Friendly Alternative for Tall Building Structures, Green, Michael, available online cwc.ca. 2012.

Climate Classification for Building Energy Codes and Standards, Briggs, Lucas, Taylor, Pacific NW National Laboratory, 2002.

Compatibility of Fasteners and Connectors with Residential Pressure Treated Wood, Homeowner Protection Office, Branch of BC Housing, Builder Insight Bulletin #8, 2011.

Cross-Laminated Timber (CLT) Handbook (Canadian Edition). FPInnovations. 2011.

Cross-Laminated Timber (CLT) Handbook (US Edition). FPInnovations, Forest Products Laboratory, BSLC, American Wood Council, APA, WoodWorks. 2013.

Designing for durable wood construction: the 4 Ds. Hazleden, D.G. and P.I. Morris. Proceedings, 8th International Conference on Durability of Building Materials and Components, Lacasse, M.A and Vanieer, D.J., Eds. 1:734-745. NRC Research Press, Ottawa, ON, Canada, 1999.*Field Investigations on the Application of ACQ Treated Wood and Use of Metal Fasteners and Connectors in Residential Construction*, Ruddick, John, for the Homeowner Protection Office, 2006.

Guide to Insulating Sheathing, Building Science Corporation, 2007.

High Performance Home Technologies – Guide to Determining Climate Regions by County, Building America US Department of Energy. 2010.

International Energy Conservation Code (IECC). International Code Council. 2012.

Introduction of Wood Design, Canadian Wood Council, 2002.

Moisture and Wood-Frame Buildings. Canadian Wood Council. BS No. 1. Available at cwc.ca.

Moisture Control for Buildings. Lstiburek, Joseph, ASHRAE Journal. 2002.

Moisture Index Approach to Characterizing Climates for Moisture Management of Building Envelopes, Cornick, S.M., Dalgliesh, W.A., NRCC-45704, National Research Council of Canada, 2003.

National Building Code of Canada (NBC). NRC-CRNC. 2010.

National Energy Code for Buildings (NECB). NRC-CRNC. 1997 and 2011.

Online Code Environment & Advocacy Network (OCEAN). 2013. *Code Status: Residential*. Building Codes Assistance Project, Washington, D.C., USA. Online: www.energycodesocean.org/code-status-residential.

Passive Design Toolkit, City of Vancouver. vancouver.ca/sustainability/PassiveDesignGuidelines.htm. 2009.

Performance Monitoring of Rainscreen Walls in Vancouver, RDH Building Engineering Ltd. for the Homeowner Protection Office, 2007, www.hpo.bc.ca.

The Performance of Rainscreen Walls in Coastal British Columbia, Finch, Graham, MASc Thesis, University of Waterloo, Ontario. 20007.

Rain Penetration and its Control, Canadian Building Digest No. 40, G.K. Garden, 1963.

Requirements for Exterior Walls, Canadian Building Digest No. 48, National Research Council of Canada, 1963.

Survey of Building Envelope Failures in the Coastal Climate of British Columbia, Canada Mortgage and Housing Corporation, 1996.

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

Toronto Building Bylaw 2010, City of Toronto, toronto.ca, 2010.

Understanding deterioration of wood in structures. Morris, P.I. Forintek report to British Columbia Building Envelope Council. Vancouver, BC, Canada. 1998.

Vancouver Building Bylaw 2007, City of Vancouver, vancouver.ca, 2007.

Wind-driven Rain Study in the Coastal Climate of British Columbia, Ge, H. and R. Krpan, for the Homeowner Protection Office, hpo.bc.ca.

Wood Reference Handbook, Canadian Wood Council, 1997.

Wood Handbook – Wood as an Engineering Material (Centennial Edition), US Forest Products Laboratory, United States Department of Agriculture, 2010.

GLOSSARY OF TERMS

Term	Definition
air barrier	The materials and components that together control the airflow through an **assembly** and limit the potential for heat loss and **condensation**.
air leakage	The uncontrolled flow of air through the **building enclosure** (i.e., infiltration or exfiltration) as the result of building pressurization and the enclosure airtightness.
airtightness	A measure of the air porosity of the assemblies that make up the **building enclosure** at a certain pressure difference. Airtightness can be visualized in terms of an equivalent-sized hole in the building enclosure. Typically, airtightness is measured at a standard test pressure of 50 or 75 pa to overcome the effects of wind and stack and obtain a repeatable measurement.
apartment	A multi-unit residential building in which each unit and the common areas are owned by one owner. The individual units are rented out to tenants who pay rent to the owner.
assembly	The arrangement of more than one material or component for the purpose of performing specific overall functions.
balcony	An outdoor horizontal surface intended for pedestrian use, which projects from the building, but is not located over a living space or acting as a roof. *See also* **deck**.
base flashing	**Flashing** that is part of the roofing and is turned up at the intersection of a roof with a wall or another roof penetration. It may be made of the same material as the main roofing membrane or of a compatible material.
below-grade	The portion of a building that is below the ground surface level.
bottom plate	The lower horizontal member of a wood-frame wall on which the bottom of the wall **studs** and the floor-framing members rest.
building enclosure	Referred to in building codes as one type of **environmental separator**, it comprises the parts of the building that separate inside conditioned space from unconditioned or outside space while facilitating climate control.
building paper	*See* **sheathing paper**.
butt joint	A square joint between two building materials or components at right angles.
cap flashing	**Flashing** that sheds water from the top of walls. It is difficult to make metal cap flashing waterproof at joints and intersections, therefore requiring a secondary, continuous, waterproof membrane below it.
capillarity	The movement of water through a network of capillary pores or a thin layer between **materials**.
capillary break	A material or an air space in an **assembly** that allows little or no capillary action.
cladding	A material or component of the wall **assembly** that forms the outer surface of the wall and is exposed to the full force of the environment.
combustible construction	Construction that does not meet the requirements for **non-combustible construction**.
compatibility	The ability of two or more materials to exist in close and permanent association for an indefinite period with no adverse effect of one on the other.

compartmentalization	Separating a single volume (floor/room/suite/office) within a larger building volume, with the primary intention of controlling airflows into, within, and out of the enclosed space caused by wind, stack, or mechanical pressures. Compartmentalization is typically performed for fire, smoke, odour, and acoustic separation; however, it also has important benefits for HVAC control. An example is the air-sealing of floors and vertical shafts within a multi-storey building to control air movement and pressures.
concealed barrier	A rain-penetration control strategy that relies on the elimination of holes through a **perfect barrier**. The barrier is protected or concealed behind the **cladding**. *See also* **face seal**.
condensation	The appearance of moisture (water vapour) on a surface caused by air coming into contact with a surface that is at or below the **dew point** of the air.
condominium	A multi-unit residential building in which each unit is individually owned and the common areas are jointly owned.
control joint	An intentional joint placed within brittle materials, such as concrete or stucco, to promote cracking due to shrinkage at a specific location.
counter flashing	**Flashing** that is placed over the top of the **base flashing** to prevent water from penetrating behind the top edge of the base flashing.
cross cavity flashing	**Flashing** that intercepts and directs any water flowing down the cavity of a wall **assembly** to the exterior. Sometimes located at the window head level, thus functioning as a **head flashing**.
dead load	The weight of all permanent structural and nonstructural components of a building. *See also* **live load**.
deck	An outdoor horizontal surface intended for pedestrian use, which projects from the building that is located over a living space and also functions as a roof. *See also* **balcony**.
deflection	A water-management principle that utilizes features of the building and **assembly** geometry to limit exposure to rain.
detail	A location within a building enclosure assembly where the typical **assembly** construction is interrupted by a **penetration** of the **assembly** or of interfaces with an adjacent **assembly**.
dew point	The temperature at which air is saturated with water vapour (100% RH). An adjacent surface at a temperature lower than the dew point will lead to the formation of **condensation** on the surface.
diffusion	The movement of water vapour through materials (including air) caused by a difference in vapour pressure. It does not depend on air movement.
drainage	A water management principle that utilizes surfaces of the **assemblies** to drain water away from and out of the assembly.
drained cavity	The space behind a watershed surface, such as the wall **cladding**, that provides a **capillary break,** facilitating drainage of liquid water present within the **assembly**.
drip edge, **drip flashing**	**Flashing** that directs water that is flowing down the face of vertical **assemblies**, such as walls or windows, away from the surface so that it does not continue to run down the surface below.
drying	A water management principle that utilizes features and materials to speed **diffusion** and evaporation of materials that get wet within an **assembly**.

durability	The ability of a building or any of its components to perform the required functions in its service environment over a period of time without unforeseen cost for **maintenance**, **repair,** or **renewal**.
eave	The vertical portion of the roof edge that overhangs a wall.
eaves trough	*See* **gutter**.
effective thermal resistance value	An improved approximation for the thermal resistance of a building **assembly** section, accounting for the effects of **thermal bridging**. *See also* **nominal thermal resistance value**.
EIFS	*See* **exterior insulation finish system**.
emissivity	The measure of a surface's ability to emit long-wave infrared radiation.
environmental separator	The separation of environmentally dissimilar places, most commonly inside conditioned spaces and outside unconditioned spaces. *See also* **building enclosure**.
ethylene propylene diene monomer (EPDM)	A synthetic rubber that is resistant to weathering and high temperatures, which is typically used in outdoor applications.
expansion joint	A joint that is used as a structural separation between building elements to allow independent movement without damage to the **assembly**.
exterior insulation finish system (EIFS)	An exterior wall-**cladding** system that incorporates insulation and a reinforced stucco-like covering.
face seal	A **perfect barrier,** rain-penetration control strategy that relies on the elimination of holes through a single layer, usually the **cladding**. *See also* **concealed barrier** and **perfect barrier**.
failure	The inability of a material, component, **assembly**, **interface**, or detail to perform its intended function(s).
fascia	A finish member around the face of **eaves** and roof projections.
fenestration	The arrangement and proportion of window and door openings in a building.
flange-mounted window	A window installed in a rough opening that utilizes fin-shaped projections from the **frames**, which are attached to the exterior face of the **sheathing**.
flashing	The material used to prevent water penetration or direct the flow of water at **interfaces** and joints between construction **assemblies**.
frame (glazing)	The associated **head**, **jamb**, **sill**, and where applicable, **mullion** and **muntin** members that house the **sash** or fixed **glazing** when assembled.
frame (structural)	The primary and secondary structural members of a building that support other structural and non-structural components of the building.
gigajoule (GJ)	A unit of energy commonly used to measure gas consumption.

greenhouse gas (GHG)	Gases or compounds that lead to heat being trapped in the atmosphere, primarily via blocking infrared radiation that would otherwise be re-radiated out to space. Greenhouse gases are emitted during the production of electrical energy and burning of natural gas. The predominant greenhouse gas is carbon dioxide (CO_2), however, methane, nitrous oxide, sulphur hexafluoride, perfluorocarbons, and hydrofluorocarbons are concerns. Scientific evidence suggests that maintaining current rates of GHG emissions will likely lead to serious adverse climate impacts.
guard	A protective barrier around openings in floors or at the open sides of stairs, **balconies**, raised **walkways**, or other locations, to prevent accidental falls from one level to another. Such a barrier may or may not have openings through it.
guardrail	A horizontal rail of metal, wood, or cable fastened to intermittent uprights of metal, wood, or concrete around the edges of a platform.
gutter	A trough fixed to an **eave** that collects and diverts water from a roof.
head	The horizontal member that forms the top of the window **frame**. *See also* **sill**.
head flashing	**Flashing** that is installed in a wall over a window opening or projection.
horizontal movement joint	A horizontal joint on a wall that provides capability for differential movement of portions of the building structure (**expansion joint**), or prevents or localizes cracking of brittle materials such as stucco (**control joint**).
housewrap	A sheet plastic material that is used as a breather-type sheathing membrane, usually between the wall-sheathing material and the exterior cladding. Also referred to as synthetic **sheathing membrane**.
heating, ventilating, and air conditioning (HVAC)	The system used to condition the interior air of a building.
hygrothermal	The combined effects of moisture and heat transfer through building materials.
interface	A location within the **building enclosure** where two different components or **assemblies** meet.
jamb	The vertical members that form the sides of a window or door **frame**.
kilowatt hour (kWh)	A unit of energy commonly used to measure electrical consumption.
live load	A variable load due to the intended use and occupancy that is assumed in the design of the structural **members** of a building. *See also* **dead load**.
load bearing	The ability of an **assembly** to carry loads in addition to its own **dead load**.
maintenance	A regular process of inspection, minor repair, and replacement of components of the **building enclosure** to maintain a desired level of performance without unforeseen **renewals**.
make-up air (MUA)	Outdoor air supplied to the building to replace exhaust air and exfiltration. In multi-unit residential buildings, make-up air is often supplied to corridors and intended to enter suites through the entry door undercuts. **Make-up air** is typically tempered at the source (i.e., before it is supplied to the space), and therefore contributes to space heating (whether intentional or not). Make-up air may also be cooled. *See also* **space heating**. Make-up air is typically provided by a **make-up air unit.**

make-up air unit (MAU)	A large air handler that conditions 100% outside air (no re-circulated air) for ventilation is known as a make-up air unit (MAU). Air is heated, typically by natural gas, within make-up air units. Make-up air units are typically located on the roof.
masonry	Construction using individual units composed of stone, brick, tile, concrete, or similar material.
nominal thermal resistance value	The R-value of a material only. The nominal value does not account for the use of the material within an assembly of materials with differing thermal properties and thermal bridges.
noncombustible construction	Construction in which a degree of fire safety is attained by the use of non-combustible materials as defined in the building codes. *See also* **combustible construction**.
parapet	The part of a wall that extends above the roof level.
penetration	An intentional opening through an **assembly** for ducts, electrical wires, pipes, and fasteners to pass through.
perfect barrier	A strategy that relies solely on the elimination of holes to control water penetration.
premature failure	The inability of an **assembly**, **interface**, or **detail** to perform its intended function(s) during its expected service life.
pressure moderated rainscreen	A **rainscreen assembly** with reduced pressure differentials across the **cladding** to further limit water penetration. Features could include **compartmentalization** of the exterior **drained cavity** and optimization of venting arrangement, cavity size, and stiffness of the cladding and **air barrier**.
pressure-treated wood	The high-pressure application of various chemicals to provide greater **durability** to wood products.
primary structure	A structural system that carries the gravity loads and lateral loads imposed on the foundation. *See also* **secondary structure**.
rainscreen	A rain-penetration control strategy that relies on **deflection** of the majority of water at the **cladding** but also incorporates a cavity that provides a drainage path for water that penetrates past the cladding.
rainwater leader (RWL)	A vertical pipe that is used to carry rainwater from the gutter to the ground or a drainage system.
rehabilitate	A program of comprehensive overall improvements to the building-enclosure assemblies and **details** so that it can fulfill its originally intended functions.
relative humidity (RH)	The ratio of the amount of water vapour in a volume of air to the maximum amount of water vapour that volume of air can hold at a given temperature.
renewals	The replacement of worn-out components or materials.
repair	The localized or minor reconstruction of **assemblies**, components, or materials of a **building enclosure** so that it can fulfill its originally intended functions.
RSI value or R-value	A material’s thermal resistance to conductive heat flow. Higher values indicate greater insulating capabilities. The inverse of U-value.
saddle	The intersection of small horizontal surfaces, such as the top of a balcony guardrail or **parapet** wall, with a vertical surface, such as a wall.

sealant	An **elastomeric material** that is used to form an airtight or waterproof bond at a joint or opening.
secondary structure	A structural support system (framing, clips, and fasteners) required to transfer the imposed gravity loads and lateral loads acting on or through the **building enclosure** to the **primary structure**.
sheathing	A material that is used to provide structural stiffness to the wall framing and structural backing to the **cladding** and **sheathing membrane**. Oriented strand board (OSB) or plywood is typically used.
sheathing membrane	A material in an exterior wall **assembly** that limits the penetration of water further into the structure once past the **cladding**. These materials include both breather-type (vapour permeable) sheathing membranes, such as **sheathing paper** and **housewraps**, and waterproof (non-vapour permeable) sheathing membranes, such as self-adhering modified bituminous membranes.
sheathing paper	An asphalt-treated organic sheet material (breather-type **sheathing membrane**) that is used behind the **cladding** as protection against water and airflow.
sill	The horizontal member that forms the bottom of the **frame**. *See also* **head**.
soffit	The underside of the elements of a building, such as roof overhangs or beams.
space conditioning	The general term for heating (to heat the building to some desirable indoor temperature), cooling (to extract heat to cool the building to a desired temperature) and ventilation (the provision of outdoor air to an interior space). Regardless of the means of generating the desired quality (temperature, humidity, flow rate, and quantity of outdoor air), the air is said to be conditioned.
space cooling	Providing cooling to a space within a building, either a suite or common area.
space heating	Providing heat to a space within a building, either a suite or a common area. This may be in the form of convection (forced air such as **make-up air**) or radiation (such as electric baseboards and hydronic radiators).
stepped flashing	**Flashing** that is installed at the intersection between a sloping roof and a vertical wall. Both base flashing and counter flashing are overlapped and installed in pieces, following the slope to form the complete stepped flashing.
stud	A series of vertical framing members used in walls and partitions.
sub-sill flashing	A membrane material placed under the window frame within the rough opening to drain water that penetrates through or around the window frame to the exterior of the water resistive barrier.
system	An **assembly** of materials and components that work together to perform a specific function, such as an air-barrier system.
thermal bridging	The transfer of heat through building-enclosure elements that have relatively low thermal resistance in comparison to adjacent elements. Studs within an insulated wall **assembly** are one example.
threshold	The lowest horizontal member of a door that rests on the floor between the jambs of a door frame.
U-value	The measure of the conductive heat transmission property of a material or an **assembly** of materials, expressed as a rate of heat flux through a material. The inverse of **R-value or RSI**.
valley flashing	**Flashing** that is installed in the valley of a roof to give continuity to the roofing system.

vapour retarder	A material with low vapour permeability that is located within the **assembly** to control the flow of vapour.
ventilation	The process of supplying air to or removing air from a space for the purpose of controlling air-contaminant levels, humidity, or temperature with the space.
ventilation (natural)	The flow of air through open windows, doors, grilles, and other planned penetrations, driven by natural pressure differentials.
ventilation (mechanical)	The intentional movement of air into and out of a building using fans and intake and exhaust vents.
walkway	An outdoor corridor, which provides pedestrian access between suites and stairwells or elevators. It may or may not also act as a roof.
water-resistive barrier (WRB)	The surface farthest from the exterior that can accommodate moisture in the form of liquid water without causing damage to the materials within the **assembly** or to adjacent materials. The primary material forming the water-resistive barrier is usually the **sheathing membrane**.
water-shedding surface (WSS)	The surface of **assemblies**, **interfaces**, and **details** that deflect and drain the majority of moisture at the exterior of a building in the form of liquid water.

ISSN 1925-0509
Special Publication 53

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ISSN 1925-0509 Special Publication SP-53